CLEARING THE AIR
Implications of Biomass Combustion for District Energy in Urban Areas

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CLEARING THE AIR: IMPLICATIONS OF BIOMASS COMBUSTION FOR DISTRICT ENERGY IN URBAN AREAS

by

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We accept this project as conforming
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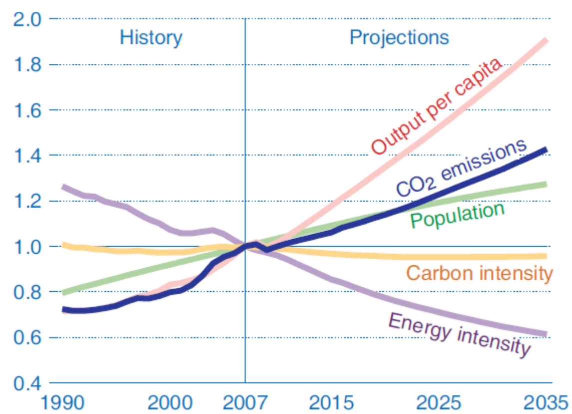
1. Introduction

1.1 Context/Background

The threats posed by climate change and dwindling oil and gas reserves are making policymakers around the world think differently about energy. At the local level, energy is playing a bigger role than ever in discussions about growth, development and policy changes because of commitments to reduce community greenhouse gas emissions. In 2008, BC passed Bill 27, which requires local governments to set greenhouse gas reduction targets and develop policies and actions to achieve those targets in their Official Community Plans.

For policymakers, the two most readily influenced determinants of greenhouse gas (GHG) emissions are the energy intensity of the economy (or energy consumed per economic output) and the carbon intensity of energy (the amount of energy-related carbon dioxide emissions emitted per unit of energy produced) (EIA, 2010). Conservation and efficiency improvement are the goals of policies targeting energy intensity while alternative renewable energy sources can help reduce carbon intensity. A recent study by the U.S. Energy Information Association projected that worldwide increases in output per capita and relatively moderate population growth in the coming decades will overwhelm projected improvements in energy intensity and carbon intensity assuming no new climate policies (See Figure 1). This suggests that more immediate and drastic steps are needed in these areas at multiple levels if we are to curb global emissions and avoid catastrophic climate change.

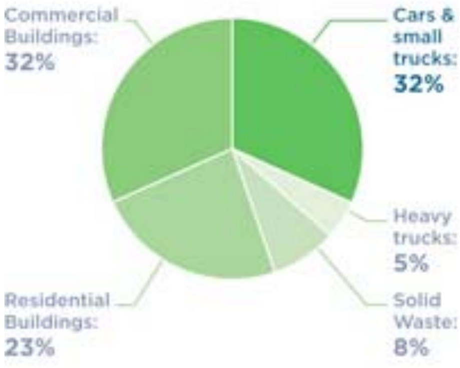
Figure 1: Global Trends in Kaya Factors (Components influencing GHG Emissions) 1990-2035 (index: 2007 = 1.0)



Source: EIA, 2010

While these challenges necessitate action from all sectors, governments, and people, local municipalities are uniquely positioned to influence the shape of future development and the characteristics of associated energy infrastructure. Increasingly, local governments are seeking ways to reduce community-wide energy consumption and reliance on fossil fuels in the interest of long-term sustainability and resilience. The City of Vancouver has committed to meaningful action on climate change both in its own operations and at the community level. The city has set a number of Climate Protection Targets, including the reduction of community emissions by 33% by 2020 and 80% by 2050 (from 1990 levels) (CoV, 2007). To meet these targets, continuous improvements are required in a variety of sectors. With building energy use accounting for over half of greenhouse gas (GHG) emissions in the city (see Figure 2), improving the energy efficiency of new and existing buildings are key elements of the City's emission reduction strategies. The City has already taken a variety of actions to this end: adopting the greenest building code for new houses in North America; removing policy barriers to green roofs, solar energy systems and passive building design; and developing tools to enable investment in renewable energy, high performing new buildings, and retrofits to existing buildings (CoV, 2009).

