BCIT Biomass Waste-to-Energy Report

Prepared for: BC Ministry of Environment

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Executive Summary

The political push for sustainability forces local governments to make a stark decision between keeping local air quality high and reducing globally effective GHG emissions. Moreover, plans to redirect the amount of waste going to landfill seem to collide with the mandate to protect the local air shed from pollution. The BC Ministry of the Environment and Metro Vancouver strive to harmonize these policies, formulating guidelines leading to a compatible balance between these apparently opposing objectives.

The scientific community has called for a 75% (factor IV) reduction in global levels of energy and material consumption to achieve ecological sustainability. This target has often been perceived as "unrealistic", and the goal of BCIT School of Construction and the Environment's Factor IV initiative is to explore how these reductions are possible and whether they can be achieved without compromising service levels.

BCIT's School of Construction plans to use its 250 tonnes of wood waste generated by the Carpentry and Joinery workshops as a fuel to heat part of the campus. This project is a key element of BCIT School of Construction and the Environment Factor IV initiative.

The wood waste, however, contains fractions of plywood and MDF, substances that contain "glue and resins". Under the current local legislation, these are not considered 'biomass' and may not be burned. Regulators, the environmental community, and the general public are concerned that contaminated waste wood could potentially create unacceptable levels of air pollution.

To date neither the Ministry nor Metro Vancouver have guidelines that are specific to the burning of construction and demolition wood-based material. Research at BCIT's biomass boiler could build the scientific knowledge base needed to manage this waste source wisely, providing valuable information for setting emission limits and best practise recommendations that are specific to construction and demolition material combustion.

As a one of the initial steps this study has researched the wood waste streams existing at BCIT. A physical waste audit and chemical analyses shall be used as a baseline, gauging the potential impact that burning BCIT's wood waste – or any other construction waste for that matter – may cause.

The audit revealed that only one third of the waste contains resins and glues, while the rest is clean, chemically untreated wood. There was a small fraction of non-woody waste, beverage containers, cardboard etc. that BCIT will have to keep out of its waste bin in the future.

The chemical analyses show that BCIT's wood waste is very clean, even meeting all chemical requirements of the European Pellet Norm. Except for a slightly low energy content, BCIT's mix of wood waste could be used as a feedstock for Class 1A pellets even though in contains material such as MDF and plywood.

The fuel analyses gave little evidence that combusting plywood or MDF will result in higher air emissions compared to untreated fuel. In fact, biomass such as 'uncontaminated' hog fuel with its significantly higher ash and moisture content may result in "higher criteria air contaminants" and hazardous air pollution than combusting BCIT's plywood or MDF.

A chemical analysis is only an indication of potential emission problems. To fully understand the impact on air quality, the combustion process and downstream filtering technology need to be taken into account. Only a continuous emission monitoring system (CEMs) and/or frequent stack sampling will allow quantifying air emissions.

BCIT's wood waste composition is typical for a joinery or carpentry workshop, but cannot be compared to standard demolition and construction wood as found at sites such as Urban Wood Waste. Consequently any results from emission tests done using BCIT's waste will only be a first step towards understanding the combustion of typical construction and demolition wood.

On the financial side, BCIT has completed feasibility studies to understand the cost of building a small-scale clean biomass-to-energy facility connected to a district energy system. Results show that building to minimize cost will lead to a positive ROI but with a payback that might be considered too long for private sector. Government and utility companies might have to intervene to make the technology more attractive from a pure ROI perspective.

While there are alternative solutions, exporting its fuel while importing natural gas makes limited sense in times of climate change. The fact that the campus already has a district heating system is a major stepping stone towards a more sustainable energy supply. It would be a lost opportunity, also in terms of research and training the next generation of carpenters and cabinet makers on technology they are likely to be exposed to during their future professional life.

Likewise Metro Vancouver may want to consider using BCIT's campus to showcase and demonstrate both, its waste diversion strategy and district heating plans at an existing, well managed facility. The research data collected but also the experiences made will be instrumental when formulating best practises, guidelines and standards.

Table of Contents

Acknowledgements

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Disclaimer

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Conversion of units used in this report

1 kilogram (kg)	=	2.2	pounds (lb)
1 metric tonne (t)	=	1,000	kilograms (kg)
1 gram (g)	=	1000	milligrams (mg)
1 cubic metre (m3)	=	1,000	litres (L)
1 litre (L)	=	0.001	cubic metres (m^3)
1 gigajoule (GJ)	=	0.278	megawatthour (MWh)
1 gigajoule (GJ)	=	0.95	mmBTU
1 mega watthour (MWh)	=	3.413	mmBTU/h
1 kilowatthour (kWh)	=	3.6	megajoule (MJ)
1 kilowatthour (kWh)	=	3,415	BTU/h
1 megawatthour (MWh)	=	3.6	gigajoule (GJ)

1. Introduction

1.1. Background

The scientific community has called for a 75% (factor IV) reduction in global levels of energy and material consumption to achieve ecological sustainability. This target has often been perceived as "unrealistic", and the goal of BCIT School of Construction and the Environment's Factor IV initiative is to explore how these reductions are possible and whether they can be achieved without compromising service levels. A biomass boiler using internal wood waste is a key project of the Factor IV initiative.

BCIT's Carpentry and Joinery Department produce approximately 250 tonnes of wood waste per year. This wood is sent off-site to locations at the discretion of BFI Canada Ltd, BCIT's waste management contractor. Both departments plan to use this wood waste as a fuel heating part of the campus. Biomass, including refuse derived fuel is considered a carbon-neutral fuel, as the carbon contained in it would be released to the atmosphere whether landfilled or combusted.

A 250 kW boiler system could transform the wood from waste to energy and tie-in with BCIT's district energy system to offset approximately 4,000 GJ of natural gas per year, almost the same amount used by 44 Canadian detached homes. With commercial and carpentry workshops in BC, each of them is likely to face a similar opportunity and challenge regarding their wood waste.

Like most carpentry or joinery workshops, BCIT's wood waste consists primarily of solid, untreated wood, but also contains some plywood and medium density fibreboard (MDF). The latter two contain resins. According to Metro Vancouver's Biomass Boiler Regulation, wood containing resins is not classified as biomass and may not be burned without a special permit. [1]

This creates a conundrum for BCIT, Metro Vancouver and the BC Ministry of Environment: using construction and demolition waste will reduce global greenhouse gas (GHG) emissions, but might also increase local air pollution.

According to Envirochem Services Inc., 430,000 tonnes of urban wood waste (primarily construction, demolition, and deconstruction wood waste) is generated in Metro Vancouver, of which 170,000 tonnes is being recycled and 260,000 tonnes is being sent to the landfill.[2] This means that only 40% of the waste is being diverted from the landfill. Metro Vancouver wants to

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[1] Greater Vancouver Regional District, "Boilers and Process Heaters Emission Regulation", Bylaw No. 1087, 2008, item 4 (e).

[2] Paul A. Beauchemin, Martin Tampier, Envirochem Services Inc.: "Biomass Availability Study For District Heating Systems", Feb 2012

increase this diversion rate to 80% by 2020.[3] Metro Vancouver's Integrated Solid Waste and Resource Management Plan "promote additional diversion of biomass, such as food residuals and treated wood, for use as renewable sources of energy."[4] Concretely, "Metro Vancouver will [...] [d]irect recoverable loads of combustible material received at transfer stations to public or private energy recovery facilities." [5]

To date, neither the Ministry nor Metro Vancouver have guidelines that are specific to the burning of construction and demolition material.[6] Standards will have to be developed to determine what type of wood waste may be combusted and what best practises are to minimize the impact on the local air shed. As a first, small, yet important step, the Ministry provided BCIT with the means to research the properties of its own wood residue, a baseline study of the existing wood waste, its potential environmental impacts, and alternatives to combustion on site. This report presents the findings of this study.

1.2. Scope

The BCIT School of Construction and Environment (SoCE)[7] is proposing a waste-to-energy biomass project. This study evaluates the quantities, qualities, and potential impact of using BCIT's wood waste streams (from its carpentry and joinery programs) as a fuel in a biomass heating system and discusses the significance as it relates to Metro Vancouver and BC.

Concretely, a wood waste audit and direct sampling and analysis of each BCIT wood stream were ordered. Further investigation of the Lower Fraser Valley's urban wood waste sources and users, and the cost benefit/economic feasibility of a BCIT biomass project were also carried out.

The following tasks have been conducted:

1. Identification of BCIT's wood waste streams;
2. Characterization and chemically analyses of each wood stream and the overall fuel mix;
3. Evaluation of the potential impact on air quality and greenhouse gas emissions;

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[3] Metro Vancouver, "Integrated Solid Waste and Resource Management – a Solid Waste Management Plan", July 2010, page 5, http://www.metrovancouver.org/about/publications/Publications/ISWRMP.pdf
[4] Metro Vancouver, "Integrated Solid Waste and Resource Management – a Solid Waste Management Plan", July 2010, page 8, http://www.metrovancouver.org/about/publications/Publications/ISWRMP.pdf
[5] Metro Vancouver, "Integrated Solid Waste and Resource Management – a Solid Waste Management Plan", July 2010, page 26, http://www.metrovancouver.org/about/publications/Publications/ISWRMP.pdf
[6] Tony Wakelin, MoE in a conference call with BCIT staff on March 9, 2012, see the Minutes of the Meeting in Appendix 6
[7] BCIT has 6 schools. SoCE in one of the 6 schools and is the leader behind the BCIT biomass project.

4. Comparison of BCIT wood waste with other urban waste sources;
5. Overview of the financial feasibility of the BCIT biomass boiler project;
6. Identification of alternative solutions to BCIT's wood waste issue.

1.3. Objectives

The primary objective of this report is to establish the types and chemical composition of wood waste generated at BCIT. Using professional waste auditors and certified laboratories, the goal was to get a sense of what air emissions may be expected from combusting this type wood waste mix.

The information contained in this study may also be used when addressing the general public about BCIT's intention to establish a wood waste burner. BCIT will need to apply for a special air permit to combust plywood and MDF.

While beyond the scope of this study, the larger rationale is to understand what type of contamination there may be in various refuse derived woody fuels, and building the scientific knowledge base needed to solve the conundrum of protecting the air shed and the climate. This project may be considered as a first probe for future, more extensive fuel investigations that will have to be conducted when establishing fuel standards.

2. Wood Residue Generated at BCIT's Burnaby Campus

BCIT operates three workshops at its Burnaby campus that generate wood waste. These are the Joinery department's workshop (building NE2), the Carpentry department's workshop (building NE4), and the Carpentry department's overflow workshop (NW3). There is also a warehouse next to the community garden (building SE30) where wood waste is collected from other areas of campus.

While the warehouse (SE30) disposes its wood waste independently, the Joinery Department NE2) and the Carpentry Department (NE4) are adjacent to each other and use the same waste disposal methods. The overflow Carpentry department workshop is used when NE4 requires more space for students, therefore has the same wood supplies as NE4. The wood waste is disposed in the same methods as NE2 and NE 04. A dust extraction system services the Joinery workshop and the Carpentry workshop. Off-cuts from the workshops are collected at a waste bin jointly used by both departments. Once the biomass boiler is in operation, all combustible cut-offs will be sent through a chipper and it is anticipated that all the different wood types will end up fully mixed together, including the dust.

2.1. Waste Audit Results

BCIT conducted two audits of the 40-yard (31 m^3, 40 cyd) bin located outside of the Joinery (NE2) and Carpentry facility (NE4). This is the bin used to collect all Joinery and Carpentry wood waste (except the dust). BFI Canada Ltd. is contracted by BCIT to remove all waste for the entire campus including the 40-yard bin. The wood portion of the waste management contract with BFI amounts to approximately $20,000 per year. BCIT has no control on what BFI does with the wood waste which is either sent to the landfill or, to either Urban Wood Waste Recyclers or Basran Fuels.[8]

Figure 1: 40-yard bin located outside of NE2 and NE4

The majority of the audited 40-yard bin contains wood products though it was found through the audit exercise, that other departments and passersby have discarded non-wood waste such as cardboard and food. These contaminants could easily controlled by changing the location of the bin.

Figure 2: Contents of the 40-yard bin are mostly solid pieces of wood

BCIT and stakeholders wanted to know the composition of the 40-yard bin and contracted Waste Audit Canada to conduct two separate audits of the contents. Both audits were conducted offsite at Urban Wood Waste Recyclers. Scientifically two audits are not enough to obtain a statistically significant representation of BCIT's wood waste. However, the two initial audits are deemed sufficient to meet the objectives of this study.

It should be noted that the waste audit was conducted on the Carpentry's and the Joinery's workshop waste only.

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[8] Cindy MacIntosh, BCIT Supervisor, Custodial Services – Facilities and Campus Development. cindy_macintosh@bcit.ca. "Information request". March 7, 2012.

Figure 3 and Table 1 below illustrate the average waste composition found by Waste Audit Canada. The data is the average of the two waste audits, one conducted on March 13, 2012, and one on April 18, 2012. Note that the audit was conducted for the 40-yard bin located outside of the Joinery and Carpentry facilities. The dust from the dust extraction system and the bin by the warehouse were not included in the audit.

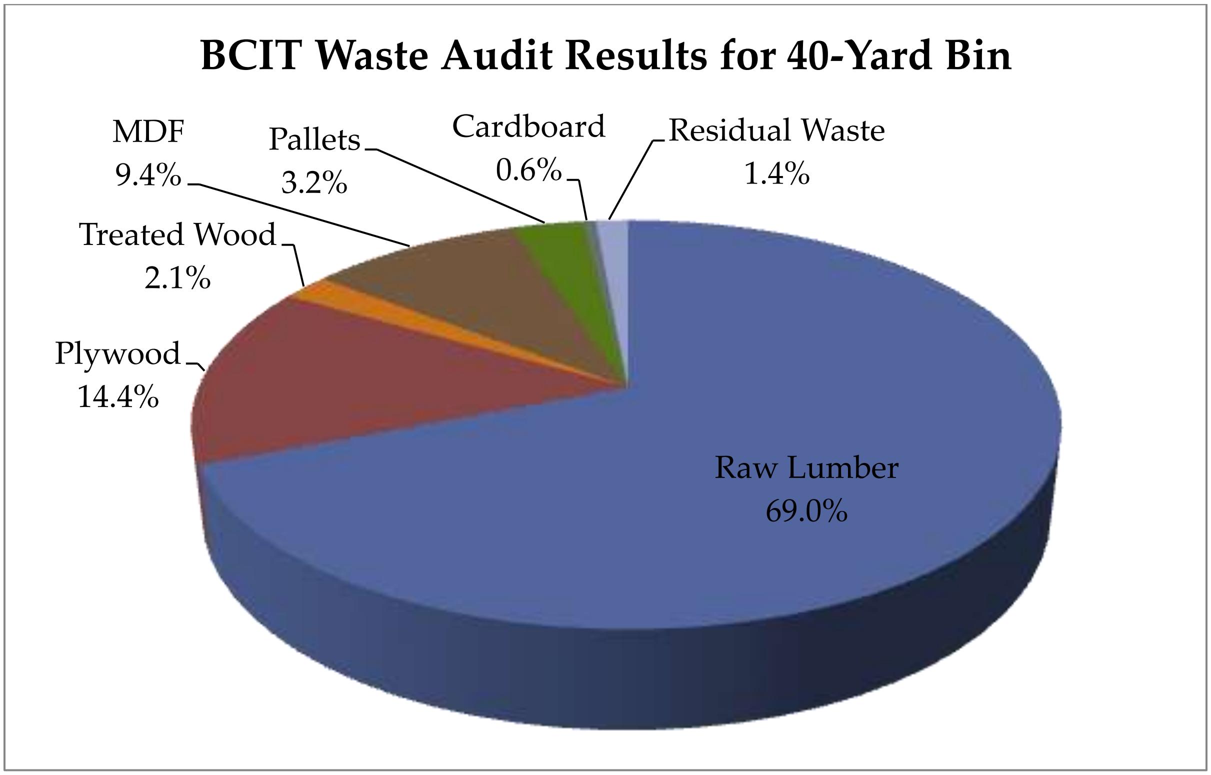

Figure 3: BCIT waste audit results for the 40-yard bin at NE4

Material	Details	Audit 13-Mar-2012	Audit 18-Apr-2012	Average of both audits	% of Overall
Raw Lumber	untreated 2X4's, 2X6's studs	2,603 kg	2,947 kg	2,775 kg	69.0%
Plywood	All types of plywood	577 kg	577 kg	577 kg	14.4%
MDF	Particle board, artificial wood of all types	735 kg	23 kg	379 kg	9.4%
Pallets	Used broken pallets	164 kg	90 kg	127 kg	3.2%
Treated Wood	Treated with wood preservative	123 kg	42 kg	83 kg	2.1%
Cardboard	Cardboard boxes	45 kg	0 kg	23 kg	0.6%
Residual Waste	beverage containers, food packaging, fast food	53 kg	61 kg	57 kg	1.4%
Total Weight		**4,300 kg**	**3,740 kg**	**4,020 kg**	**100.0%**
Waste suited for combustion:		**4,079 kg**	**3,637 kg**	**3,858 kg**	**96.0%**
Waste not suited for combustion:		**221 kg**	**103 kg**	**162 kg**	**4.0%**

Table 1: Waste audit results for 40-yard bin at NE04

The majority of the wood waste audited is raw, untreated lumber (69%), off-cuts of clean 2X4's and 2X6's studs. The latter comes mainly from the Carpentry department at BCIT.

