Biomass Waste-to-Energy: A Proposed Demonstration Project at BCIT

The Biomass Waste-to-Energy Project

The British Columbia Institute of Technology is considering a waste-to-energy project that uses wood waste (biomass) from the Joinery and Carpentry programs for on-site energy production. There are a number of factors to evaluate in consideration of this proposal including the type of biomass system to be used, fuel supply, existing infrastructure, and cost. Additionally, the project must be integrated with BCIT's mission and research. This case study outlines the use of wood biomass as an energy source and the many factors that will influence this project as it progresses from proposal to demonstration project.

The Joinery and Carpentry programs operate within the School of Construction and the Environment and are located in the campus's "Sustainability Precinct." The School seeks to apply leading edge technology to the challenge of achieving a four- to ten-fold reduction in energy and materials consumption for the Sustainability Precinct. The proposed biomass waste-to-energy project would contribute to this target by reducing energy throughput by burning existing wood waste to generate energy, thereby displacing natural gas as a fuel.

The project also fits with BCIT's GHG and Energy Management Vision "…to demonstrate the wisest energy and GHG management in BC on our campuses. Student, staff, and faculty groups will design, share and implement creative and innovative ways to eliminate waste and use energy efficiently. We will use only the energy we really need, in the most efficient way possible, to deliver excellent services." According to the same vision, a visitor on campus would be able to observe the on-site production of clean and renewable energy through this and other demonstration projects. BCIT's Campus Planning, Safety and Security, and facilities departments have each endorsed the proposal for a biomass system.

Located on the Burnaby campus in the NE2 and NE4 buildings, the Joinery and Carpentry shops are each approximately 2,000 square meters in size. Together these programs generate approximately 265,000 kg of wood waste per year. At the time of writing, construction off-cuts fill a 40-cubic-yard bin each week; dust extraction and shavings fill a 4-cubic-yard bin each day (note: at the time of writing, a certain level uncertainty still existed in regards with exactly how much wood waste was available each year). Refer to appendix A for conservative figures to be used in building the business case and the sensitivity analysis. Wood waste is currently being trucked away by a waste management company at a cost of between $8,000 and $12,000 a year.

In anticipation of a biomass system on campus, Joinery and Carpentry have taken several steps to enable the waste-to-energy project. Wood waste is sorted into useful fuel types as off-cuts, shavings, and sawdust. A new dust extraction system with centralized collection has replaced the former system of six distributed collection bins, requiring less staff time to collect and empty the bins. The programs have also initiated a certified materials purchasing program, buying Forest Stewardship Council (FSC) lumber to ensure the carbon being released in the biomass burning process is then recaptured or reused by the trees that have been replanted in a sustainably managed forest. No Added Urea Formaldehyde (NAUF) panel products are purchased because they can be burned with fewer emissions.

The introduction of a biomass system would use this waste wood as fuel to produce heat for campus buildings, saving the cost of disposal and also saving money on the purchase of fuel. BCIT is currently generating most of its heat from a central heating plant with a natural gas-fired boiler. A district energy loop runs hot water from the central boiler to a few campus buildings, and the loop is located in proximity to NE2. The introduction of a biomass system would supply some of the heat (as hot water) needed by campus buildings by connecting the biomass system to the existing loop. NE2 and NE4 are currently not connected to the centralized heat supply system, however, instead using radiant heat from burning natural gas on site. BCIT is discussing the possible expansion of the district energy system with a new loop into the Sustainability Precinct. In that case, the biomass system could be providing heat specifically to the buildings located in the Sustainability Precinct.

Why Biomass?

Biomass is organic matter that can be processed into energy for heat, power generation, or liquid fuels. Biomass sources include wood, plants, agricultural residues, animal waste, and the organic components of municipal and industrial wastes. Chipped wood is the primary source used in heating applications.

There are a number of benefits of using wood biomass as a fuel source for heat. Using the wood waste from BCIT's trade programs reduces the amount of waste sent to landfills. This waste diversion also saves the cost of collection, transport and disposal, and at the same time offsets truck fuel costs and associated greenhouse gas emissions. The 265,000 kg of annual wood waste generated at BCIT represents an energy content of approximately 4,500 GJ per year (refer to appendix A for conservative figures to be used in building the business case and the sensitivity analysis). BCIT purchases natural gas for its boiler at an historical price varying between approximately $9 and $11 per GJ (all costs included); using its wood waste instead of an equivalent amount of natural gas has the potential to save the Institute +/- $50,000 a year in fuel costs.