Figure 2 - Vancouver Community GHG emissions by sector, 2008



Source: City of Vancouver

One approach to meeting the space heating (and cooling) needs of buildings more efficiently is through district energy (DE) systems. District energy systems work by generating thermal energy (heating/cooling) at a central energy plant or a combination of several smaller plants connected through a network of piping to service nearby buildings with space heating, hot water, steam and/or chilled water (Canadian Urban Institute, 2007). Through the use of combined heat and power (CHP) plants (also referred to as cogeneration), DE systems can meet the heating and electricity needs of a district simultaneously from a single fuel source.

While district energy systems do have direct emission benefits compared to conventional boiler or furnace heating through improved efficiency, their greatest potential is achieved when they are powered by a renewable, GHG neutral fuel source. The Neighbourhood Energy Utility (NEU) in South-East False Creek (SEFC) is a local example of this. By using sewer heat recovery technology, supplemented by solar-heated hot water, GHG emissions from the nearby 2010 Olympic Athlete's Village were reduced by over 50% when compared to conventional natural gas furnaces. However, sewer heat recovery is not a viable option everywhere in the City, and powering the heat pump still requires some electricity (of which a portion is derived from fossil fuels). Wind and solar technologies are limited in their ability to produce the bulk heat required for space heating and hot water. An attractive alternative heat source is biomass combustion, or the burning of woody or non-woody organic material (raw or manufactured). High efficiency boilers combined with advanced emission control technologies have made biomass a viable energy source throughout Europe and increasingly in North America, even in urban centres.

A study prepared for the BC Ministry of Environment identified three significant advantages offered by the use of biomass. These benefits are discussed in greater detail throughout the report but are summarized here:

1. Biomass is greenhouse gas neutral if harvested sustainably since the greenhouse gases (GHG, principally CO_2) released during combustion are recaptured in new forest growth (see Section 3.1);
2. It is renewable if the resource forests are sustainably managed; and
3. It is a readily available and proven fuel in BC, the use of which enhances local economic benefits while reducing energy imports. (Envirochem, 2008a).

"Biomass" means:

- wood or wood products;
- uncontaminated wood waste, such as mill ends, wood chips, shavings, sawdust, sander dust, clean construction waste and hog fuel;
- manufactured wood fuel (e.g. pellets); and
- vegetative or agricultural products

Source: GVRD Emission Regulation Bylaw No. 1087)

A biomass heat source was originally recommended as the preferred option in the development of the SEFC NEU because of its reduced capital costs as well as improved GHG emission reduction benefits and ease of implementation over sewer heat recovery (CoV, 2006). Due to the time constraints of the SEFC project schedule, however, the necessary public process in support of an air quality permit from Metro Vancouver was not feasibly possible. The sewer heat recovery option was a viable alternative at this site that still achieved considerable GHG reductions without requiring an air quality permit. Through the initial assessment of the biomass option, a variety of concerns were raised by the public related to the air quality impacts of wood combustion, environmental impacts of the delivery of wood pellet fuel, and the aesthetic impact of the facility. Since energy production and air quality management are new territories for the City, a knowledge gap was identified related to these concerns. The intent of this report is to fill this gap and inform future policy and project work related to district energy systems.

1.2 Methodology

This project was completed under the City of Vancouver & University of British Columbia Greenest City Scholar program. The project evolved over the course of the summer of 2010 to include intra-agency consultation, a review of applicable literature and regulations as well as key informant interviews with municipal, industry and regulatory representatives. Staff members of the City of Vancouver's Sustainability Group were instrumental in providing support and guidance throughout the project. Relevant findings with respect to air contaminants and emission controls, regulations, and case studies were also synthesized into quick-reference guides, included here as Appendices A through C.

1.3 Document Overview

This report was prepared to assess the relative merits of biomass combustion as a heat source for district energy systems in Vancouver. The intent is to build the City's capacity to both understand and evaluate options for thermal energy production, and to address citizen and interest group concerns related to air quality. The report is structured as follows and endeavours to answer the pertinent questions below:

1. **Introduction**

2. **District Energy in Vancouver**
   What is the existing state of district energy in Vancouver?
   What potential exists for the expansion of existing systems and/or introduction of new systems?