Plywood was the second largest waste fraction within the bin (14.4%). 9.4% were Medium Density Fibreboard (MDF). This material is only used in the Joinery Department. MDF is a panel board made from wood fibres glued under heat and pressure and used to make furniture such as cabinets. The resin of standard MDF may contain formaldehyde which is known to cause cancer and other health issues such as burning sensations in the eyes and throat[9]. The Joinery Department, however, has embarked on a program purchasing mainly 'No Added Urea Formaldehyde' (NAUF) panel products. [10] Studies suggest, however, that formaldehyde contained in the wood fuel may be destroyed if combusted properly. [11]

Pallets, as used for delivering goods, are generally made from untreated wood that can be used as biomass fuel if chipped and if nails are removed. Treated wood, especially wood treated with wood preservatives, cardboard boxes, and residual waste (refundable beverage containers, food packaging - fast food) should not be burned in BCIT's biomass boiler and would need to be separated prior to chipping. Those three waste streams equate to 4% of the bin waste. Once the biomass boiler is in operation, the waste bin will be relocated inside the fenced area between the Carpentry and the Joinery workshop. Neither cardboard nor MSW-type food packing and food waste should enter the bin and should definitely not be run though the chipper.

Sawdust and planer shavings were not included in the waste audit. Separate records exist for those and annual quantities are known. The sawdust was included in the chemical analysis presented later in this report.

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[9] EPA, http://www.epa.gov/iaq/formalde.html, Access April 3, 2012

[10] Rob Sawatzky, BCIT Joinery Instructor, rob_sawatzky@bcit.ca. "'No Added Urea Formaldehyde' (NAUF) panel products". Sent April 14, 2012.

[11] The University of Wisconsin-Madison conducted comparative emission test using plywood and particleboard. Formaldehyde concentrations were close to zero at combustion temperatures above 800°C, Jeffrey M.Hoerning, Michelle A. Evans, Danny J. Aerts, Kenneth W. Ragland, Department of Mechanical Engineering University of Wisconsin-Madison: "Organic Emissions From Combustion of Plywood And Particleboard", Madison,Wi, USA,(no date); see http://web.anl.gov/PCS/acsfuel/preprint%20archive/Files/40_3_CHICAGO_08-95_0676.pdf

2.2. Dust Extraction System

The dust extraction system is located throughout the adjacent Carpentry and the Joinery workshops. Dust is extracted from various locations and collected at a dumpster on the West side outside the joinery building. It collects the dust from both the Carpentry and Joinery shops. This waste is put into a bin separate from the 40-yard bin. Approximately 32 tonnes per year of dust is sent to the landfill, costing BCIT approximately $6,000 per year in tipping fees[12].

Figure 4: Dust extraction system at NE2 (left) and spare hoppers (right)

2.3. Additional Wood Waste

There is another wood waste bin located by SE30 (BCIT warehouse) that contains the wood waste generated from campus rather than workshops. Internal accounts estimate 21 tonnes of waste comes from SE40's bin, costing $2,153 per year in tipping fees[13]. Since this waste streams varies in content and types of material, no professional waste audit or chemical analysis was undertaken. Deacon Tong, co-author of this report, inspected the bin on April 5, 2012 and estimated that 50% consists of broken pallets, the reminder mainly of old furniture. Since this stream of wood waste is not associated to BCIT wood program it will be treated separately and is therefore outside the scope of this report. A sorting process could allow BCIT to use some of this waste.

2.4. Annual Waste Volumes

BCIT has various estimates of total waste that are sent to landfills. Some data is based on the total number of waste bins hauled to landfills each year, assuming the same fill level for each haul. Others are actual weight measurements over a period of the year that are extrapolated to an entire year.

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[12] This estimate is based on the weight from two months (February and March) of recorded hauling data for the dust pucks. An average of the two months were taken and calculated over a twelve month period.

[13] From Cindy MacIntosh, BCIT Supervisor, Custodial Services – Facilities and Campus Development. cindy_macintosh@bcit.ca.

According to a review done by Stantec in 2008 [14] there are 270 tonnes of wood waste available at BCIT, thereof 165 tonnes from the Carpentry program. Weight measurements recorded by BCIT staff in the period from April 2010 to the end of February 2011 resulted in 189 tonnes. Extrapolating from this 10 month period to a full year results in 206 tonnes per annum. An inquiry to the waste hauling company BFI, yielded 216 tonnes, an average of 4.5 bins hauled each month, each bin with a load of 4 tonnes.[15]

Using the BFI's estimate for the number of bins hauled, and Waste Audit Canada's 4,020 kg average weight for the two bin audits conducted, results in 217 tonnes per year. Of the waste collected in the audited bins only 96% is actually combustible, see Table 1 above, resulting in 208 tonnes being actually available from the bins. This amount does not include the shavings and sawdust collected by the dust extraction system, a waste stream that is disposed in separate hoppers.

Net weight of these dust hoppers in the period from February 2, 2011 to March 17, 2011 resulted in 2.6 tonnes for two months. Extrapolated to an entire year yields 31 tonnes in sawdust and planer shavings collected each year[16].

Finally there is a third waste bin located at BCIT's warehouse (SE30), that is mostly used to discard wood pallets used for delivery of goods and supplies to BCIT. Weight records for the period from April 2010 to February 2011 show 19 tonnes being hauled away. Extrapolate that figure to an entire year yields 20.7 tonnes. A visual inspection by Deacon Tong on April 5, 2012 showed that approximately half the bin's content is pallets, the other half old furniture. Pallets are generally chemically untreated, possibly kiln-dried but otherwise raw lumber that, once chipped and nails are removed, provide a fine fuel. Old furniture on the other hand is often painted or lacquered and should not be combusted. The pallets collected at SE30 thus contribute 10.4 tonnes to the combustible wood waste.

Using the approximations made above, the total annual wood waste collected at BCIT is 269 tonnes. Of this 93% or 250 tonnes can be used as a fuel for a biomass boiler. The reminder, about 19 tonnes a year, is either not wood waste or is chemically treated or painted. While technically combustible, the contaminated waste streams should be separated out or be tested for their chemical contents.

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[14] Stantec, "Biomass Energy System – A Review of MAWERA Boiler Proposal", Burnaby 2008, page 2

[15] Alexandre Hebert - Investigation recorded in a spreadsheet titled "Wood Check and Tipping Fees".

[16] Alexandre Hebert - Investigation recorded in a spreadsheet titled "Wood Check and Tipping Fees".

Table 2 below details BCIT's total annual wood waste volumes.

Bin location	Total annual amounts		Thereof combustible wood		
NE2 (Dust)	31	t/yr	31	t/yr	100%
NE4 (solid wood)	217	t/yr	209	t/yr	96%
SE30 (solid wood)	21	t/yr	10	t/yr	50%
TOTAL	**269**	**t/yr**	**250**	**t/yr**	
	100%		**93%**		

Table 2: Annual amount of wood waste incurring at BCIT

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Wood waste type	Waste Details	Amount	
Raw Lumber	Untreated 2X4's, 2X6's studs	150t/yr	60 %
Plywood	All types of plywood	31t/yr	12 %
Wood dust	Compressed planer shavings & sawdust	31t/yr	12 %
MDF	Particle board, artificial wood of all types	22t/yr	9 %
Pallets	Raw lumber, heat treated, may contain nails	16t/yr	6 %
SUB-TOTAL - readily combustible wood		**250t/yr**	**100%**
Discarded furniture	lacquered or painted or laminated	10t/yr	56 %
Chemically treated wood	Wood with preservatives	4t/yr	21 %
Residual waste	Beverage containers, food packaging, food etc.	3t/yr	17 %
Cardboard	Packaging material	1t/yr	7 %
SUB-TOTAL - not researched and contaminated or otherwise not combustible		**19t/yr**	**100%**

Table 3: Breakdown of waste collected in wood waste bins at BCIT

3. Evaluation of Laboratory Test Results

Air emissions from biomass combustion are influenced by the combustion technology and combustion conditions, but are also a result of fuel properties. For example, emissions of carbon monoxide, organic compounds, and of aromatic hydrocarbons are mainly due to incomplete combustion, i.e. a technology issue, while emissions of trace elements are mainly influenced by fuel properties.

In order to gauge the quality and properties of the various waste streams BCIT staff collected four fuel samples from the different biomass sources identified in the previous section for chemical analysis in a commercial laboratory. Econotech Laboratories in Delta, BC was selected to determined moisture content, ash content, gross and net calorific value, and chemical composition of five samples (the additional sample being sourced offsite at Urban Wood Waste).

3.1. Sampling Process

Four of the fuel samples originated from BCIT. A fifth sample was taken from outside BCIT for comparison with BCIT fuel sources. This fifth sample was construction and demolition waste taken from Urban Wood Waste Recyclers at the New Westminster location. Neither the pallets, the furniture waste, cardboard, nor the wood containing preservatives were sampled and tested. This should be done at one point to verify that these waste streams are too contaminated to be combusted.

Table 3 describes the samples taken.

Sample source	Sampling location	Sample form	Sampling date
Sawdust and planer shavings	Waste bin near the briquette press outside BCIT's Joinery Workshop (NE 02)	Small particles (generally < 2 mm) from the dust collection system (Joinery and Carpentry), compressed to a puck shape (50 mm diameter, 25 mm thickness)	Friday, March 9 at approximately 1:30pm
Solid wood (2 x 4 stud)	Waste bin outside of BCIT's Carpentry Workshop (NE 04)	Off-cuts from a piece of dimensional lumber (2x4")	Friday, March 9 at approximately 1:30pm
Plywood	Waste bin outside of BCIT's Carpentry Workshop (NE 04)	Off-cuts from a piece of plywood (3/8")	Friday, March 9 at approximately 1:30pm
Medium Density Fibreboard (MDF)	Obtained inside BCIT's Joinery Workshop (NE 04)	One piece of cut-off from an uncovered, unlaminated board of MDF	Friday, March 9 at approximately 1:30pm
Demolition, land clearing, and construction wood residue (DLC)	Centre of a large pile at Urban Wood Waste Recyclers at 4 Spruce Street, New Westminster, BC, V3L 5G6	Chips with some fines (mostly < 25 mm – 1")	Monday March 12 at approximately 10:00am

Table 3: List of biomass samples collected

A 3 kg sample of each biomass source was collected in a water tight plastic bag and shipped off to Econotech's laboratory in Delta, BC. As for the construction and demolition waste, a front loader was used to dig up a load from the inside of a large pile. Then a 3 kg sample was taken from the load dumped by the front loader. All samples are deemed representative. In order to assert this assumption, at some point in the future at least three samples will have to be taken from each waste stream.

3.2. Test Results

A proximate analysis, an ultimate analysis, and a mineral analysis were undertaken on each sample.[17]

The proximate analysis included determination of the calorific content, moisture content, fixed carbon, volatile matter and ash content of the sample. The ultimate analysis provided the composition of the elemental carbon, hydrogen, nitrogen, sulphur, chloride, fluoride, and oxygen. The mineral analysis detailed the amount of trace elements found in the ash of the species. Additionally each sample was tested for its ash fusion temperature.

The test results reveal important information about combustion parameters and emissions to expect from the various sources available at BCIT.

Prior to conducting the various tests, the laboratory grounded all samples to a 20 – 40 mesh size.

The test results displayed in the following chapters are those of the five samples tested and are given as reported by Econotech. Using the results for the four BCIT waste streams a weighted average has been calculated by the authors. This average contains 6% pallets that were not tested, but assumed to have similar properties to the 2x4' studs sample, as it is assumed to be essentially untreated wood.

3.2.1. Moisture Content

The moisture content of the wood samples was tested according to ASTM E871 standard. Moisture content was calculated relative to sample weight on as-received basis, i.e. wet basis. [18]

All of BCIT's wood samples had less than 12% moisture content, based on the weight of the moist wood. The average of BCIT's wood waste stream had less than 10% moisture, the level set forth for A1-class pellets. Since the bin is located outside the workshop, it is not covered. Wood waste is hence exposed to the elements, potentially soaking up precipitation and increasing the moisture content of the wood.

Due to the low moisture content, no negative effects on the combustion conditions are expected. Likewise the biomass boiler efficiency will not be negatively impacted by the moisture contained in the fuel. A high moisture content would make it more difficult to achieve a sufficiently high temperature in the combustion chamber, leading to incomplete combustion

[17] Proximate and ultimate analysis are two test methods that were designed for coal and coke but are also applied to biomass

[18] Wet basis: Moisture content may be given as a weight percentage of the wood fibre only (dry basis) or as a weight percentage of the wood fibre plus the moisture contained in it (wet basis).

and therefore to higher emission levels. A temperature above 850°C is necessary to ensure a low level of carbon monoxide (CO), and the presence of excessive moisture can inhibit the combustor's ability to achieve such a high temperature.

Storage conditions can have an influence on the amount of moisture absorbed by the fuel. It should be noted that the moisture content of the sawdust is higher than the sources it is supposedly made of. This may be explained by a higher surface area of the sawdust and/or a leak in the dust extraction system drawing in rain or moist outside air. Furthermore the dust bin in use is underneath the dust collector, but bins already filled up may partly be exposed to rain (see picture page 10).

Figure 5 illustrates the moisture content of the various fuels tested.

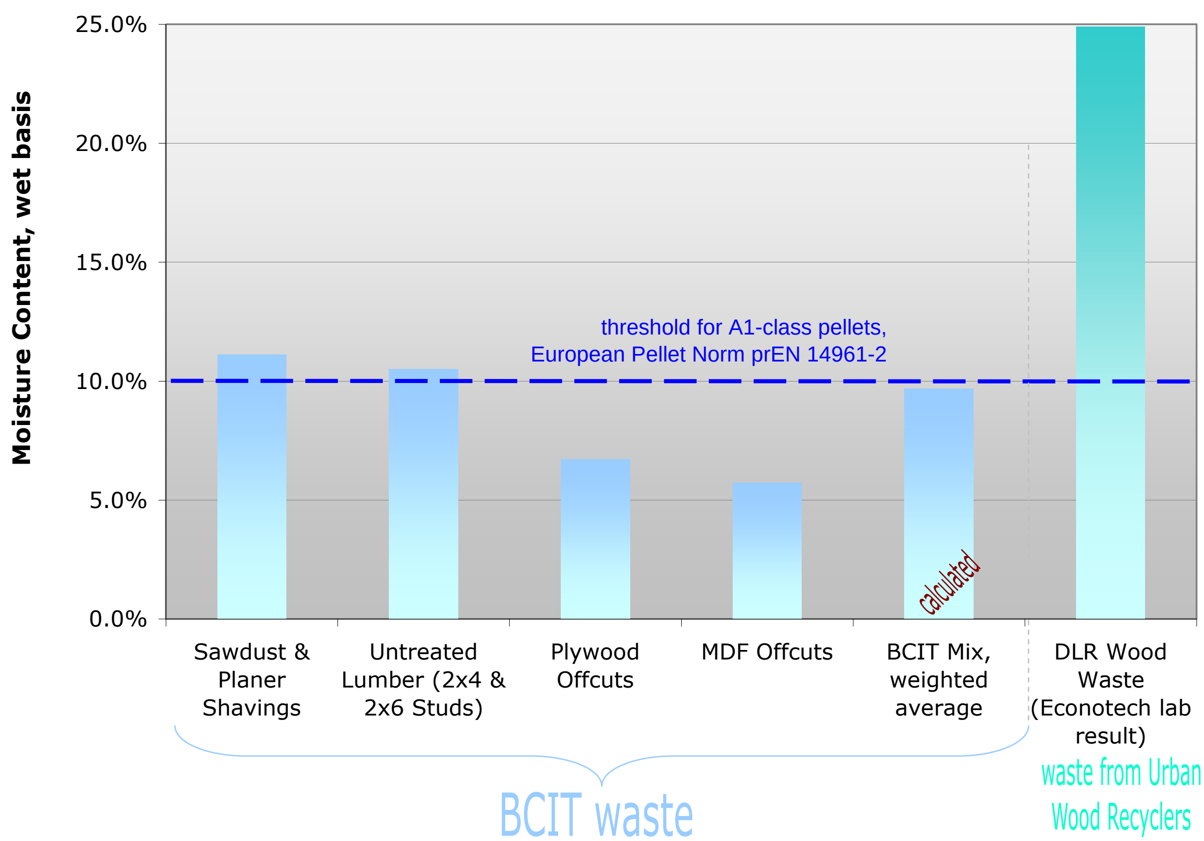

Figure 5: Moisture content of samples tested

3.2.2. Energy Content

The Higher Heating Value was determined in a bomb calorimeter using the ASTM -D5865/E711 standard. The Lower Heating Value [19] was calculated using a standard formula involving the moisture content and the hydrogen content of the sample. Again, the moisture content was measured according to ASTM E871 standard.