Additional environmental benefits include the reduction of greenhouse gases produced through the consumption of fossil fuels to generate heat. When wood waste from sustainable forestry and manufacturing practices is burned to produce energy in place of fossil fuels there is a net reduction in greenhouse gas emissions. When biomass is used for fuel, the carbon in the displaced fossil fuel remains in the ground rather than being discharged to the atmosphere as carbon dioxide. Most experts agree that burning wood for energy in a biomass combustion system does not add any new carbon to the existing carbon cycle—wood is therefore considered carbon neutral. Burning wood releases the carbon dioxide that the tree absorbed during its lifetime, which is the same amount that would be released if the tree was left to decompose on the forest floor. Unlike non-renewable fossil fuels such as natural gas, the biomass resource base can be sustained indefinitely through sustainable forest practices. However, it is important to consider that the growth rate of trees means that carbon is reabsorbed over a long term,[1] while the burning of biomass releases carbon very quickly.

It is estimated that displacing natural gas with wood waste for 4,500 GJ of energy will reduce emissions by 225 metric tonnes of CO2 equivalent per year. A sensitivity analysis can be developed to understand the potential deviation around this figure.

Converting Biomass to Heat Energy

Fuels

Chipped wood used in heating systems comes from four main sources: wood harvesting operations use mobile wood chippers to turn roadside debris and culled logs into chips; sawmills produce chipped wood from slabs and green wood not suitable for lumber; forest products industries like manufacturing produce wood chips from waste off-cuts; municipal wood waste from construction and demolition, industrial processes and urban tree waste is a fourth source but rarely used (as it occurs only on a seasonal basis and is of various size and quality).[2]

Biomass Heating Systems[3]

The process of burning biomass for heat energy is reflected in the components that make up the system. Generally, these components include a large storage area for the fuel, a transport system to move the fuel to the burner area, a combustor to burn the fuel, a boiler (heat exchanger) to extract the heat from combustion, and a chimney or stack to disperse the combustion gases (emissions). Other components include ash disposal equipment, any necessary exhaust-gas cleaning devices, and equipment controls to operate the system.

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[1] Cushman, J., G. Marland, B. Schlamadinger. *Biomass Fuels, Energy, Carbon, and Global Climate Change.* http://www.ornl.gov/info/ornlreview/rev28_2/text/bio.htm Accessed November 2, 2010.
[2] Maker, T. M., 2004. *Wood-Chip Heating Systems: A guide for institutional and commercial biomass installations.* Montpelier, Vermont: Biomass Energy Resource Centre, 11, 15.
[3] Adapted from Maker, T. M., 2004.

Biomass boiler plants require more space than conventional systems. Unlike grid-connected energy such as electricity and natural gas, biomass energy systems require storage of the biomass fuel as well as space for the transport and loading of fuel. The fuel storage area may be located above or below ground; above ground storage bins are usually concrete or metal silos, and underground storage bins are commonly accessed by external loading doors. Biomass fuel produced on site may help to minimize the space needed for fuel transport if the quantity of fuel is sufficient to run the boiler; the addition of externally sourced fuel sources will require adequate space for transport vehicles. If wood waste is produced on site (on campus), chipping machinery must also be accommodated for waste that needs size reduction (sawdust and planer shavings do not need to be run through the chipper). Legislation requires the stacks of biomass systems to be taller than those used for other fuels (20 meters in Metro Vancouver), and the overall area needed to house the system is typically larger since wood-fueled boilers are larger and the fuel-handling equipment takes up additional space. When a biomass system is added on to an existing boiler plant, the biomass boiler is often outside the building to avoid increased insurance premiums. Moreover, most biomass boilers are sized for the base load, requiring an additional (fossil-fuel-fired) peak boiler.

Combustion and Heat Exchange

The burner or combustor is the part of the system where the solid fuel undergoes combustion. The fuel is burned to produce heat from the flame and from exhaust. The heat exchanger transfers the heat from flue gases to the transfer medium: through radiation and convection, the medium (water, air, or steam) is heated; after the fuel is burned heat continues to be transferred from the hot exhaust in the flue (the space in the chimney or stack) to the medium. The somewhat cooler exhaust exits the top of the stack. The transfer medium carries heat generated from the biomass system to its point of use. In hot water systems, heated water is pumped through pipes to bring heat to buildings.

The type of heat exchanger used depends on the design of the system and the type of transfer medium. In hot water or steam systems it is typical for the boiler to have the heat exchanger located on top of the combustor in a single unit. The heat exchanger consists either of a series of metal flue passages surrounded by water (fire tube boilers), or for large and high pressure systems a series of metal water tubes surrounded by hot exhaust gases (water tube boilers). In either case, as the hot exhaust moves through the passages it heats the metal which in turn heats the water. The exhaust has a temperature of approximately 850° to 1050°C degrees Celsius. The boiler heat exchanger heats water to between 85° and 121° degrees Celsius, thereby reducing the stack temperature of the exhaust to 135° to 230° degrees. Steam boilers can operate at higher temperatures and pressures.

System efficiency is dependent on the sizing of the heat exchanger. If an exchanger is oversized there will not be enough heat from the exhaust gases to heat the transfer medium. An undersized heat exchanger will not be able to extract heat from the exhaust fast enough, losing this energy as it exits the stack at a very high temperature.[4]

Emissions and Particulates

Today's wood biomass technology has greatly reduced the amount of combustion emissions from this fuel source. High-efficiency biomass systems emit virtually no visible smoke, and no odor. However, emissions and particulate matter are produced and released into the outdoor air. Emissions are lessened as system efficiency increases. Particulate matter is largely a result of the moisture content of the fuel.

Carbon Monoxide (CO), Volatile Organic Compounds (VOC), and Nitrogen Oxides NOx

Several types of emissions are of possible concern. Carbon monoxide from wood biomass burning can be a problem in areas that already have high CO concentrations from automobile exhaust (i.e. urban areas). VOC and NOx contribute to ozone, smog, and respiratory problems, and some VOC are toxic.[5]

CO and VOC in emissions from biomass systems indicate incomplete combustion: CO is formed by the incomplete combustion of the carbon atoms, and VOC is formed by the incomplete breakdown of the organic components. Greater efficiency of the combustion process in the furnace reduces these emissions. Specifically, efficiency is increased with sufficient time, temperature, turbulence, air distribution, and good fuel preparation and operation of the equipment.[6] However, the higher temperatures that increase combustion efficiency also result in greater NOx formation. Controls to limit NOx formation focus on reducing flame temperature without compromising combustion efficiency or heat transfer. Such controls include staged combustion (secondary air is introduced after the main combustion zone), and recirculation of the flue exhaust.[7]

Particulates

The greater efficiency of improving technologies continues to reduce the amount of larger particles emitted from wood burning. Though the amount of emissions is decreasing, so is the size of the air-born particles.[8] The emission component of greatest concern in relation to health impacts is fine particulate matter with

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[4] Maker, T. M., 2004, 24.
[5] Maker, T. M., 2004, 36.
[6] BC Ministry of Environment, 2008. *Emissions from Wood-Fired Combustion Equipment.* Paul A. Beauchemin and Martin Tampier, Envirochem Services Inc. 11-12. http://www.env.gov.bc.ca/epd/industrial/pulp_paper_lumber/pdf/emissions_report_08.pdf Accessed November 3, 2010.
[7] BC Ministry of Environment, 2008, 11.
[8] BC Ministry of Environment, 2008, 10.

particles smaller than 10 micrometers (PM10) diameter.[9] To help mitigate exposure to PM10, the minimum stack height for biomass boilers is 20 meters above ground level.[10]

Operation and Maintenance[11]

After installation of a biomass heating system, the equipment is commissioned by the contractor who installed it to ensure expected performance. Commissioning should take place during full load conditions—which occur during the coldest weather (mid-winter). Operator training is also important while the contractor is on site. The operator must be trained in operating, maintaining, and trouble-shooting the system.