The Higher Heating Value includes the condensation energy of the combustion product H_20 (steam). The Lower Heating Value is more useful as most biomass boilers do not have condensing heat exchangers. The authors of this report recalculated all values from a dry basis (MJ per kg of dry matter in the sample) to a wet basis or 'as received' result (MJ per kg of sample material, containing wood and moisture). [18]

Figure 4 shows the result of the measurements and calculations.

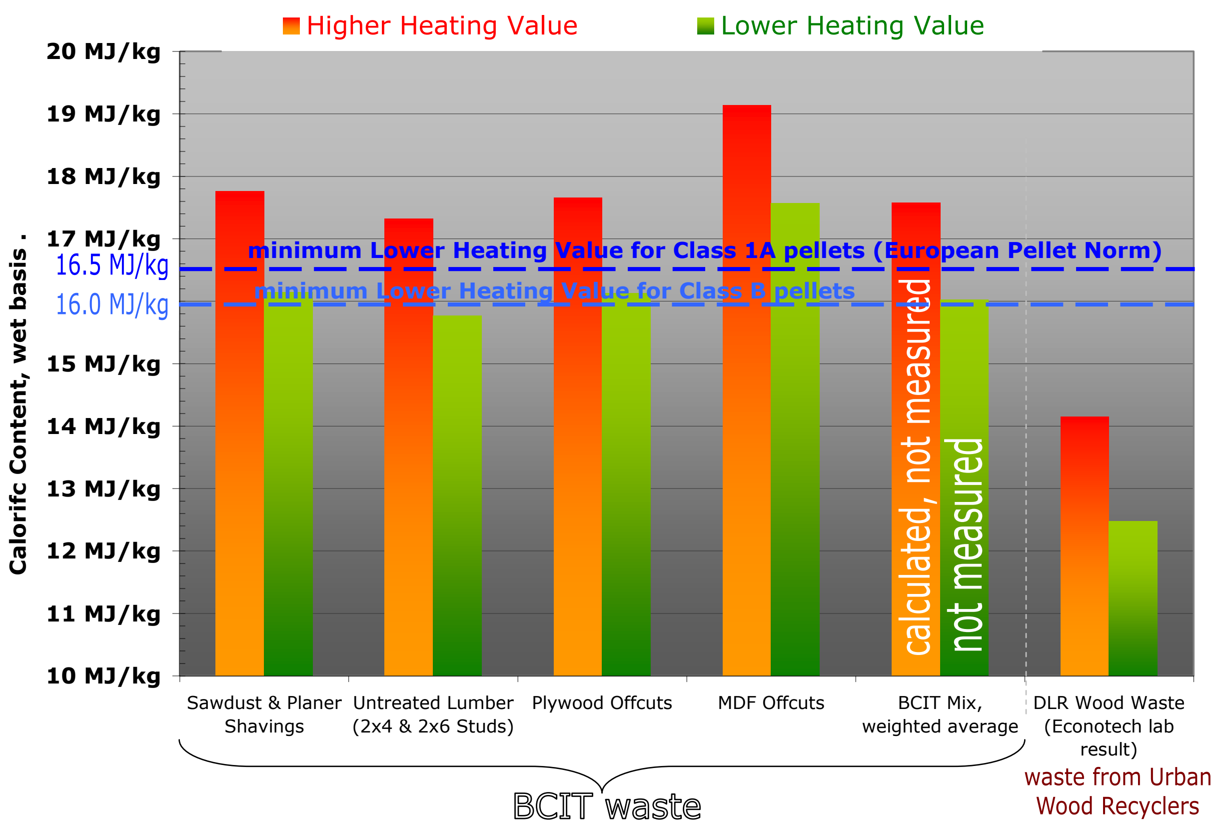

Figure 6: Higher and Lower Heating Value of samples tested

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[19] Lower Heating Value: a measure of the calorific content of a fuel. Other than the Higher Heating Value (HHV), this is the energy released after subtracting the latent heat released when condensing the steam contained in the flue gases. For biomass, this value is more representative than the higher heating value as there are no condensing boilers on the market that could make use of the energy contained in the steam.

The Lower Heating Value of BCIT's wood waste is 16.02 MJ/kg on average. For reasons stated in the last chapter, the actual calorific value may be even slightly higher as some of BCIT's wood samples may have been exposed to rain when being stored in the open waste bin.

This net calorific content would fall short of the minimum requirements for Class 1A pellets (16.5 MJ/kg), but would meet the less stringent requirements for Class B pellets (16.0 MJ/kg).[20] In comparison the DLC wood waste sampled at Urban Wood Waste Recyclers had a lower calorific value of 12.47 MJ/kg. This can be explained by the higher moisture content of the DLC sample (25% m.c. wet basis, as compared to an average of less than 10% for BCIT's waste).

Assuming pallets have the same moisture content and same calorific content as the untreated lumber tested, and assuming the waste of SE30 consist of 50% plywood and 50% raw lumber, the following calculation regarding the energy content of BCIT's wood waste can be made:

Wood waste type	**Waste Details**	**Annual amount**	**Lower Heating Value** (wet basis)	**Net Calorific Value** (wet basis)
Raw Lumber	Untreated 2X4's, 2X6's studs	150 t/yr	15.8 MJ/kg	2,363 GJ/yr.
Plywood	All types of plywood	31 t/yr	16.1 MJ/kg	503 GJ/yr.
Wood dust	Compressed planer shavings & sawdust	31 t/yr	16.1 MJ/kg	503 GJ/yr.
MDF	Particle board, artificial wood of all types	22 t/yr	17.6 MJ/kg	391 GJ/yr.
Pallets	Raw lumber, heat treated, may contain nails	16 t/yr	15.8 MJ/kg	251 GJ/yr.
Total		**250 t/yr**	**16.0 MJ/kg**	**4,011 GJ/yr.**

Table 4: Annual energy content of combustible wood waste incurring at BCIT

The table above shows that close to 4,000 Gigajoules of usable wood energy are shipped out from BCIT's Burnaby campus every year, enough to heat 43 single detached homes[21] or all buildings in the Factor IV area.

BCIT plans to combust the waste in a state-of-the-art biomass boiler which will connect to the existing campus district heating system. If operated in a steady state mode, a seasonal boiler efficiency of 85% can be expected, turning these 4,000 GJ contained in the wood fuel into 3,400 GJ of usable heat. The natural gas consumption of the central boiler house will be reduced by approximately 6%.[22] A biomass boiler with a rated output of 250 kW if run continuously 24/7/365 would consume all of the above waste running at 50% capacity. Downtime from

[20] Net Calorific Content according to the European Pellet Norm prEN 14961-2

[21] According to Statistics Canada an average detached home consumes 92 GJ of natural gas per year.

[22] BCIT's boiler house consumes approximately 64,000 GJ per year [28]. The average efficiency of the gas boilers is reported to be 82.5% [27]

maintenance, seasonal fluctuations in wood waste, and the shutdown of the heating network during summer and seasonal peaks, will require the boiler to run at a rate higher than 50%.

3.2.3. Ash Content

The ash content of the waste was measured according to ASTM - E1755 by heating the samples to 575°C until only incombustible components are left in the sample. Ash contents are given on a dry basis, i.e. as a percentage of the weight of the dry wood.

Figure 7 below illustrates the results of the ash test.

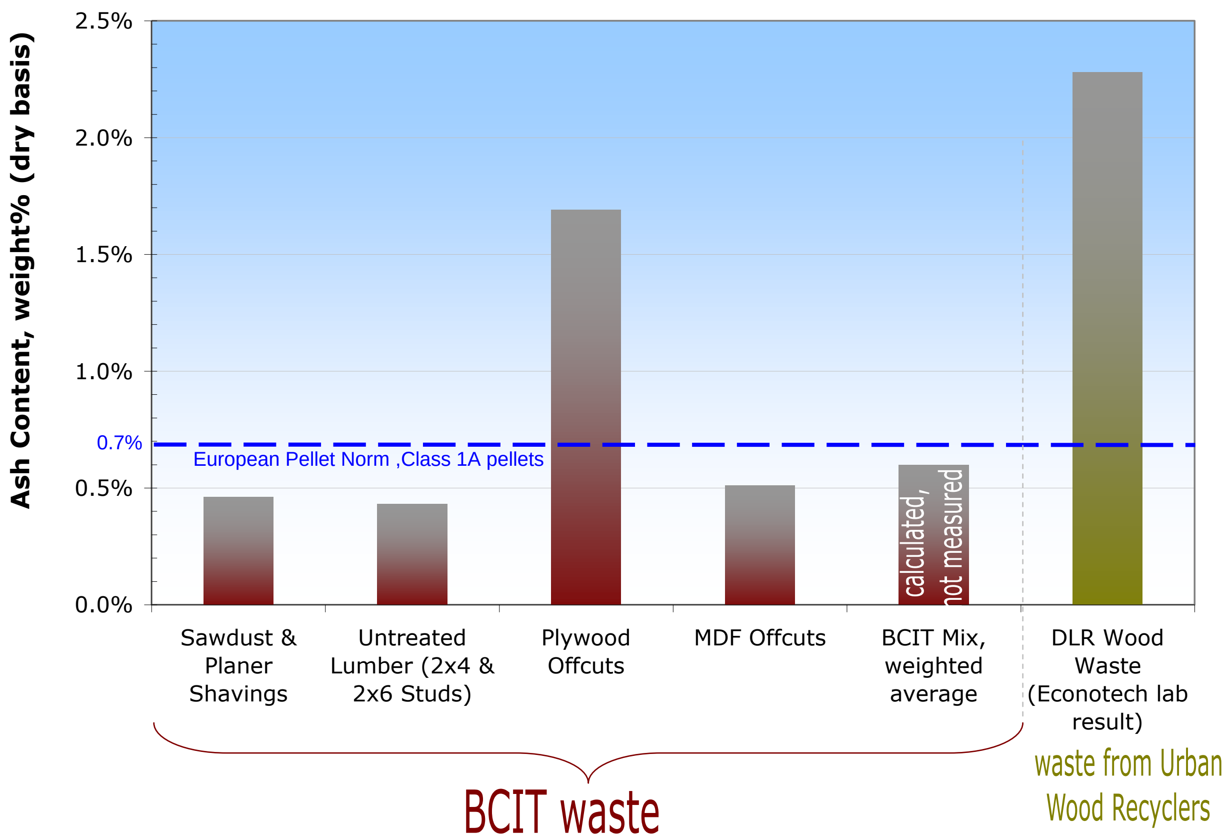

Figure 7: Ash content of the samples tested

The ash content of BCIT's wood waste streams is a low 0.62% average. Plywood is an exemption to this with ash content of 1.69%. This is probably due to the type of resin used when laminating the plies.

Hog fuel, the most common feedstock for biomass boilers in BC, has a higher ash content than BCIT's wood waste. FP Innovations stated the ash content of hog fuel – usually mostly bark - as used in pulp and paper mills is 2.45%, i.e. almost four times the ash content of BCIT's waste mix. [23] BCIT's wood waste also compares well to the DLC sample collected at Urban Waste Wood Recyclers which was tested at 2.28% ash content.

On the low end, the European Pellet Norm prEN 14961-2 can be taken as a benchmark. The norm requires wood pellets to have an ash content of less than 0.7% of the dry wood weight and BCIT's fuel mix would meet that criteria.

From a technical point of view, BCIT's wood waste is low enough in ash content to warrant the use of a pile burner or underfeed stoker. High-ash content fuels are typically burned in more sophisticated stepped grate burners as used in the greenhouse industry. Low ash content fuels result in lower particulate matter concentrations in the flue gas and hence less filtering requirements to meet the same emission threshold.

Burning all of the combustible wood waste available at BCIT (250 tonnes per year) will result in 1.5 tonnes of ash, approximately one 30 kg bucket a week. This ash will be produced in various fractions: Most of the ash will incur as grate ash that will be collected in the combustor's bottom ash removal system. Some of the ash, however, will be carried along with the flue gases as 'fly ash' that precipitates in the boiler. It will be collected in the flue gas filtering system, or will exist via the chimney.

The chemical composition of these individual ash fractions will vary from the average as some elements have a higher boiling point resulting in a tendency to end up as grate ash rather than fly ash. Fly ash is typically more contaminated with volatile heavy metals than bottom or grate ash.

The chemical composition of the ash is discussed in Chapter 4.2.8.

3.2.4. Ash Fusion Temperature

A parameter as important as the ash amount is the thermal behaviour of the ash when exposed to high temperatures. Ash is typically a powdery substance, but some ash melts and turns into a liquid lava-like substance called clinker or slag. Slag deposition in the combustion chamber and fouling of the downstream boiler or heat exchanger can be the result. Figure 8 shows an example of the effects of clinker from combusting plywood.

[23] Wenli Duo, FP Innovations / Parican, "Biomass Combustion in Pulp and Paper Mill Boilers", http://www.biomass.ubc.ca/docs/Duo_07.pdf, Accessed April 7, 2012

 

Figure 8: Example of clinker in a fixed grate combustor (left) and slag in a boiler (right)

The plywood sample is a prime example for this: the test (ASTM method D1857) yielded in initial deformation of the ash sample at 682°C and was completely fluid at 796°C, i.e. well below typical combustion temperatures of 850°C to 1,000°C. On its own, this specific type of plywood will result in major clinker formation when combusted in a biomass boiler, possibly rendering the combustor in a state similar to that of the pictures above. Fouling, the condensation of liquid ash on the heat transfer surface, may be a secondary effect causing down time or loss of thermal efficiency.

The reason for the low ash melting temperature can be found in the chemical composition of the ash: The plywood sample had a more than 300 times higher Sodium (Na) content than untreated wood and even contained five times more Sodium than the MDF sample. As a rule of thumb, fuel where the sum of K_2O and Na_2O is above 0.2 g per MJ of calorific content tend to create fouling problems, i.e. sintering of previously liquid alkaline onto the heat exchanger surfaces. For the samples tested in this study this ratio is exceeded for plywood only.

The most effective way of avoiding this problem is proper mixing of the plywood chips with the rest of the waste that has been tested for much higher ash fusion temperatures. This can be done by (a) chipping plywood scraps along with other off-cuts, (b) selecting a horizontal fuel storage system resulting in rather thin layers of a specific fuel and (c) employing a fuel reclaim system, such as a walking floor system that mixes up fuel prior to stoking it into the biomass boiler.

3.2.5. Nitrogen Content

The nitrogen, just as the chlorine, hydrogen, and sulfur content, were measured in a so-called CHN-analyzer according to ASTM method D5373. Samples were dried at 105°C ± 3°C prior to analysis, and then broken down into simple compounds using automated flash combustion. A gas chromatographer finally quantified the amount of elemental composition of the wood sample.

Wood naturally contains small amounts of nitrogen, usually in form of amino acids. Plywood boards and MDF boards used at BCIT, however, show elevated levels of nitrogen. The nitrogen is most likely part of the resin used in these boards. MDF, containing more resin than plywood, was tested to contain 11 times more nitrogen than untreated wood (studs), while the plywood sample had 4 times the nitrogen level of the untreated wood sample. Both, plywood and MDF, exceed the nitrogen threshold for A1-Class pellets if used on their own rather than as a part of the mix of wood waste produced at BCIT.

The presence of nitrogen could contribute to the formation of oxides of nitrogen (NOx), such as NO or NO_2. Both are precursors contributing to the formation of Ozone (O_3), a radical with negative impacts on respiratory tracts. High concentrations of ground level ozone are sometimes referred to as 'summer smog'. Ozone formation requires sun light and is therefore more prevalent in the summer than in the winter. NOx is also harmful to human health in its own right.

Plywood and MDF, if used as a fuel, should be mixed prior to combustion with other wood waste, such as untreated wood. The nitrogen content in the mix of all wood waste present at BCIT is calculated to be 0.29% of the dry matter weight of the wood, just below the 0.3% threshold required for A1-class pellets. Nitrogen levels are illustrated in Figure 9 below.

It can thus be expected that there will be slightly elevated level of oxides of nitrogen (NOx) in the flue gases. Special consideration should be taken to minimize NOx emissions by employing low-NOx combustors. The geometry of the combustion chamber and operation of the boiler plant can have significant impact on reducing the amount of NOx produced.