The contractor should provide a list of ongoing maintenance tasks. This list should include the following key tasks (for which there is an associated maintenance cost):

- ash removal — grates
- ash removal — under grates
- boiler tube cleaning
- fly ash removal
- cleaning of furnace and other heat exchange surfaces
- lubrication
- inspection of drive chains, belts and gearboxes
- inspection of refractory
- checking of safety devices
- checking and adjustment of fuel feed rates and combustion air

Time and frequency of the above tasks largely depend on the fuel and the sophistication of the equipment. The system manufacturer's service representative should be retained for a yearly maintenance check. It is also possible to contract daily operation and maintenance activities. The benefits of this arrangement include the high level of expertise brought by an expert contractor and addresses any on-site human resource issues (such as capability, time, or interest in the system).

Mitigating Risk

Every heating system has its own inherent risks. There are a number of risks with biomass boiler systems, ranging from safety concerns to operational efficiency challenges.

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[9] Maker, T. M., 2004, 34.

[10] Metro Vancouver (formerly Greater Vancouver Regional District), *Boilers and Process Heaters Emission Regulation Bylaw No. 1087, 2008.* Section 28. Additionally, the bylaw states that:

- The concentration of filterable particulate matter in flue gases must not exceed 18 mg/m^3
- The opacity must not exceed 5%
- Minimum stack height must be 20 m above ground unless otherwise specified by the district director

[11] Adapted from Maker, T. M., 2004, 68-69.

Fire Safety
The combustion action in biomass boiler systems leads to the risk of burnback—fire travelling backwards from the combustion area along the fuel stream. Temperature sensors are used to detect this burning fuel, initiating an automated water-quenching system to douse the fuel stream. Boiler rooms must also be equipped with sprinklers. Rotary air locks and vertical drops along the fuel conveyor may also be designed into the system to prevent burnback.[12]

Dust has a higher level of flammability than larger wood chips, increasing the risk of fire and dust explosions. As one of the fuel sources produced from BCIT trade programs, the Institute must pay particular attention to fire risks. A self-contained boiler could reduce fire consequences if properly designed.

Disruption and Warning Systems[13]
The operation of the biomass system may be disrupted due to a variety of situations:

- during periods when the heating load is too small for the biomass boiler to run efficiently without smoking
- when the system is shut down intentionally for servicing
- when the fuel storage bin is empty
- when an oversized wood chip unexpectedly jams an auger and stops the fuel supply
- when the load on the system exceeds the system's capacity
- power outage

For these cases of disruption, the boiler room may be equipped with automatic alarm systems or indicators to alert operators to a malfunction or dangerous situation. This disruption factor could be a problem if a building was to rely solely on the biomass boiler for heat, particularly in winter months. A district energy system with distributed power (multiple smaller power sources rather than one large central power source) could help mitigate this risk of disruption.

Selecting a System for BCIT

The proposed waste-to-energy project is currently at the stage of choosing the specific equipment for a biomass system by building the business case. Factors that influence this choice include cost (initial and life-cycle), existing infrastructure or retrofits, and the demand for system outputs (heat, and potentially power).

[12] Maker, T. M., 2004, 11.
[13] Adapted from Maker, T. M., 2004, 26.

Alignment with the Institute's mission and strategic plan are also key considerations. Some of the questions that help to evaluate a proposal against BCIT's mission and plan are:

• *Why should the Institute give consideration to this initiative? What advantages and benefits to BCIT are expected as a result of this initiative? What is the impact if BCIT does not do this initiative?*

• *How does this initiative add value to other areas of BCIT (including links to targeted priorities of the schools, pan-institutional needs, or other objectives such as diversity)? Are there any adverse impacts or challenges created by this initiative?*

• *What organizations are involved or committed to this initiative? How is strategic partnering able to add value and how could it capitalize on existing programs and/or services at BCIT or at other government or related organizations?*

Proposal 1: Biomass boiler for heat production only

The initial exploration into specific biomass systems suited to the BCIT context involved an initial proposal for a fully automated system to supply heat (as hot water) from wood waste generated on campus. In this type of system, fuel is moved along a conveyor from the supply bin to the boiler at a rate managed by computer controls, and the system automatically maintains the pressure and temperature inside the boiler. Much of the maintenance is automated as well, though equipment specifications vary: some units include automated ash extraction and boiler cleaning.

The proposal for this automated biomass boiler system was developed with the help of a biomass consultant. All figures are presented in appendix A and B.

Integration of System Outputs

Infrastructure is in place to receive the hot water generated by the biomass boiler. An existing district energy system on the campus runs in close proximity to the NE2 building and could receive energy inputs. Retrofit costs would be incurred. Again, future expansion of the district energy to the Sustainability Precinct must be considered.