The most common post combustion treatment of NOx is Selective Non-Catalytic Reduction (SNCR): *SNCR* is a chemical process that changes NOx into molecular nitrogen (N_2). A reducing agent, typically ammonia or urea, is injected into and mixed with the hot flue gas. The reagent then, without a catalyst, reacts with the NOx in the gas stream, converting it to harmless nitrogen gas and water vapour, both components of air.

SNCR devices are, however, not common and may not even be commercially available for the size of combustor BCIT has planned to install (250 kW output). Moreover, SNCRs used at temperatures below 1,000°C have an ammonia or urea slip that results in release of highly corrosive gases with a sharp odour. Considering the amount of nitrogen present in the fuel might make the side effects of an SNCR device worse than the reduction of NOx it may achieve.

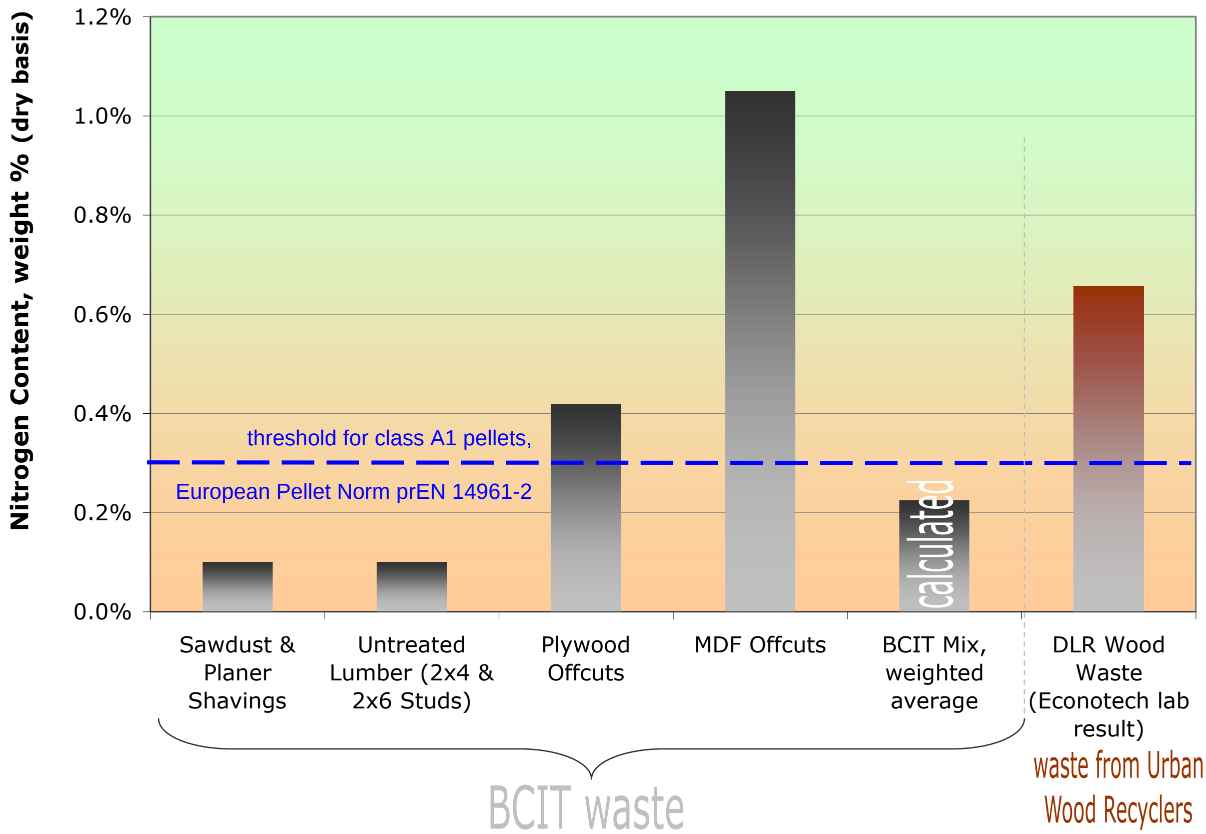

Figure 9: Nitrogen content of the samples tested

3.2.6. Sulfur Content

All trees sources contain small amounts of Sulfur. The amount varies from species to species. Compared to untreated wood all waste streams at BCIT feature low sulphur content and would pass the requirement of the European Pellet Norm prEN 14961-2 for A1-class pellets. The DLC sample, however, was tested for 20 times higher sulphur levels than the average BCIT waste. Figure 10 illustrates the results for sulphur. The test was done according to European Standard ESM-266B.

The sulphur content in a fuel determines the formation of SOx and sulphuric acid during the combustion process. Both are corrosive causing electrochemical erosion to the boiler.

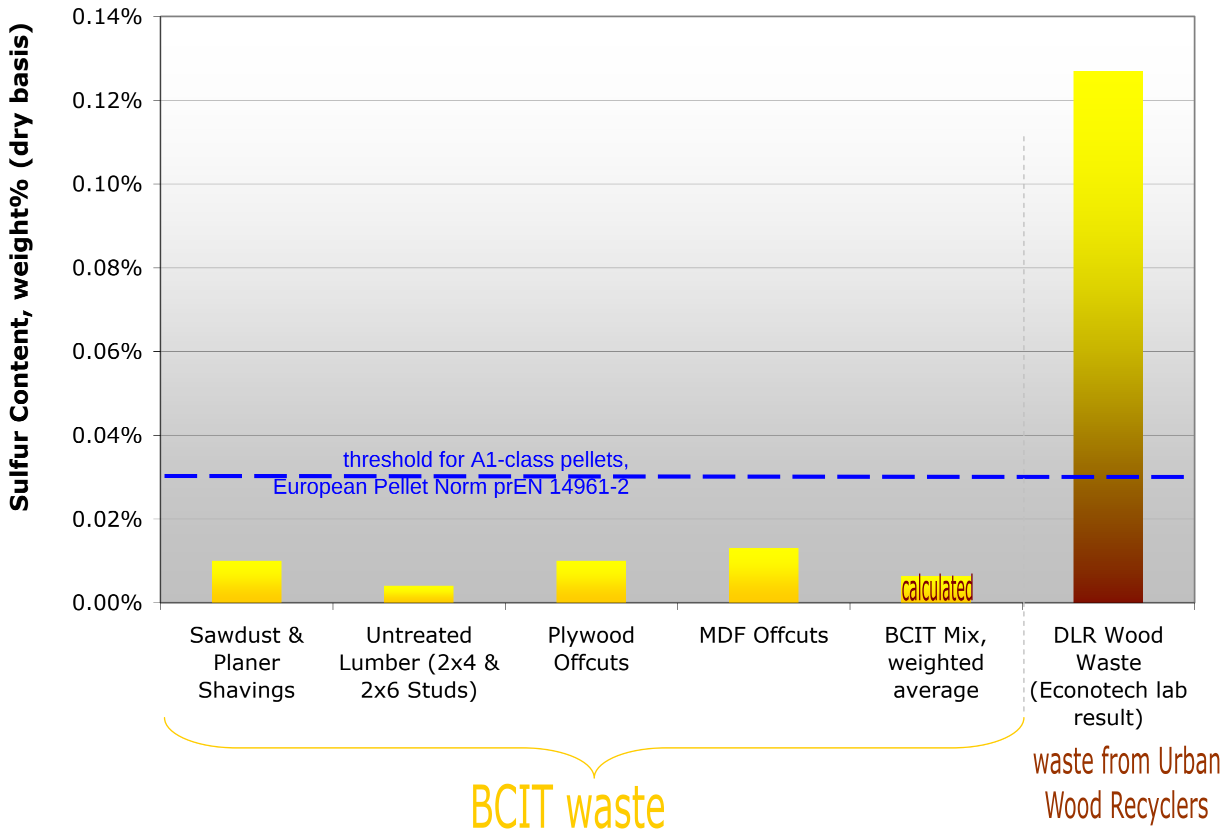

Figure 10: Sulfur content of the samples tested

3.2.7. Chloride Content

The chloride content in BCIT's wood waste streams was tested according to standard ESM-360B/040C. Most of the wastes at BCIT feature a medium to low chloride content. MDF has an increased level of Chloride, probably due to the resin contained in the particle board. Intuitively a higher level of chloride is expected to result in a higher concentration of chloride compounds.

Experimental evidence, however, show that a high chloride or fluoride content does not necessarily result in a high level of PCDD/F formation. Fuel with a chloride content of 0.02% of the dry wood weight (i.e. similar as in MDF samples) resulted in the same amount of Dioxin released as fuel with a 100 time higher chloride level.[24] Furthermore Dioxins and Furans were also found in flue gases of residential stoves using clean, untreated wood. [25] Dioxin and furan emissions appear to be less dependent on the fuel composition than the combustion process and

[24] Wenli Duo, FP Innovations - Parican, "Biomass Combustion in Pulp and Paper Mill Boilers", http://www.biomass.ubc.ca/docs/Duo_07.pdf, Accessed April 7, 2012

[25] Fernando Preto, NRCan "Emissions from Residential Wood Combustion", presentation given in Paris, France on Oct 21, 2005 at the IEA Workshop on Recent Developments in Small Scale Combustion Devices

post-combustion treatment of the flue gases. Larger, electronically controlled combustors are less likely to create dioxins and furans than smaller, uncontrolled stoves.

When averaged, wood waste generated by BCIT has chloride content below the threshold for A1-class pellets (see Figure 11 below). The DLC waste sample was tested to have a four times higher chlorine content than the average BCIT wood waste and more than twice the maximum values allowed for A1-class pellets.

Chloride in a fuel is the main precursor to the formation hydrochloric acid, a contributor to "acid rain". Hydrochloric acid (HCl) formed from chloride, is also responsible for corrosion of the boiler. Increased level of chloride may reduce the lifetime of the biomass boiler.

Chloride-rich deposit on the boiler passes can induce high-temperature corrosion. This may occur without any associated slagging or fouling and therefore not be detected right away.

In fuels with a high alkaline metal content, like the plywood sample, chloride may react with the alkaline to form alkali chlorides, a potent corrosive element when deposited on the boiler's metal surface. As for the fuel properties, the corrosive effect of plywood can be reduced by blending this high chloride, high alkali fuels with other wood waste sources.

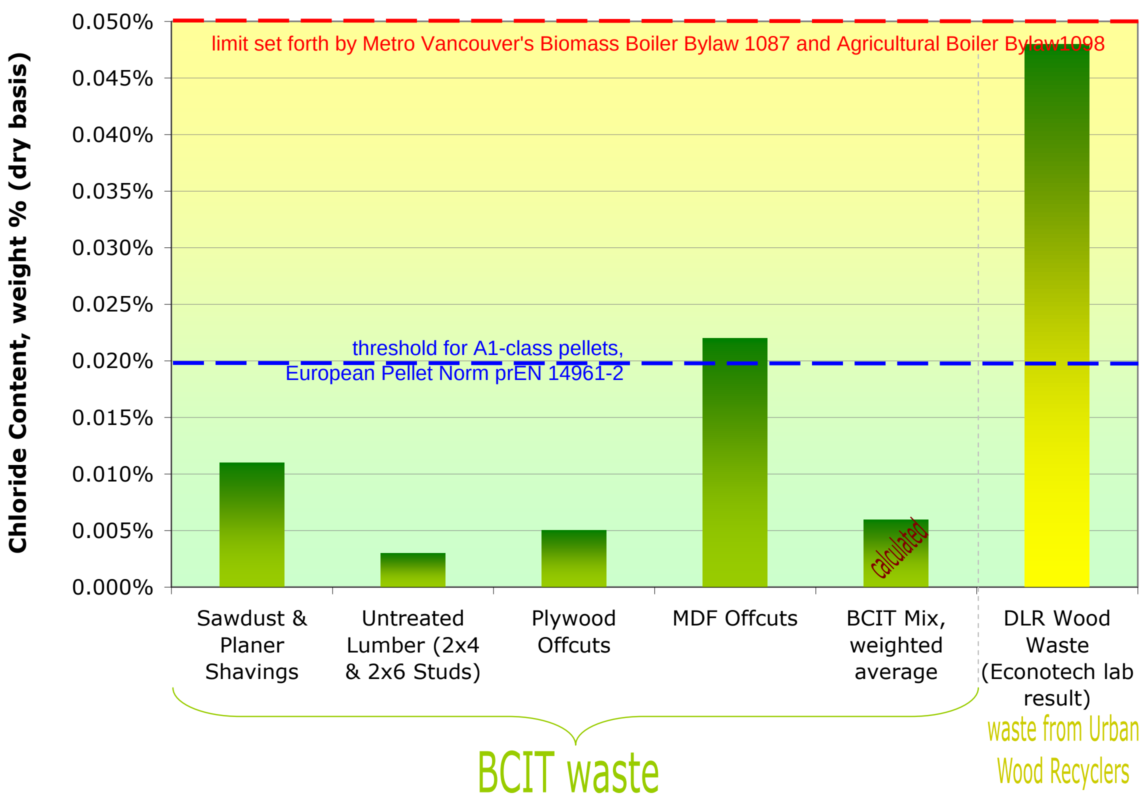

Figure 11: Chloride content of the samples tested

3.2.8. Metal and Metalloid Content

The chemical composition of the ash contained in the waste samples was measured. The results for trace elements contained in the ash are given relative to the weight of ash, not the wood.

From a procedural point of view, the samples were turned into ash, then tested using inductively coupled plasma optical emission spectrometry (ICP-OES) according the EPA method 200.8. [26] The detailed results of the spectrometry can be found in Appendix 2.

The ash was tested for metal and metalloid content, also called trace elements. Non-metals, such as sulphur have not been tested for.

The results represent the average chemical composition of the total ash produced in the tests. Trace elements found in the ash can be separated into desirable nutrients like Potassium (K), Magnesium (Mg) and Phosphorus (P) and toxic heavy metals like Cadmium (Cd), Lead (Pb), Nickel (Ni) and Zinc (Zn). Only the latter are evaluated in this chapter.

The chemical analyses of the five samples have yielded no significant level of potentially toxic elements in the ash of BCIT's waste.

- Arsenic levels were equal to or below the detection level of 0.2 mg/kg of ash for all BCIT samples. Arsenic levels found in the DLC waste contained more than 195 times the Arsenic.
- Cadmium was found to be higher (0.07 mg/kg) in the untreated wood (studs) than in the other waste streams. In comparison the DLC sample contained 15 times more Cadmium than the average BCIT waste.
- Chromium levels were found to be at a low level, slightly higher for the treated or composite wood samples. The DLC sample was tested to 117 times more Chromium than the average BCIT waste.
- Copper levels were 35 times lower in BCIT's wood waste than in the DLC sample. Surprisingly the sawdust contained almost twice the amount of Copper than the waste it was supposedly made off. There might be contamination from saw blades or the dust extraction system itself.
- Lead: None of the treated wood had higher Lead content than the untreated wood. The average BCIT waste had 215 times lower Lead content than the DLC waste.
- Mercury levels are very low for all BCIT samples, 0.0023 mg/kg on average – 42 times lower than the DLC sample tested.

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[26] EPA Method 200.8: "Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma - Mass Spectrometry", Revision 5.4, U.S. Environmental Protection Agency, May 1994.

- Zinc was found to be lower for MDF and plywood than for the untreated wood. Sawdust had a higher Zinc content than the material that the sawdust was made of. This may be explained by abrasions from the galvanized ducts of the dust extraction system. The DLC waste sample contained 16 times more Zinc than the average BCIT waste.

The results of these analyses are displayed in Figure 12 below.

Combusting BCIT's wood waste should not result in higher air pollution with toxic metals or metalloids than combustion of untreated wood. Since most heavy metals have a low condensation temperature, running the flue gases through a condenser will allow the downstream electrostatic precipitator to further filter out toxic trace elements.

The laboratory analysis conducted is a positive indication, but not sufficient to assess whether the ash may be used as a fertilizer. A test of grate ash and fly ash sampled at the biomass boiler installation will have to be conducted prior to allowing the ash to re-enter the eco-system. As for the business case it should be assumed that the ash will have to be landfilled. Even if the ash were clean enough to re-introduce it to the eco-system, it will be devoid of nitrogen and phosphorus, two important components of fertilizer. Clean wood ashes may, however, be used as a supplement to cement production. It is very unlikely though that the small amounts produced would allow entering into an agreement with a cement producer. The monetary value of clean wood ashes should therefore be assumed as zero.

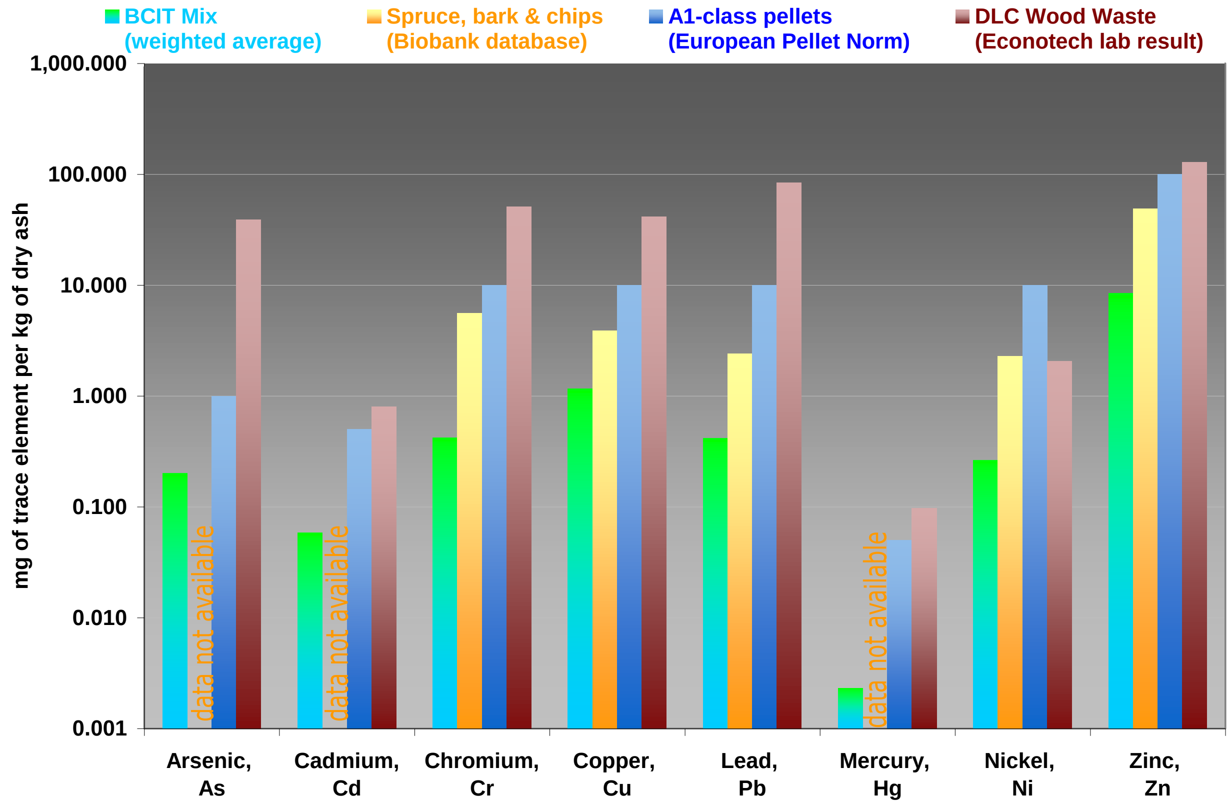

Figure 12: Toxic metal and metalloid content of the samples tested (Note the logarithmic scale)

3.3. Comparison of Test Results with Literature Data

There are various literature data that can be used as a benchmark for BCIT's wood waste streams. The following databases have been researched:

- Phyllis, an extensive database listing the composition of biomass and waste source. The database is compiled and maintained by the Energy Research Centre of the Netherlands (ECN). The databank is extensive, but has limited data on elemental analyses (trace elements). Website: http://www.ecn.nl/phyllis/
- Biobank is the most comprehensive set of data pertaining to chemical analyses, yet limited data on toxic metals and metalloids is available. The database is compiled by Bios Bioenergiesysteme GmbH, in Austria, and can be accessed on the International Energy Agency's website for IEA Bioenergy Task 32: Biomass Combustion and Co-firing: http://www.ieabcc.nl/database/biomass.php

- BIOBIB is a database of biomass properties compiled and maintained by the Technical University of Vienna, Austria. BIOBIB is an extensive database on wood and waste wood. Laboratory results on trace elements are rarely posted though. Website: http://cdmaster2.vt.tuwien.ac.at/biobib/wood.html

- US Department of Energy, sub-department for Energy Efficiency and Renewable Energy has compiled a 'Biomass Feedstock Composition and Property Database'. Unfortunately there is limited data on softwood, particularly SPF. The database also does not contain data on elemental composition.

  Webpage: http://www.afdc.energy.gov/biomass/progs/search1.cgi

- An extensive database on North American biomass sources titled "An Atlas of Thermal Data for Biomass and Other Fuels" was established by S. Gaur and T. Reed of the National Renewable Energy Laboratory (NREL) in the US. The 'atlas' mostly consists of thermo graphic data. Little information on chemical composition is given and no data of proximate, ultimate, or mineral analysis is included

  Webpage: http://www.nrel.gov/docs/legosti/old/7965.pdf

It should be noted that most of the databases are from Europe. Both, the types of wood species and the composition of the wood waste may differ from the waste stream available in Canada. Moreover, the lab analysis uses European test standards rather than the North American ASTM standard. Finally, only few of the literature data or databases contain a full set of chemical analyses as undertaken in this project.

For this reason a comparison of chemical contents in the waste sources may be difficult. As for the ultimate analysis, the best comparison appeared to be that with data published by Canadian FP innovation / Parican. [23]

The next graph shows the chemical composition of BCIT waste (weighted average) and compares this (a) with thresholds for A1-class pellets, (b) with ultimate analysis data of DLC waste (tested by Econotech Laboratories) , (c) data for Interior BC hog fuel.

It can be seen that BCIT waste would meet the A1-class pellet threshold for sulphur and chloride. Nitrogen, Sulfur, and Chloride levels in BCIT waste are lower than that of DLC waste and hog fuel. Only the Fluoride content of BCIT waste exceeded that of DLC waste, albeit at a low level. No data on Fluoride was available for hog fuel or pellets. Fluoride is a precursor to the formation of Furan. For reasons explained in Chapter 3.2.7, no forecast can be made about the level of furan that will be emitted, especially not at these low levels of Fluoride.

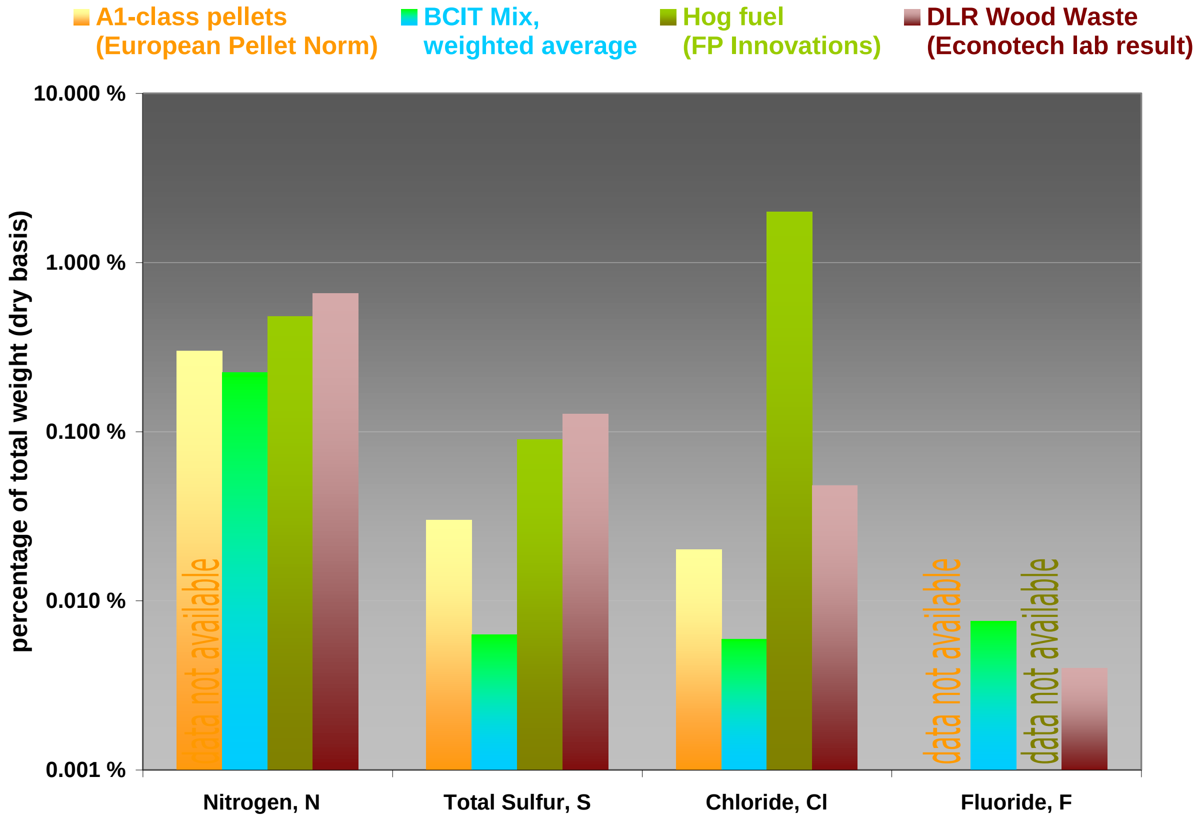

Figure 13: Comparison of chemical composition of BCIT waste with literature data

As for trace elements, BCIT's wood waste shows lower levels of toxic metals and metalloids than any of the three wood samples it is compared to: Bark and chips of Spruce logs, A1-class pellets, and DLC wood waste. It is noteworthy that from a chemical point of view, BCIT's wood waste would meet the European standard for A1-class pellets, i.e. could be used as a feedstock for pellets.

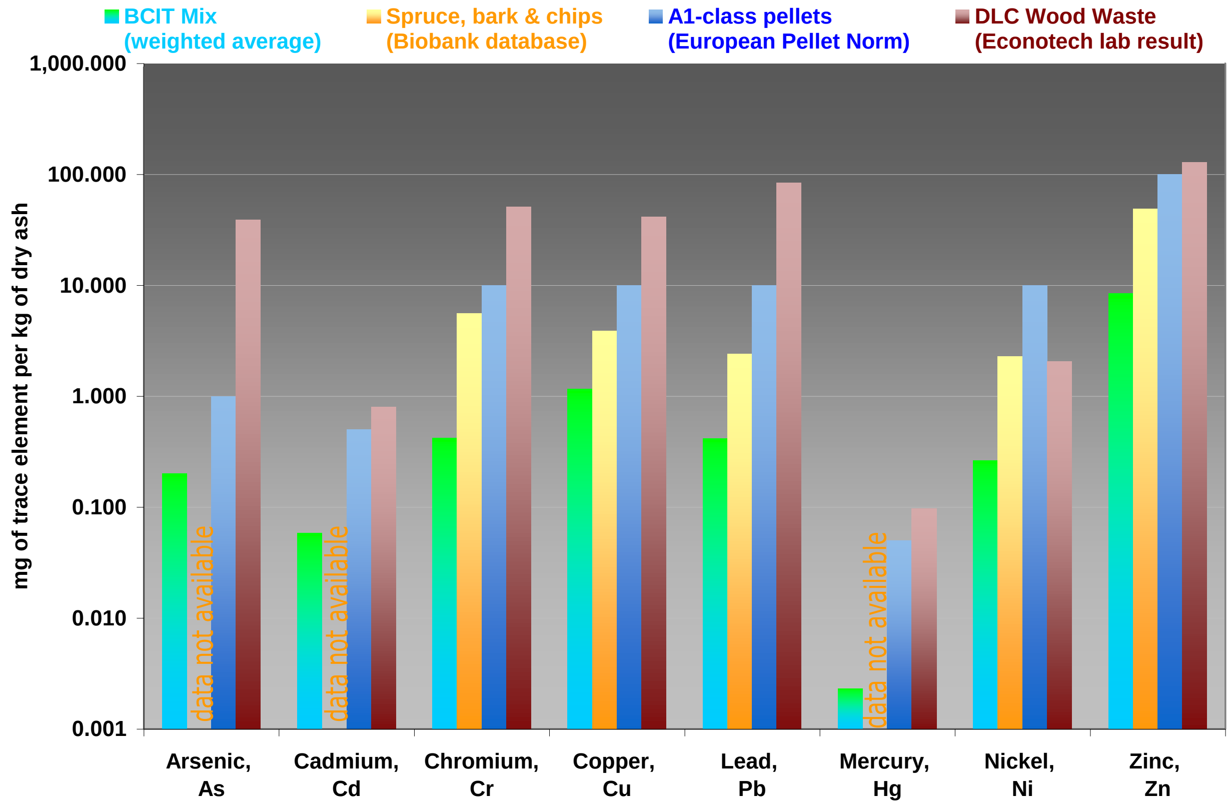

Figure 14: Comparison of metal and metalloid content with literature data

4. Comparison of Urban Wood Waste Sources

4.1. The Potential for Using Urban Wood Waste for District Heating

One of the objectives of BCIT's test facility is to assess the possibility and environmental impacts of using refuse derived wood fuel for space heating applications, mostly as distributed small scale source of heat in a district energy system. As mentioned in the introduction to this report, Metro Vancouver plans to redirect combustible material from landfill to energy recovery facilities, such as district heating.

The biomass boiler that BCIT plans to install has a capacity of 250 kW and is sized to be able to combust all of the burnable wood waste incurring at BCIT over the course of a year. The boiler shall be connected to the existing campus heating system and will replace approximately 6% of the natural gas consumption of the central boiler house. Replacing a higher percentage of natural gas would require importing wood fuel, such as DLC-waste, from landfills and/or dealers such as Urban Wood Waste Recyclers. This is not currently part of BCIT plans.

While technically a viable option - greenhouses in the Lower Mainland have used urban wood waste for years – the impacts on the environment are not clearly understood. This chapter provides an insight into the environmental impact that can reasonably be expected.

4.2. Wood Waste Requirements for BCIT's Burnaby Campus

The combustible wood waste available at BCIT will only be able to replace a small amount of fossil fuel. This chapter investigates how much wood fuel BCIT would have to import in order for BCIT to become a mainly biomass fuelled district heating network.

BCIT's boiler house provides heat to 13 of the 56 buildings on campus. Three natural gas fired boilers with a rated output of 6 MW (600 BHP) [27] consume a total of 64,000 GJ of gas a year, [28] roughly the amount used by a 4 hectare commercial greenhouses. If BCIT was to expand the Factor IV reduction to the entire Burnaby campus, 51,200 GJ or 80% of its natural gas consumption will have to be replaced by biomass. Using an annual gas boiler efficiency of 82.9%, [45] 42,430 GJ of heat needs to be replaced by heat generated in a biomass boiler. Assuming a biomass boiler efficiency of 85% generates this amount of heat, requires 49,920 GJ in wood energy. Of this 4,011 GJ are available at BCIT, the remaining 45,909 GJ would have to be imported to campus. This would require burning additional 3,681 tonnes of DLC-waste a year, fifteen times the amount of wood waste that the small 250 kW biomass boiler would combust. This would also mean that approximately 260 trucks per year with DLC (14 tonne tare) will have to arrive at BCIT, roughly one truck every workday.

4.3. Suitability of DLC Waste as a Fuel Source for District Heating

To gauge the impact of using construction and demolition (C&D) wood rather than BCIT's construction and joinery wood residue as a fuel, a sample was taken from Urban Wood Waste Recyclers at the New Westminster location. This sample was lab-tested alongside BCIT's residue samples.

Urban Wood Waste Recyclers classified the sample as "clean" demolition, land clearing, and construction wood residue (DLC) as opposed to Process Engineered Fuel (PEF) that may include plastics and waste paper. DLC is usually sourced from residential construction, residential remodelling waste (sometimes contaminated), and residential demolition.

[27] Prism Engineer Ltd, "BCIT Central Heating Plant Analysis", March 31, 2004
[28] Cornelius Suchy, "District Heating BCIT's Sustainability Precinct Area" Prefeasibility Study, March 31, 2011

Technically DLC should only contain woody materials that are not painted and not pressure treated.

The DLC sample taken revealed Cadmium and Mercury levels more than ten times higher than the wood waste samples of BCIT. Arsenic, Chromium and Lead contaminations were more than 100 times that of BCIT's wood residue. Both suggest the presence of wood preservatives and or (old) paint in the wood. Chlorine levels were four times higher and Sulfur content 13 times higher than that of BCIT's residue. Ash content was at 2.3% of dry matter rather than the 0.6% measured with BCIT's wood residue. 0.5% ash is common for stem wood, while higher ash content is an indication of contamination with non-combustible materials.

It is safe to predict that the environmental impact of combusting DLC as sampled from Urban Wood Waste Recyclers will be worse than combusting BCIT's wood residue. Arsenic, for example, was tested to be below detection levels in BCIT's residue, but significant amounts were found in the DLC sample. Combusting BCIT's residue will be of little concern in regards to this toxic element, but may be a problem with DLC waste.