NE2 and NE4 are not heated with the district energy system, instead using radiant heat from burning natural gas on site. Whether this new energy source would provide heat for NE2 and NE4 is an outstanding question, as the conversion of these buildings to utilize hot water for heating is an additional cost above the cost of the biomass system itself.

Proposal 2: Combined heat and power

Further exploration into specific biomass systems and also partnership opportunities led to a proposal for a "cogeneration" or combined heat and power

(CHP) system. Such systems simultaneously produce heat (hot water) and mechanical energy (transformed into electricity) from the same equipment. In this type of biomass system, the heat exchanger uses compressed air as the transfer medium. Once heated by the combustion gases, the compressed air is expanded over a power turbine to produce mechanical energy. This mechanical energy passes through a reduction gearbox and is converted into electricity by an asynchronous generator. The generator connects to the grid to distribute the generated electricity.

The hot compressed air, once expanded and somewhat cooled, is directed back to the combustor to recover residual energy. Similarly, residual energy remaining in combustion gases after the air-to-air heat exchange is recovered in a secondary exchanger (a boiler) to produce hot water. This hot water can be used in heating systems.

According to the manufacturer:

"Biomass is burnt in a controlled manner in a stepped moving grate combustor and the combustion gases are passed into an air-to-air heat exchanger (HEX). A series of baffles within the HEX's 'cassettes' directs the gas flow across stainless steel pipes the inside of which is compressed air from the compressor stage of the turbocharger. The combustion gases still have some heat once they've passed through the HEX and this residual energy is extracted as hot water by passing the gases through a boiler. The gases are drawn through the system by an induction fan to atmosphere."

The proposal for this CHP system offers BCIT the opportunity to partner with an industry-led organization to help advance bioenergy technologies. As a "near-term" technology that requires more testing before its release into the market, the small-scale CHP system identified in this proposal would offer a demonstration opportunity and assist with technological development. The partner organization hopes to introduce small size CHP systems into remote communities that currently rely on heavily polluting diesel fuel. By testing such a system first in the Lower Mainland, observation, timely maintenance and lower maintenance costs are more easily achieved than could be in rural communities. It can be assumed that maintenance costs for a technology in the testing phase would cost more than for commonly established technologies, and it may be possible for BCIT to gain additional support to help cover such development-related costs.

Some of the product specifications for the proposed CHP system are listed here:

CHP System (biomass generator)

Capital costs	$694,500	Boiler cost is $265,000; all other costs assumed to match Proposal 1
Max. electrical output	25 kWe	To be verified
Max. thermal output	80 kW	To be verified
Fuel consumption	20-25 kg/hour	To be verified
Operational availability	8,000 hours/year	Not tested for this duration of time

Integration of System Outputs
Specific demand for the power produced from this system has not been determined, though integration with the campus's smart microgrid is a possible option. The need for infrastructure retrofits has not been determined.

Opportunities

The development of a biomass waste-to-energy project aligns with BCIT's mandate to develop mission-driven research and demonstration projects, and to prepare students for real-world situations.

A biomass waste-to-energy system would provide an opportunity for increasing awareness of energy-efficient technologies and transferring knowledge. Locating a biomass system on campus would expose faculty, students and visitors to a technological process that produces energy while reducing waste and greenhouse gas emissions. At the same time, faculty can use the project to demonstrate the operation of such a system to students as a part of the curriculum.

A biomass demonstration project tied to the Joinery and Carpentry programs would help to transfer knowledge across disciplines. BCIT is the main trainer for the joinery trade in BC, and such a demonstration system would expose trades students to an area of knowledge that is relatively new to trades operations. This would open the energy management discussion to include not just energy managers but also those trade professionals whose daily activities are closely tied to the successful operation of newer energy technologies.

Opportunities also exist to integrate the biomass system with the campus's existing district energy system and smart microgrid project. The hot water output from the biomass boiler heat system is well suited to the needs of the district energy system, especially if a second district energy loop is being considered to serve the Sustainability Precinct. If a CHP system is used, electricity generated can feed into the campus grid (and smart microgrid) and the hot water can also be integrated with the district energy system.