Yet, high concentration of a certain element may not necessarily result in high emissions. Mercury, for example, present in the DLC sample is likely to precipitate in the heat exchanger or may be condensed and subsequently filtered out. The combustion process itself and flue gas treatment will have a significant impact on these stack emissions.

A chemical analysis can help predicting potential air contaminants, but no quantitative assessment can be made. To quantify the impact on air quality, an emission combustion test would have to be run using continuous emission monitoring (CEMs) equipment to quantify the amount of a specific chemical released.

Apart from environmental concerns, DLC would be an acceptable fuel for BCIT: moisture content is higher (25%, wet basis) than that of BCIT's dry wood residue, yet well below the 40% to 50% moisture content of so-called 'hog fuel' commonly used in the greenhouse industry. Likewise the ash content of the DLC sample, 2.28% of the dry matter weight, was below the 3% ash content typical for bark or 'hog fuel'. The ash fusion temperature was above combustion temperatures applied in state of the art biomass boilers. DLC as tested should not create a problem with slagging, fouling or clinker formation.

The main challenge of using DLC for district heating, especially in a small underfeed stoker type boiler as planned by BCIT, will be the physical fuel characteristics, particularly the homogeneity of the wood chips. Fuels for Schools programs in New England, and also in Montana has shown that low cost fuel, such as DLC, resulted in frequent downtime, often due to oversized wood pieces, tramp metal, or rocks jamming up the fuel supply chain. Small biomass boiler using augers and fixed grates are not geared to handle this type of impurities.

4.4. Urban Wood Waste Available in the Lower Fraser Valley

In 2011 the BC Bioenergy Network commissioned a fuel study detailing the types, amounts, and characteristics of solid biomass available in the Lower Fraser Valley. [29] The study was particularly aimed at district heating, such as the campus heating project under construction at UBC and two other projects in Metro Vancouver that are in the advanced planning stage.

The study informs utilities and City administrations of fuel availability, quality, and cost. The report provides input parameters for an evaluation of the economic viability of a certain district heating project. The study also identifies potential fuel resources, albeit without chemical analyses of these sources.

Four categories of biomass sources are identified, one of them being Clean Demolition, Land clearing and Construction Waste (DLC). Within the DLC category, construction waste resembles BCIT's wood waste streams the most.

The report estimates that in 2011, 430,000 tonnes of DLC was generated. Of this only 170,000 tonnes are recycled, with the reminder of 270,000 tonnes still being landfilled. The 170,000 tonnes are committed to various users today, but Metro Vancouver's push to reduce the amount of landfill by 80% [5] is expected to result in additional 155,000 tonnes becoming available in the next ten years – enough to fuel approximately 50 district heating networks of BCIT's size. The quality of this fuel may be only second choice as the prime material is already committed to existing users. Without a quality control mechanism it will be difficult to get a handle on what types of DLC will be used as a fuel for biomass boilers.

5. Economics of Burning Wood Waste at BCIT

BCIT collected the financial data for this project through a series of feasibility studies involving various members of the BCIT community and external consultants such as CBER Ltd., DA Architects and Stantec. This section presents a summary of the cost of burning BCIT's own wood waste on-site for two scenarios: a) building for education, demonstration and research and b) building to maximize direct financial return on investment. This section also presents a summary of the savings and net savings associated to this project.

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[29] Paul A. Beauchemin, Martin Tampier, Envirochem Services Inc.: "Biomass Availability Study For District Heating Systems", Feb 2012

6. Potential Alternative Uses for BCIT's Wood Waste

In BC, the demand for wood waste is currently driven by three industries: greenhouses, cement plants, and pulp mills. Hospitals are a new potential market and universities are starting to realize the carbon savings potential of biomass and have started to secure resources.[2] Since the recent closures of local sawmills and plywood mills in BC, the easily available biomass has started to dry up. As a result, biomass users have searched for alternative sources of wood fuel, including demolition and construction wood waste. The table below identifies the demand for urban wood waste by major producers. This table summarizes the top purchasers of Metro Vancouver wood waste. It only represents the consumption of fuel-grade wood generated from within Metro Vancouver (MV) and not total fuel consumption. Furthermore, Table 7 only records the wood fibre component (measure in bone dry tonnes – BDt), not the actual weight of urban wood waste that consists of waste and moisture.[2]

Demand for Urban Wood Waste by Major Producers in Metro Vancouver				
Name	**Location**	**End Use**	**Delivery Method**	**Volume (BDt, 2010)**
Howe Sound Pulp & Paper	Port Mellon	Power/ Process Steam	Barge	42,000
Catalyst Paper	Powell River & Crofton	Power/ Process Steam	Barge	34,200
Kruger Paper Mill	New Westminster	Power/ Process Steam	Truck	70,000
US Mills	WA State	Power/ Process Steam	Truck/Barge	40,000
Small Consumers	Various	Soil Manufacturer & Composting	Truck	35,000
Blueberry/Cranberry Farms	Various	Agriculture	Truck	20,000
Small Greenhouses	Various	Heat	Truck	20,000
Lafarge Concrete	Richmond	Kilns	Truck	15,000
West Coast Lawns	Delta	Soil Manufacturer	Truck	15,000
Richmond Plywood	Richmond	Kilns	Truck	7,000
Total				298,200

Table 5: Urban wood waste demand by major producers in Metro Vancouver

Currently, BCIT's wood waste is hauled out by BFI and transported to Urban Wood Waste Recyclers. Urban Wood Waste Recyclers is owned and operated by Harvest Power. According to the website (http://www.uwwr.com/), they are Metro Vancouver's largest recycler of construction, demolition, and renovation waste. They sort through the accumulated waste and recycle metals, cardboard, tires, batteries, cans, bottles, and concrete. The wood wastes that are collected are turned into two fuel streams: hog fuel and PEF. These fuel streams are used to power biomass projects in companies such as the Howe Sound Pulp and Paper and Lafarge Concrete.

If BCIT decided to continue to ship their wood waste, other viable suitors will need to be investigated. Keep in mind for BCIT to maintain its goal of minimizing its ecological footprint and emissions, BCIT would need to select purchasers in close proximity to the Burnaby campus. This would reduce the emissions to transport. As a result, viable suitors would be within the Metro Vancouver area.

6.1. BC Pulp and Paper Mills

BC's coastal pulp mills have experience many closures over the past couple of years. As BC Climate Change reports that 75% of BC's pulp and paper mills have biomass generating systems[32]. The Mercer International Group estimates that 28 million m^3 of wood per year is consumed by this segment[33]. Funding opportunities and tax credits to expand biomass and renewable sources are being offered by programs such as the Pulp and Paper Green Transformation Program and BC Hydro programs.

Unfortunately, the pulp and paper industry has experienced a decline over the past years. Many of these mills are in some form of bankruptcy protection or have shut down due to the low demand of newsprints and paper. For instance, the telephone directory printing business dropped 20% in 2011[34] reducing the demand for paper products.

There are limited pulp and paper mills in the Metro Vancouver area. Shipping the wood waste beyond this district will result in an increase in carbon footprint. Kruger Paper Mill has been identified as a viable candidate.

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[32] BC Climate Change website, http://www.bcclimatechange.ca/how-wood-products-help/bio-energy.aspx, Accessed on April 6, 2012

[33] Mercer International Group, BC's Bioenergy Strategy: Examining Progress and Potential in the Province, Presentation at the Canadian Institute's BC Power Conference, January 2010, http://www.mercerint.com/i/pdf/BCPowerConferencePresentation.pdf, Accessed on April 6, 2012

[34] Vancouver Sun website, Catalyst ready to scrap one B.C. mill, sell three others, http://www.vancouversun.com/story_print.html?id=6332861&sponsor=, Accessed on April 6, 2012

Kruger Paper Mill (formally known as Scott Paper)

This mill serves the entire region of Western Canada from Vancouver Island to the Lakehead region of Ontario. The facility includes four paper machines and 19 converting units, producing paper towels and toilet paper.

Kruger uses a direct-fired biomass gasification plant to provide process stream for the mill. It's capacity is 40,000 lb/hr of low pressure steam. At an output of 40 mmBTU/h (11.7 MW), the boiler would consume approximately 3.0 tonnes of wood (at a moisture content of 10%). The burnable content of one of BCIT's 40 cyd waste bins, holding 4 tonnes, would be used up in a little more than one hour. Since the plant already uses clean construction debris as part of its fuel, delivery to Kruger Paper Mills should be an option.

6.2. Cement Plants

Globally the cement industry has been a long-time user of alternative fuels. As one of the largest among the group of 'large industrial emitters' there is increasing pressure to switch to less carbon intensive fuels, including tires, bone and meat meal, and dry wood waste.

A recognizable association in BC is the Cement Association of Canada (CAC), which consist of eight members that cover 45 countries. In Canada, these companies operate 15 cement plants and more than 1,100 locations manufacturing cement based products[35]. The graph demonstrates the shift from fossil fuels to renewable resources and biomass in the Canadian concrete industry. Notice the limited growth in thermal energy substitutions by concrete facilities from 2007 to 2008. Although statistics since 2008 are not available, biomass growth has continued by the display of newly gasification biomass systems such as the one at Lafarge in Richmond. As more biomass projects increase, possible disposal of BCIT wood waste may be attainable. The most commonly used renewable energy sources are C&D wood waste, municipal bio-solids, non-recyclable plastics and textiles, recovered solvents, and discarded tires.

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[35] Cement Association of Canada, http://www.cement.ca/en/CAC-Members.html, Accessed on April 7, 2012

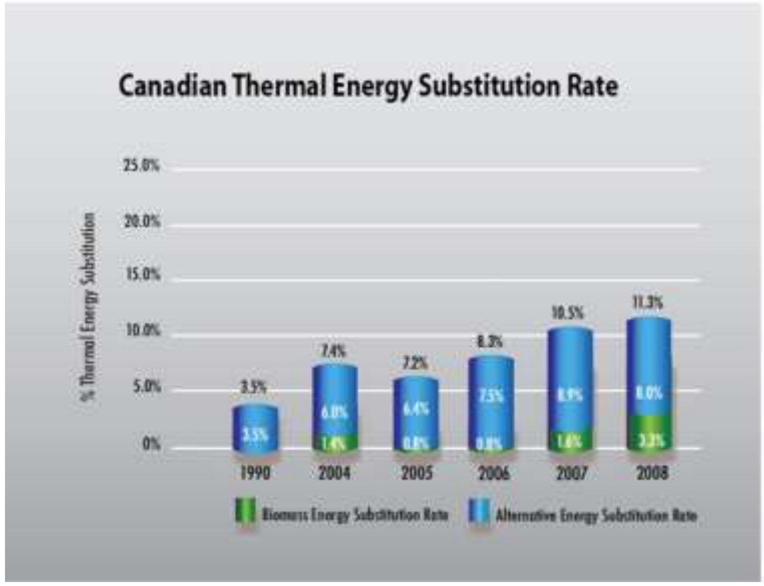

Figure 16: CAC's Canadian Thermal Energy Substitution Rate[36]

<u>Lafarge Concrete</u>

Lafarge Concrete has developed an advanced biomass energy system that utilizes wood waste. They are able to incinerate wood fuel known as Performance Enhanced Fuel (PEF). According to Urban Wood Waste Recyclers, this fuel consist of construction and demolition (C&D) waste and contains clean wood, painted wood, plywood, oriented strand board, particle board, shake and shingles, film plastics, rigid plastics, cardboard, and tar paper. There is no chlorinated plastics in PEF. Although, PEF is preferred, BCIT wood waste may be of use to Lafarge. They purchased 15,000 BDt of fuel graded wood waste from Metro Vancouver sources in 2010. [37]

6.3. Small Consumers, Blueberry/Cranberry Farms, and West Coast Lawns

Small consumers include farms and other small users of wood waste, primarily for soil manufacture and composting. This may not be a viable option as one consumer may not need or support the quantity of wood waste. As a result, numerous waste users will need to be identified and multiple contracts need to be established. Seasonal demand may not match the year around production of wood waste at BCIT.

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[36] Cement Association of Canada, http://www.cement.ca/en/Using-Alternative-and-Renewable-Energy.html, Accessed on April 7, 2012

[37] Paul A. Beauchemin, Martin Tampier, Envirochem Services Inc.: "Biomass Availability Study For District Heating Systems", Feb 2012

6.4. Public Institutions

Many post-secondary educational institutions are governed by the BC Provincial Government. These institutions must follow Acts such as the 2007 Greenhouse Gas Reduction Targets Act[38] which requires public organizations to:

- By 2010, the B.C. public sector will be carbon neutral. In other words, the government is setting an example and keeping its own carbon footprint as small as possible
- By 2020, B.C. will reduce its greenhouse gas emissions by 33 per cent, compared to 2007 levels. In addition, legally binding targets will be set this year for 2012 and 2016.
- By 2050, GHG emissions in the Province will be reduced by at least 80 per cent below 2007 levels.

With the guidance of legislation, institutions are taking measures to reduce their energy consumption. According to Livesmart BC, a BC Government initiative, in 2010, post-secondary institutions produced a total of 150,959 tonnes of CO_2e [39]. As a result, $3,769,485 was purchased in carbon offsets. With 96% of these schools participating in energy reduction methods[40], it is safe to conclude that energy efficiency is becoming essential.

With the energy efficiency goals and the objective to reduce costs, some of the larger institutions are considering or are in the process of attaining a form of biomass heating plant. For instance some organizations have adopted gasification technology. As a result, BCIT has the potential to distribute their wood waste to nearby educational institutions that would move ahead with biomass energy before BCIT.

University of British Columbia

The University of British Columbia (UBC) is located in Vancouver and uses a turnkey supply and installation of biomass gasification system[41]. This project is currently under construction and should be considered as a possible destination for wood waste.

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[38] Livesmart BC website, http://www.livesmartbc.ca/attachments/climateaction_plan_web.pdf, Accessed on April 9, 2012

[39] Livesmart BC, website, http://www.livesmartbc.ca/government/carbon_neutral/advanced_education.html, Accessed on April 9, 2012

[40] Livesmart BC, website, http://www.livesmartbc.ca/government/carbon_neutral/advanced_education.html, Accessed on April 9, 2012

[41] UBC website, http://www.nexterra.ca/industry/ubc.cfm, Accessed on April 5, 2012

Simon Fraser University (SFU)

SFU is in the process of attaining a biomass heating facility on campus that will utilize construction and demolition waste. BCIT will continue to monitor its progress.

6.5. Greenhouses

According to Envirochem, [29] the BC Greenhouse Grower Association estimates that approximately one third of their members use wood fuel as their primary energy source. BC Greenhouse Grower Association states that there are 42 members[42], and about 14 of those members have a biomass plant. The consumption of wood residue fuel is 1,6000,000 GJ per year which is equal to 80,000 BDt per year (assuming that it is a 40% moisture content allowance). Furthermore, due to the high demand of wood residue, greenhouses in the Lower Fraser Valley and Metro Vancouver district have been importing from BC's interior.

Greenhouses are trending away from hog fuel and moving towards the use of drier fuel that increases the amount of energy that can be stored on site. This would be an opportunity for BCIT. On the other hand some growers are exploring the possibility of cogeneration (0.5 – 4 MWe) using natural gas as a fuel. Heat produced would be used to heat the greenhouse, while electricity is fed into the public grid. Cogeneration plants and biomass plants have similar operational characteristics and are competing against each other. This competition is currently in favour of cogeneration as natural gas prices are at a historic low. Although many greenhouses that currently use biomass plants have indicated that they won't switch, the demand for wood fuel may not increase beyond current consumption.

Potential buyers include Sun Select (Aldergrove) and Windset Farms.

6.6. Conclusion regarding Alternative Disposal Methods for BCIT

BCIT wants to build a woody biomass waste-to-energy facility for demonstration and education purposes which represents a value above and beyond the waste and GHG reduction potential for its own operation. If BCIT had no intention to promote and educate on biomass, the above survey of potential buyers indicate that there are various opportunities for BCIT to divert its wood waste away from landfills to a use as a fuel in facilities that have a permit to burn construction and demolition waste. The small amount of wood residue that BCIT generates might create a problem when negotiating fuel prices. Many of the big consumers will not

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[42] BC Greenhouse Growers' Association website, http://www.bcgreenhouse.ca/quick_facts.htm, Accessed on April 6, 2012

consider dealing with a multitude of small suppliers and rather go through aggregators such as Urban Wood Waste Recyclers.

Realistically, BCIT is unlikely to obtain money for its wood waste, but may be able to negotiate free pick up. This should be considered in the interim until BCIT has its own biomass boiler in place. There is a chance (but officially unknown and outside BCIT's current contract with BFI) that BCIT's waste has not been landfilled but has already been processed and sold as fuel to some of the end users mentioned above.

Small consumers are more likely to pay better prices for fuel of BCIT's quality. Their seasonal demand for fuel, however, is unlikely to match BCIT's production. Long or even mid-term storage is not an option at BCIT's Burnaby campus.

7. Evaluation of Air Quality and Greenhouse Gas Considerations

To evaluate the air quality and greenhouse gas (GHG) emission, this report has used the BC Ministry of Environment's "Methodology for Reporting 2011 B.C. Public Sector Greenhouse Gas Emissions Version 2.0".[43] The methodology provides a structured method to record emission factors and to calculate the Public Sector Organizations (PSO) emissions. Under the guidelines, PSOs are required to report Bio-CO_2, CH_4, and N_2O. Bio-CO_2 is the measure of CO_2 storage and emissions from biomass combustible of wood waste. There are currently international discussions in regards to Bio- CO_2 around proper treatment and how best to account for it. Furthermore, PSOs are required to only offset the CH_4 and N_2O emissions from biomass combustion, as Bio-CO_2 is considered carbon neutral. For the purpose of this analysis, Bio-CO_2 will not be evaluated because it is carbon neutral meaning no additional carbon oxide is produced. Also, the figures used in the analysis are from "Table 1: Stationary Fuel Combustion" of the report.[44]

The natural gas boilers at BCIT have an efficiency of 82% [45], meaning it produces 52,480 GJ (64,000 GJ x 82%) of heat. Of this heat approximately 80% or 41,984 GJ can be replaced by biomass. The remaining 20% are used during peak periods and back-up power.

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[43] The "Methodology for Reporting 2011 B.C. Public Sector Greenhouse Gas Emissions Version 2.0" was used for the purpose of this study and may not be used by BCIT to report greenhouse gas emissions

[44] British Columbia Ministry of Environment, "Methodology for Reporting 2011 B.C. Public Sector Greenhouse Gas Emissions, Version 2.0", December 2011, page 9

[45] Prism Engineer Ltd, "BCIT Central Heating Plant Analysis", March 31, 2004, page 2: "Canepp provided a copy of stack analysis reports taken in October 2002. The combustion efficiency of the two boilers was measured at different firing rates. The combustion efficiency of Boiler # 3 varied from 84.8% to 85.4% across the firing range and from 84% to 85.3% for Boiler # 5. The overall seasonal efficiency is estimated at approximately 2% lower than the values measured due to standby losses." The resulting annual average efficiency should thus be 82.9%.

To gain a perspective of the impact of biomass on air quality and GHG emissions, BCIT investigated the following two options:

1. Burning its own wood waste (replacing 6% of natural gas consumption at natural gas fuelled boiler house).
2. Burning its own wood waste and additional 3,681, tonnes of DCL fuel required to replace 80% of the energy produced at the natural gas boiler house. This would require 263 truck deliveries (14 tonne tare) a year, i.e. one truck each workday.

7.1. Reduction of GHG Emissions

Based on the BCIT's analysis, the following results arrived.

Option 1: Burning only BCIT wood waste

	CO_2 (tCO_{2e})	CH_4 (tCO_{2e})	N_2O (tCO_{2e})	Total (tCO_{2e})
BCIT Wood Waste (250,398 kg)		78.87	12.44	**91.31**
Natural Gas (4,130 GJ)	205.92	0.09	1.15	**207.16**
Total Savings (Natural gas emissions minus wood fuel emissions)				**115.85**

The biomass boiler that BCIT plans to install has a capacity of 250 kW and is sized to be able to combust all of the burnable wood waste incurring at BCIT over the course of a year. As a result, this boiler will be able to displace 4,130 GJ or 6% of the natural gas consumption of the current boiler house. The savings will equate to 115.85 tCO_{2e} per year which is equivalent to approximately 22 passenger vehicles a year[46].

Option 2: Burning an additional 3,681 tonnes of DCL fuel to replace 80% of the energy produced from the natural gas boiler house.

[46] United States Environmental Protection Agency, http://www.epa.gov/cleanenergy/energy-resources/refs.html#vehicles, Accessed on April 14, 2011 :
$8.92*10^{-3}$ metric tons CO_2/gallon gasoline * 11,720 VMT $_{car/truck\ average}$ * 1/20.4 miles per gallon $_{car/truck\ average}$ * 1 CO_2, CH_4, and N_2O/0.977 CO_2 = **5.1 metric tons CO_2E /vehicle/yea**

	CO_2 (tCO_{2e})	CH_4 (t CO_{2e})	N_2O (tCO_{2e})	Total (tCO_{2e})
Natural Gas (51,200 GJ)	2552.83	1.08	14.29	**2568.19**
3,681,000 kg of DCL Imported (does not include the emissions from delivery)		1159.47	182.81	**1342.27**
BCIT Wood Waste (250,398 kg)		78.87	12.44	**91.31**
Total Savings (Natural gas emissions minus wood fuel emissions)				**1134.61**

Table 6: BCIT's breakdown of CO_{2e}

By importing an additional 3,681 tonnes of DLC, BCIT would be able to save 1134.61 tCO_{2e} per year, replacing 80% of the natural gas usage at the boiler house. For this scenario to be realized, BCIT would have to increase the size of the 250 kW biomass boiler or purchase additional boilers to handle the load. At this point, BCIT has no plans to implement this scenario. The numbers show, however, the magnitude of reduction of GHG emissions.

Note: the analyses above only include the burning of wood and natural gas. Other factors such as the emissions from trucking wood waste were not detailed in the analysis.

7.2. Air Quality Impacts

Although the tCO_2 provide an idea of possible emission discharge, it does not take into account criteria air contaminants, such as emission of heavy metals which can contribute to health concerns. Measures could be added to the stack to reduce the heavy metal emission but 100% capture is not possible. As a result, metal content must be considered in the evaluation of air quality.

The following is an attempt at quantifying the impact on the air shed using the example of Lead emissions. This evaluation is a rough approximation and will have to be taken cum grano salis.

Econotech's lab tests yielded that the DLC waste has 83.8 mg of Lead (Pb) per kg of ash, 2.28% of ash (dry basis), and a moisture content of 24.9% (dry basis). Burning 1 kg of DLC will result in 1.4 mg of Lead being released. If 3,681 tonnes of DLC are combusted each year this would result in 3,681,000 kg x 1.4 mg of Pb per kg of DLC = 5,282 g of Lead being released into the environment, either into the atmosphere or the ground. Most of the Lead will stay in the grate ash, but 20% to 30% might leave through the chimney. With a filtering system, such as the electrostatic precipitator planned for BCIT, this number will be reduced to 2%, which is 106 g in Lead emission a year from DLC.

BCIT's own wood residue is much lower in Lead content and has a higher energy content. Finally only 250,398 tonnes rather than 3,681 tonnes of DLC would be burned. As a consequence BCIT's wood waste would add a mere 0.01 g to the total Lead release.

Most of the Lead will stay in the grate ash, but 20% to 30% might leave through the chimney. With a filtering system, such as the electrostatic precipitator planned for BCIT, this number will be reduced to 2%, which yields 145 g in Lead emission a year from DLC. This number may be further reduced by condensing the flue gases prior to sending them through the filtering system. It is these types of experiments that BCIT would like to undertake to provide data and recommendation on best practice solutions.

8. Conclusions and Recommendations

8.1. Conclusions

1. The waste audit revealed that 96% of BCIT's solid wood waste is combustible. With little changes to the accessibility and use of the waste bin, BCIT could keep non-woody waste out, increasing the share of combustible material to 100%. The wood waste composition can be described as typical for a commercial wood workshop.

2. The chemical analyses show that BCIT's wood waste (as a mix) is very clean, meeting all chemical requirements of the European Pellet Norm. In other words, BCIT's wood waste could be used as a feedstock for Class 1A pellets – if used as a mix. Same for the elevated ash, nitrogen, and chloride content of the plywood and MDF, the fuel analyses gave little evidence that combusting plywood or MDF will result in higher air emissions compared to untreated fuel. In fact, biomass such as 'uncontaminated' hog fuel with its significantly higher ash and moisture content may result in higher criteria air contaminants and hazardous air pollution than combusting BCIT's plywood or MDF.

3. A chemical analysis is an indication of potential emission problems. To fully understand the impact on air quality, the combustion process and downstream filtering technology need to be taken into account. Only a continuous emission monitoring system (CEMs) as used for municipal solid waste incinerators and/or frequent stack sampling will allow quantifying air emissions.

4. BCIT's wood waste composition is typical for a joinery or carpentry workshop, but cannot be compared to standard demolition and construction wood as found at sites such as Urban Wood Waste. Consequently any results from emission tests done using BCIT's waste will only be a first step towards understanding the combustion of typical construction and demolition wood. BCIT's wood waste composition is, however, typical for a Joinery or Carpentry workshop. The underfeed-type stoker BCIT plans to install is the type used for dry fuel as generated by medium to large size wood workshops.

5. On the financial side, BCIT has completed feasibility studies to understand the cost of building a small-scale clean biomass-to-energy facility connected to a district energy system. Results show that building to minimize cost will lead to a positive ROI but with a payback that might be considered too long for private sector. Government and utility companies might have to intervene to make the technology more attractive from a pure ROI perspective.

8.2. Recommendations to BCIT

A. To fully take advantage of the value of its wood fuel it should be used on campus, avoiding intermediaries such as waste management companies. Exporting wood fuel and importing fossil fuel makes limited sense in times of climate change. The fact that the campus already has a district heating system is a major stepping stone towards a more sustainable energy supply.

B. Without a permit from Metro Vancouver neither plywood nor MDF may be combusted. The chemical analysis undertaken is a first step to ease concerns about air pollution and should be used when applying for a permit. With debates regarding the definition of biomass in the Biomass Boiler Regulation, the Ministry of Environment and Metro Vancouver are open to evidence that would provide the scientific basis for new guidelines and may even amend existing regulations.

C. The Province of BC plans to become a leader in bioenergy technology. As a vocational school, BCIT should train the next generation of carpenters and cabinet makers on potential combustion equipment that they may encounter in the future. Extending the wood waste boiler project to include monitoring would also allow BCIT to revamp its emission monitoring and verification program. The demand for on-site emission testing is poised to increase as authorities are looking for skilled and trained staff to enforce regulations. BCIT should also work with its industry partners at evolving the particle board industry to that they design their product with "cradle-to-energy" in mind.

8.3. Recommendations to the BC Ministry of Environment and Metro Vancouver

I. BCIT is a combination of a vocational school and research facility and therefore in a good position to conduct applied research using real-life conditions. Other than a commercial workshop, however, BCIT has less operational constraints, allowing tests to be conducted and recorded within and by the scientific community.

II. The research should be constrained to clean, woody construction waste as it incurs in wood workshops. Of all the DLC waste available within the Lower Fraser Valley workshop waste will result in the least impact on the air shed and is therefore a good candidate to be added to the definition of 'biomass'. On the other hand, testing demolition wood in a small underfeed stoker will not result in conclusive results. DLC is most commonly used as a fuel in larger scale stepped grate or fluidized bed combustors or gasifiers that combust differently.

III. In order to provide legislators with evidence about the impact of air emissions from the combustion of contaminated wood, such as panel products, these waste streams should be tested under various operational conditions, taking the effect of filtering equipment into account. The data will be instrumental when formulating best practises, guidelines and standards.

9. GLOSSARY & ACRONYMS

24/7/365	24 hours a day, seven days a week, and 365 days a year
°C	Degree Celsius sometimes referred to as 'Centigrade'.
ASTM	American Society for Testing and Materials
BC	British Columbia
BCIT	British Columbia Institute of Technology
Bdt	Bone-dry tonne, a forestry unit used to measure the pure wood content of moist wood fibre
BFI	Waste disposal company
BHP	Boiler Horse Power
BIOBIB	A database of biomass properties compiled and maintained by the Technical University of Vienna, Austria
Bio-CO_2	The measure of CO_2 storage and emissions of wood waste
BTU	British Thermal Unit; an imperial unit used for heat or steam energy; 1,000,000 BTU = 273 kilowatt hours (kW)h
BTU/lb	British Thermal Unit per pound
C&D	Construction and Demolition
CAC	Cement Association of Canada
Cd	Cadmium
CEM	Continuous Emission Monitoring
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide-equivalent: a factor taking the potency of a specific GHG into account and comparing it to the GHG effect of CO_2

Cyd	cubic yard
DLC	Demolition, land clearing, and construction wood residue
ECN	Energy Research Centre of the Netherlands
EPA	Environment Protection Agency
ESM	A method of testing
European Pellet Norm prEN 14961-2	European standard for wood pellets
GHG	Greenhouse Gas
GJ	"Gigajoule, an energy unit; 1 GJ is 1 billion Joule; 1 J = 1 Ws (Watt second) 1 GJ = 3.6 MWh = 0.94 mm BTU ; to convert GJ to MWh, multiply by 3.6, to convert MWh to GJ divide by 3.61 GJ is equal to slightly more than the energy content of two propane cylinders like the ones used on most gas bar-b-ques. 1 GJ is equal to the energy content of 28 litres of gasoline (at 20°C)
GJ/t	Gigajoule per tonne
HHV	Higher Heating Value
H_2O	Water
HST	Harmonized Sales Tax
IEA	International Energy Agency
K	Potassium
K_2O	Potassium oxide
Kg	Kilogram; 1 kg = 2.2 lb
kilowatts (kW)	Kilowatt; power or capacity measurement unit;
M	Metre
m.c.	Moisture content

m.c. (dry basis)	Percentage of water in relation to the mass of the bone-dry biomass (i.e. without the water contained in the biomass)
m.c. (wet basis)	Percentage of water in relation to the mass of the bone-dry biomass and the water contained in the biomass
m^2	square metre; 1 m^2
m^3	cubic metre
m^3	Cubic meter; 1 m^3 = 1,000 litres
MDF	Medium Density Fibreboard
Mg	Milligrams
Mg	Magnesium
mg/kg	Milligram per kilogram
MJ	Megajoule
MJ/kg	Megajoule per kilogram
Mm	millimetre; 25.4 mm = 1 inch
mmBTU/h	million BTU per hour, an imperial unit used for boiler capacity; 1 mmBTU/h = 273 kilowatts (kW)
MoE	Ministry of Environment
MSW	Municipal Solid Waste
MW	"Megawatt; power or capacity measurement unit; 1 MW = 1,000 kilowatts (kW) = 1,000,000 W"
MWe	Megawatt equivalent
MV	Metro Vancouver
N_2	Nitrogen
N_2O	Nitrous oxide

Na	Sodium
Na_2O	Sodium oxide
NAUF	No Added Urea Formaldehyde
Ni	Nickel
NOx	Oxides of nitrogen, primarily NO and N_2O
NO_2	Nitrogen dioxide
NREL	National Renewable Energy Laboratory
O_3	Ozone
O&M	Operation and maintenance
P	Phosphorus
Pb	Lead
PCDD/F	Polychlorinated dibenzodioxins/furans
PEF	Process Engineered Fuel
PSO	Public Sector Organizations
SFU	Simon Fraser University
SNCR	Selective Non-Catalytic Reduction is a chemical process that changes NOx into molecular nitrogen (N_2)
SoCE	School of Construction and Environment
SOx	Oxide of Sulfur
SPF	Spruce Pine Fir
T	Metric tonne; 1 tonne = 1,000 kg =2,204 lb
t/yr	Tonnes per year
UBC	University of British Columbia

UNBC	University of Northern British Columbia
W	Watt
Zn	Zinc

10. Work Cited

BC Climate Change website, http://www.bcclimatechange.ca/how-wood-products-help/bio-energy.aspx, Accessed on April 6, 2012

BC Greenhouse Growers' Association website, http://www.bcgreenhouse.ca/quick_facts.htm, Accessed on April 6, 2012

British Columbia Ministry of Environment, "Methodology for Reporting 2011 B.C. Public Sector Greenhouse Gas Emissions, Version 2.0", December 2011, page 9

Cement Association of Canada, http://www.cement.ca/en/CAC-Members.html, Accessed on April 7, 2012

Cement Association of Canada, http://www.cement.ca/en/Using-Alternative-and-Renewable-Energy.html, Accessed on April 7, 2012

Cindy MacIntosh, BCIT Supervisor, Custodial Services – Facilities and Campus Development. cindy_macintosh@bcit.ca. "Information request". March 7, 2012.

Cornelius Suchy, "District Heating BCIT's Sustainability Precinct Area" Prefeasibility Study, March 31, 2011

EPA, http://www.epa.gov/iaq/formalde.html, Access April 3, 2012

EPA Method 200.8: "Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma - Mass Spectrometry", Revision 5.4, U.S. Environmental Protection Agency, May 1994.

Fernando Preto, NRCan, "Emissions from Residential Wood Combustion", presentation given in Paris, France on Oct 21, 2005 at the IEA Workshop on Recent Developments in Small Scale Combustion Devices

Greater Vancouver Regional District, "Boilers and Process Heaters Emission Regulation", Bylaw No. 1087, 2008, item 4 (e).