BCIT receives local, national and international exposure for its campus demonstration projects, specifically those related to sustainable energy management. A biomass system would be an exciting addition to the various initiatives in the Sustainability Precinct. The project would also receive exposure as the architectural woodworking industry moves forward with its Green Certification program; BCIT's biomass energy system and the surrounding precinct would serve as a showcase for Canada and the US.

Project Evaluation and Decision Making

Questions for Students

1. What are the next steps for making this demonstration project happen?
2. Are there other biomass technologies that could be considered? Are there other uses for the wood waste (not related to energy production)?
3. Are there other risks that should be considered?
4. Would you consider a bigger system that would need to truck in wood from external sources? What are the pros and cons of using wood from external sources?
5. Would you consider having an external company be the owner of the equipment and sell you the energy (you would save money on equipment costs), or is it more important for you to save money on the cost of the energy? Is cost your main concern?
6. How will you compare the two proposals? Is there additional information you will need?
7. What might be some future uncertainties that could affect the success of the project?
8. How will you evaluate the proposed demonstration project? What criteria will you use?

Notes for Instructor

Re: Question 2
Gasification is another biomass technology that could use this wood waste. In this process, the biomass is burned using less oxygen to produce a synthetic gas. This “syngas” is then itself used as a fuel.
For additional information:
http://www.cbc.ca/technology/story/2010/08/17/ubc-nexterra-biomass.html
http://biomassmagazine.com/articles/5092/nexterra-biomass-gasifier-emissions-test-complete
http://www.ecn.nl/docs/library/report/2005/rx05186.pdf
[refer to section 1: Introduction]

Re: Question 3
Appearance and public perception
The aesthetic of wood burning as dirty, often reinforced in public perception with the visual reminder of the smoke stack is a possible risk for acceptance by the various stakeholders (including the BCIT community). The risk could be mitigated by a public consultation and awareness building initiative, by including aesthetics as a decision criteria in the RFP, and by leveraging the fact that there is already a large smoke stack on campus (i.e. the community is used to it). Interpretive signage could also be installed to explain the technology to visitors, staff and students walking by it on campus. The explanation could include a discussion of the carbon neutrality debate and emissions.

Sound level
This is a particular concern for the chipper component of the system used to transform the wood from carpentry off-cuts to a usable size. This risk could be mitigated by choosing a suitable location, by building an enclosure for the chipper, and by planning for its use during appropriate hours of the day.

User Safety
Physical health and safety is a concern for the operators of the chipper and the heating system.

Re: Question 5
Some context for this question is the possible move by natural gas providers to switch from being in the business of supplying natural gas to supplying “heat.” In this scenario, natural gas providers could supply heating equipment (e.g. a biomass system) and charge the customer for the energy that the customer produces. In such a scenario the potential cost savings of the customer supplying its own fuel (the wood biomass) is unclear.

Re: Question 7
There are many future unknowns that could affect the success of the project. Some include:

- What is the future price of wood? What will this mean for the availability of biomass generally, as wood waste or as a commodity such as wood pellets? (This question may apply more generally to off-campus projects rather than this particular project, at least in the known short term.)
- What is the future of Joinery and Carpentry? If these trades were no longer taught at BCIT, where would the fuel come from?
- If the project required a biomass source from off-campus, can a source be guaranteed? At what cost? What if the source was very far away (what would be the net greenhouse gas emissions)?
- If we fail to sustainably manage our forests, or lose more of them to development or fire, will the public accept wood as a fuel source?

Biomass Specific Assumptions

Wood from Joinery [saw dust + chipped material]	Value	Unit	
Caloric value of wood (with significant amount of resine)	18.7	GJ/bdt	where bdt: bone dry metric tonne
Bulk Volume	208	m3/yr	(fines & chips)
Density	0.28	tonne/m3	
Total Weight	58	tonne/yr	
Moisture Content	8%	wet basis	
Total weight - Dry	54	bdt/yr	where bdt: bone dry metric tonne
Calorific Value per tonne of wood waste	17.0	GJ/tonne	
Energy Available	989	GJ/yr	

Wood from Carpentry [saw dust + chipped material]	Value	Unit	
Caloric value of wood	18.4	GJ/bdt	where bdt: bone dry metric tonne
Bulk Volume	917	m3/yr	
Density	0.18	tonne/m3	
Total Weight	165	tonne/yr	
Moisture Content	15%	%	
Total weight - Dry	140	tbd/yr	where bdt: bone dry metric tonne
Calorific Value per tonne of wood waste	15.2	GJ/tonne	
Energy Available	2,512	GJ/yr	

Energy - Total Wood Waste	Value	Unit
Heat energy available	3501	GJ/yr
Boiler conversion efficiency	85%	%
Heat energy produced	2,976	GJ/yr
biomass boiler:	7	kWh electricity per GJ of heat generated
chipper	4	kWh electricity per tonne of wood chipped
electricty to operate all equipment:		kWh/yr

GHG Emissions	Value	Unit
Carbon intensity of Natural Gas	0.0503	tonnes CO2e/GJ
Emissions avoided by displacing GJ by biomass	176	tonnes CO2e/yr

Biomass boiler Heat only
Option 1 Assessment

Option 1 Description

Boiler size: 250 kW
Boiler make: To be selected
Wood residue: See assumptions worksheet
Heating load: All campus - Connected to main line/central plant
Other features: Are fix - same for all options assessed thus only include in the financial analysis below
General Description: Heat only Firebox boiler (self contained), fully automated, with silo, with chipper and with smoke stack and air particulate filter.

Capital Investment

CIVIL WORKS				
	Foundation, incl.	for silo, container & stack	$20,000	
	excavation & dirt removal	incl. trench for pipes		
	L-shaped concrete platform	10" deep		
	resurfacing	(perimeter of platform, trench)		
				$20,000
UPGRADE OF DUST EXTRACTION SYSTEM				
	chipper		$45,000	
	chipper connection to overhead duct		$5,000	
	retrofit of dust extraction system	hopper replacement/retrofit	$10,000	
	auger from dust extraction hopper to silo	28 m (92')	$10,000	
				$70,000
FUEL STORAGE				
	silo	950 cft	$18,000	
	silo installation		$4,000	
				$22,000
FIREBOX BOILER				
	firebox boiler, incl.	250 kW	$120,000	
	fuel extraction system for silo			
	auger from silo to combustor			
	rotary air lock			
	stoker screw			
	deluge system / emergency fuel cut-off			
	flue gas recirc.			
	automatic deashing			
	ash hopper			
	pneumatic soot blower			
	safety valves			
	boiler bypass incl. 3-way valve			
				$120,000
FLUEGAS TREATMENT				
	particulate filter	PM < 18mg/sm^3	$85,000	
	Chimney	40' insulated, incl. guy wires	$20,000	
				$105,000

INSTALLATION

	electrical installation			$10,000	
	installation inside container	40' hi-cube incl 2 doors		$45,000	
	heating installation, incl.			$15,000	
	T from ring pipeline to heat exchanger				
	heat exchanger	250 kW		$4,000	
	all valves downstream of boiler bypass			$1,000	
	pipes	3"		$1,000	
	heat meter			$1,500	
	system main pump			$2,000	
	crane rental			$1,000	
	container shipment			$5,000	
					$85,500

ENGINEERING

	building permit			$2,000	
	mechanical engineering			$5,000	
	heating engineering			$6,000	
	stack tester			$2,000	
	coordinating engineer			$5,000	
					$20,000
SUB-TOTAL		excl. HST			**$442,500**
contingencies			20%	$89,000	
HST			4%	$18,000	
Total Capital Cost					**$549,500**

Operation and Maintenance Cost

Fixed O&M Costs				**Total hours/yr**	**Rate**	**Total**	
staffing cost during operation		1	hour per day	365	$32.75	$11,954	
displaced staffing cost (existing cost to empty old 6 bins of old dust extraction unit)		-0.75	hour per day	-274	$32.75	-$8,965	
grates, ash and container cleanup		4	hours per 2-week period	104	$32.75	$3,406	
filter & boiler tube cleaning		8	hours per 4-week period	104	$32.75	$3,406	
total annual staffing costs			**Total hours per year:**	299		**$9,800**	**per year**
Variable O&M Costs							
ash dumping (1% of tbd)		1%	tonne per year	2	$50.00	$97	per year
electricity consumption			kWh/yr (incl chipper)	0	$0.039	$0	per year
variable maintenance cost (due to hrs of operation)	[included in fixed cost - assuming boiler is running at full capacity]					$0	
total variable O&M costs						**$97**	**per year**
TOTAL O&M costs						**$9,897**	**per year**