Jeffrey M.Hoerning, Michelle A. Evans, Danny J. Aerts, Kenneth W. Ragland, Department of Mechanical Engineering University of Wisconsin-Madison: "Organic Emissions From Combustion of Plywood And Particleboard", Madison,Wi, USA,(no date); http://web.anl.gov/PCS/acsfuel/preprint%20archive/Files/40_3_CHICAGO_08-95_0676.pdf

Livesmart BC website, http://www.livesmartbc.ca/attachments/climateaction_plan_web.pdf, Accessed on April 9, 2012

Livesmart BC, website, http://www.livesmartbc.ca/government/carbon_neutral/advanced_education.html, Accessed on April 9, 2012

Mercer International Group, "BC's Bioenergy Strategy: Examining Progress and Potential in the Province", Presentation at the Canadian Institute's BC Power Conference, January 2010, http://www.mercerint.com/i/pdf/BCPowerConferencePresentation.pdf, Accessed on April 6, 2012

Metro Vancouver, "Integrated Solid Waste and Resource Management – a Solid Waste Management Plan", July 2010, page 26, http://www.metrovancouver.org/about/publications/Publications/ISWRMP.pdf

Paul A. Beauchemin, Martin Tampier, Envirochem Services Inc.: "Biomass Availability Study for District Heating Systems", Feb 2012

Prism Engineer Ltd, "BCIT Central Heating Plant Analysis", March 31, 2004

Rob Sawatzky, BCIT Joinery Instructor, rob_sawatzky@bcit.ca. "'No Added Urea Formaldehyde' (NAUF) panel products". April 14, 2012

Stantec, "Biomass Energy System – A Review of MAWERA Boiler Proposal", Burnaby 2008

Tony Wakelin, MoE in a conference call with BCIT staff on March 9, 2012, see the Minutes of the Meeting in Appendix 6

University of British Columbia, http://www.nexterra.ca/industry/ubc.cfm, Accessed on April 5, 2012

United States Environmental Protection Agency, http://www.epa.gov/cleanenergy/energy-resources/refs.html#vehicles, Accessed on April 14, 2011

Vancouver Sun website, "Catalyst ready to scrap one B.C. mill, sell three others", http://www.vancouversun.com/story_print.html?id=6332861&sponsor=, Accessed on April 6, 2012

Wenli Duo, FP Innovations / Parican, "Biomass Combustion in Pulp and Paper Mill Boilers", http://www.biomass.ubc.ca/docs/Duo_07.pdf, Accessed April 7, 2012

Appendix 1: Waste Audit Canada's Results for the BCIT 40-yard Bin Waste Audit

Appendix 2: Econotech Laboratory's Results of the Proximate and Ultimate Analyses

British Columbia Institute of Technology		**Report date:**	April 26, 2012
3700 Willington Avenue		**Our ref:**	B12163 LIQ:12:232
Burnaby, BC V5G 3H2		**Your ref:**	P0063896
		Page:	1 of 3
Attention:	Deacon Tong		

Sample:	Five (5) fuel sample	**Date rec'd:**	March 12, 2012

ANALYSIS RESULTS

Residual environmental samples will be retained for a period of one month, process samples for three months, unless otherwise instructed by your company. Details of methods and dates analyzed are available on request. Results only relate to samples tested.

British Columbia Institute of Technology

LIQ:12:232

W.O.#B12163

Page 2

Analysis	Unit	Analytical Method	Dust	2 x 4 Wood Sample	Plywood	MDF	Wood Waste
Ultimate Analysis							
Ash @ 575°C	%, dry basis	ASTM E1755	0.46	0.43	1.69	0.51	2.28
Carbon, C	%, dry basis	ASTM D5373	52.30	52.20	51.60	54.00	50.90
Hydrogen, H	%, dry basis	ASTM D5373	7.16	6.81	6.87	7.18	6.63
Nitrogen, N	%, dry basis	ASTM D5373	<0.1	<0.1	0.419	1.05	0.656
Total sulfur, S	%, dry basis	ESM 266B	0.010	0.004	0.010	0.013	0.127
Chloride content, Cl	%, dry basis	ESM 360B/040C	0.011	0.003	0.005	0.022	0.048
Fluoride content, F	%, dry basis	ESM 360B/040C	0.003	0.009	0.008	0.003	0.004
Oxygen, O (by difference)	%, dry basis		40.058	40.542	39.398	37.227	39.36
Total			**100.00**	**100.00**	**100.00**	**100.01**	**100.00**
Moisture content	%, as-rec'd	ASTM E871	11.1	10.5	6.71	5.73	24.9
Higher Heating Value	BTU/lb, dry basis	ASTM D5865/E711	8590	8390/8250	8140	8730	8100

Net Heating Value	BTU/lb, dry basis	ASTM D5865/E711	7940	7700(7770/7630)	7510	8080	7490
Proximate Analysis							
Volatile matter	%, dry basis	ASTM E872	91.76	91.83	79.33	84.07	88.20
Fixed carbon @ 950°C	%, dry basis	by calculation	7.78	7.74	18.98	15.42	9.52
Ash @ 575°C	%, dry basis	ASTM E1755	0.46	0.43	1.69	0.51	2.28
Total			**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
****Ash Fusion Temperature***							
(reducing atmosphere)							
Initial Deformation	°C	ASTM D1857	1398	>1482	682	1065	1073
Softening (h=W)	°C	ASTM D1857	1408	>1482	706	1082	1126
Hemispherical	°C	ASTM D1857	1411	>1482	733	1085	1135
Fluid	°C	ASTM D1857	1415	>1482	796	1132	1171

*subcontracted analysis

Analysis	**Unit**	**Analytical Method**	**Dust**	**2 x 4 Wood Sample**	**Plywood**	**MDF**	**Wood Waste**
Metals scan							
Aluminum, Al	mg/kg, dry basis	ESM 266B	24.4	20.4	7.4	48	823
Arsenic, As	mg/kg, dry basis	ESM 266B	<0.2	<0.2	<0.2	<0.2	38.9
Barium, Ba	mg/kg, dry basis	ESM 266B	9.4	6.12	7.75	9.6	64.4
Boron, B	mg/kg, dry basis	ESM 266B	9.66	2.03	1.86	24.6	21.9
Cadmium, Cd	mg/kg, dry basis	ESM 266B	0.05	0.07	0.03	0.02	0.8
Calcium, Ca	mg/kg, dry basis	ESM 266B	911	1210	333	641	3320
Chromium, Cr	mg/kg, dry basis	ESM 266B	0.45	0.39	0.45	0.57	50.8
Cobalt, Co	mg/kg, dry basis	ESM 266B	0.06	<0.05	<0.05	<0.05	0.68
Copper, Cu	mg/kg, dry basis	ESM 266B	2.22	0.99	1.17	0.95	41.2
Iron, Fe	mg/kg, dry basis	ESM 266B	72.2	146	22.1	90.3	1120
Lead, Pb	mg/kg, dry basis	ESM 266B	0.5	0.5	0.12	<0.1	83.8
Lithium, Li	mg/kg, dry basis	ESM 266B	0.04	<0.02	0.03	0.04	0.39

Magnesium, Mg	mg/kg, dry basis	ESM 266B	170	204	68.7	114	358
Manganese, Mn	mg/kg, dry basis	ESM 266B	49.4	85	23.1	41.1	67.4
*Mercury, Hg	mg/kg, dry basis	ESM 266B	0.0016	0.0024	0.0026	0.0023	0.0974
Molybdenum, Mo	mg/kg, dry basis	ESM 266B	<0.2	<0.2	0.3	<0.2	0.7
Nickel, Ni	mg/kg, dry basis	ESM 266B	0.23	0.29	0.16	0.26	2.07
Phosphorus, P	mg/kg, dry basis	ESM 266B	34.1	4.12	4750	64.2	60.6
Potassium, K	mg/kg, dry basis	ESM 266B	366	274	255	483	332
Silicon, Si	mg/kg, dry basis	ESM 266B	62.8	69.9	14.5	161	2630
Sodium, Na	mg/kg, dry basis	ESM 266B	403	9.9	3130	672	944
Strontium, Sr	mg/kg, dry basis	ESM 266B	5.5	6.8	3.8	5.4	17
Titanium, Ti	mg/kg, dry basis	ESM 266B	10.9	2.72	0.473	2.42	227
Vanadium, V	mg/kg, dry basis	ESM 266B	0.074	0.015	0.028	0.102	1.85
Zinc, Zn	mg/kg, dry basis	ESM 266B	10.6	9.9	2.73	3.32	129

*subcontracted analysis

Samples were fused prior to metals analysis.

Comments:

Moisture content and density results were calculated relative to sample weight on as-received basis. Ash results were calculated relative to the weight of ash. All other results were calculated relative to sample weight on oven dry basis. **CHN-O:** determined by automated flash combustion and gas chromatography. **CHN analysis:** samples were dried at 105 ± 3ºC prior to analysis. **Higher & Net Heating Value:** determined by Parr oxygen bomb calorimetry. **Metals scan:** determined by OES-ICP.

Thomas Y.C. Yuen

Supervisor - Analytical (Pulping & Liquor) /js

Econotech is responsible for subcontracted work.

Appendix 3: Calculation of Lower and Higher Heating Values

Analysis	unit	Analytical Method	BCIT Mix, weighted average		Sawdust & Planer Shavings		Untreated Lumber (2x4 & 2x6 Studs)	Plywood Offcuts	MDF Offcuts	DLR Wood Waste (Econotech lab result)
PERCENTAGE OF TOTAL WEIGHT			**100%**		12%		66%	12%	9%	
Ultimate Analysis:							76%	14%	10%	
Ash @ 575 °C	%, dry basis	ASTM - E1755	0.60		0.46		0.43	1.69	0.51	2.28
Carbon, C	%, dry basis	ASTM - D5373	52.30		52.30		52.20	51.60	54.00	50.90
Hydrogen, H	%, dry basis	ASTM - D5373	6.89		7.16		6.81	6.87	7.18	6.63
Nitrogen, N	%, dry basis	ASTM - D5373	0.22	<	0.1	<	0.1	0.419	1.05	0.656
Total Sulfur, S	%, dry basis	ESM-266B	0.01		0.010		0.004	0.010	0.013	0.127
Chloride, Cl	%, dry basis	ESM-360B/040C	0.01		0.011		0.003	0.005	0.022	0.048
Fluoride, F	%, dry basis	ESM-360B/040C	0.008		0.003		0.009	0.008	0.003	0.004
Oxygen, O (by difference)	%, dry basis		40.04		40.058		40.542	39.398	37.227	39.36
Total			**100.08**		**100.10**		**100.10**	**100.00**	**100.01**	**100.00**
S/Cl			1.06		0.91		1.33	2.00	0.59	2.65
Moisture As-received	%, wet basis	ASTM E871	9.68		11.1		10.5	6.71	5.73	24.9
Higher Heating Value	BTU/lb, dry basis	ASTM -D5865/E711	8,368		8,590		8,320	8,140	8,730	8,100
Higher Heating Value	MJ/kg, dry basis		19.46 MJ/kg		19.97 MJ/kg		19.35 MJ/kg	18.93 MJ/kg	20.30 MJ/kg	18.84 MJ/kg
Higher Heating Value	MJ/kg, wet basis		17.58 MJ/kg		17.76 MJ/kg		17.32 MJ/kg	17.66 MJ/kg	19.14 MJ/kg	14.15 MJ/kg
Calculated HHV	**MJ/kg, dry basis**		**22.22 MJ/kg**		**22.54 MJ/kg**		**22.05 MJ/kg**	**21.99 MJ/kg**	**23.44 MJ/kg**	**21.47 MJ/kg**
Lower Heating Value	BTU/lb, dry basis		7,740		7940		7700	7510	8080	7490
Lower Heating Value	MJ/kg, dry basis		18.00 MJ/kg		18.46 MJ/kg		17.91 MJ/kg	17.46 MJ/kg	18.79 MJ/kg	17.42 MJ/kg
Lower Heating Value	MJ/kg, wet basis		16.02 MJ/kg		16.14 MJ/kg		15.77 MJ/kg	16.13 MJ/kg	17.57 MJ/kg	12.47 MJ/kg
Calculated LHV	**MJ/kg, wet basis**		**15.97 MJ/kg**		**16.08 MJ/kg**		**15.71 MJ/kg**	**16.08 MJ/kg**	**17.50 MJ/kg**	**12.44 MJ/kg**

Appendix 4: Estimated Carbon Offset Calculation

Calculation of GHG					
Burn BCIT Waste					
Actual Consumption	250,000	kg			
Energy Conversion Factor	0.018	GJ/kg			
Converted Fuel Consumption	4,500	GJ			
	Bio CO2	CO2	CH4	N2O	
Emission Factor (kg/GJ)	83.33	0	0.8333	0.0089	
Emission by GHG	374,985.00	-	3,749.85	40.05	
Global Warming Potential (GW	1	1	21	310	
Emissions (kgCO2e)	374,985	-	78,747	12,416	
Total CO2e	466,147		91,162		
Emissions in tonnes CO2e	466.15	tCO2e	91.16	tCO2 without Bio CO2	
Natural Gas					
Converted Fuel Consumption	4,000	GJ			
	Bio CO2	CO2	CH4	N2O	
Emission Factor (kg/GJ)	0	49.86	0.001	0.0009	
Emission by GHG	-	199,440.00	4.00	3.60	
Global Warming Potential (GW	1	1	21	310	
Emissions (kgCO2e)	-	199,440	84	1,116	
Total CO2e	200,640				
Emissions in tonnes CO2e	200.64	tCO2e			
GHG Saved	109.48				
Carbon Offsets Saved	**$ 2,736.94**				

Appendix 5: GHG Calculations

Calculation of GHG - Option 1 - Burning only BCIT wood waste				
Burn BCIT Waste				
Actual Consumption	250,398	kg		
Energy Conversion Factor	0.018	GJ/kg		
Converted Fuel Consumption	4,507	GJ		
	Bio CO2	CO2	CH4	N2O
Emission Factor (kg/GJ)	83.33	0	0.8333	0.0089
Emission by GHG	375,581.98	-	3,755.82	40.11
Global Warming Potential (GWP)	1	1	21	310
Emissions (kgCO2e)	375,582	-	78,872	12,435
Emissions (tCO2e)	375.58	-	78.87	12.44
Total tCO2e	466.89	tCO2e	91.31	tCO2 without Bio CO2
Natural Gas				
Converted Fuel Consumption	4,130	GJ		
	Bio CO2	CO2	CH4	N2O
Emission Factor (kg/GJ)	0	49.86	0.001	0.0009
Emission by GHG	-	205,921.80	4.13	3.72
Global Warming Potential (GWP)	1	1	21	310
Emissions (kgCO2e)	-	205,922	87	1,152
Emissions (tCO2e)	-	205.92	0.09	1.15
Total tCO2e	207.16	tCO2e		
GHG Saved	115.85			

Calculation of GHG - Option 2 - Burning an additional 3,681 tonnes of DCL fuel				
Burn BCIT Waste				
Actual Consumption	250,398	kg		
Energy Conversion Factor	0.018	GJ/kg		
Converted Fuel Consumption	4,507	GJ		
	Bio CO2	CO2	CH4	N2O
Emission Factor (kg/GJ)	83.33	0	0.8333	0.0089
Emission by GHG	375,581.98	-	3,755.82	40.11
Global Warming Potential (GWP)	1	1	21	310
Emissions (kgCO2e)	375,582	-	78,872	12,435
Emissions (tCO2e)	375.58	-	78.87	12.44
Total tCO2e	466.89	tCO2e	91.31	tCO2 without Bio CO2
Ship in 3,681 tonnes of DLC				
Actual Consumption	3,681,000	kg		
Energy Conversion Factor	0.018	GJ/kg		
Converted Fuel Consumption	66,258	GJ		
	Bio CO2	CO2	CH4	N2O
Emission Factor (kg/GJ)	83.33	0	0.8333	0.0089
Emission by GHG	5,521,279	-	55,213	590
Global Warming Potential (GWP)	1	1	21	310
Emissions (kgCO2e)	5,521,279	-	1,159,469	182,806
Emissions (tCO2e)	5,521.28	-	1,159.47	182.81
Total tCO2e	6,863.55	tCO2e	1,342.27	tCO2 without Bio CO2
Natural Gas (80%)				
Converted Fuel Consumption	51,200	GJ		
	Bio CO2	CO2	CH4	N2O
Emission Factor (kg/GJ)	0	49.86	0.001	0.0009
Emission by GHG	-	2,552,832	51	46
Global Warming Potential (GWP)	1	1	21	310
Emissions (kgCO2e)	-	2,552,832	1,075	14,285
Emissions (tCO2e)	-	2,552.83	1.08	14.28
Total tCO2e	2,568	tCO2e		
GHG Saved	1,134.61			

Appendix 6: Minutes of the Meeting