3. **Biomass Combustion for District Energy**
   Why is biomass combustion considered GHG-neutral?
   How is biomass currently used in Vancouver?
   Where else is biomass used for district energy?

4. **Air Quality, Contaminants & Regulations**
   What are the health-impacting air contaminants associated with the burning of biomass?
   What are the locally applicable emission regulations and/or permitting requirements?
   How do these regulations compare with those of other jurisdictions?

5. **Biomass Combustion & Emission Control**
   What burner technologies and air pollutant control measures are available?
   What are the typical and best achievable emission levels of air pollutants?
   How do boiler size and fuel type affect emission levels?
   How do emissions from biomass and natural gas combustion compare?
   How could these emissions impact ambient air quality?

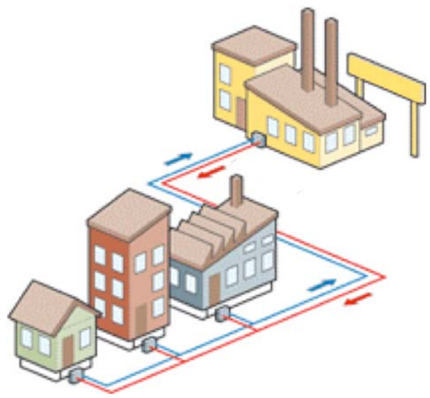
6. **Other Considerations**
   How will the availability and quality of biomass fuels evolve over the coming decades?
   What strategies for public engagement and involvement are necessary to enable biomass DE systems where appropriate?
   How can biomass district energy be integrated into design and land use planning decisions?

7. **Conclusions/Recommendations**
   What can the City of Vancouver (and other municipalities) do to achieve climate objectives through biomass DE systems without compromising air quality objectives?

2. District Energy in Vancouver

2.1 Intro to District Energy

Figure 3: Concept Diagram of a District Energy System



Source: SDHA, 2010

District energy, for the purposes of this report, is the localized production and distribution of heat energy to multiple buildings in a district. Distribution of heat can be by way of hot water pipes or high-pressure steam lines. This heat is converted to ambient heat within connected buildings through radiant heating systems, heat pumps or other heat exchange systems (See Figure 3). By combining the load profiles of multiple users, a more constant energy demand is created, improving efficiency over conventional single-building boilers and furnaces. In some cases, waste heat from certain users (e.g. industrial applications, grocery store refrigeration, excess solar thermal gain, etc) can be fed back into the system, offsetting the heat load requirements of other users.

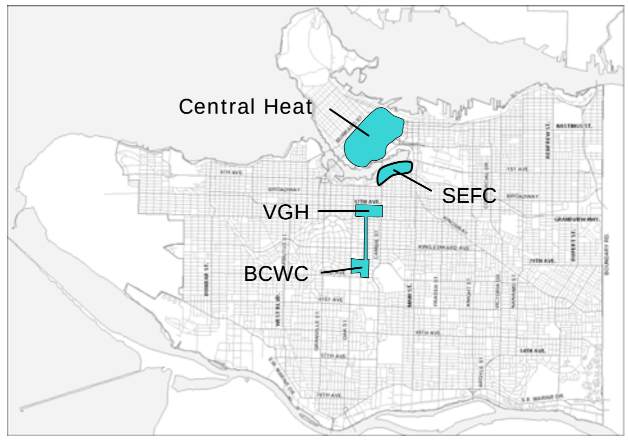
The heat source for a DE system can vary significantly. Waste heat from industrial activities or existing infrastructure (e.g. sewer heat recovery) can provide base load heat in some areas, but combustion boilers are much more common. Boilers essentially turn the heat energy produced from a combustion process into useable steam or hot water. This can be done by passing hot combustion gases through tubes immersed in water (firetube boilers) or around tubes filled with water (watertube boilers). The combustion process can be powered by any number of fuels but in modern DE applications natural gas, oil or biomass are typically used.

Proponents of electrical baseboard heating will argue that since the vast majority of Vancouver's electrical supply is hydro-electric, GHG emissions are minimal when this type of distributed heating is used. While electric resistance may be a clean source of heat locally, it may not be the best use of our limited electricity supply and its use precludes the export of that electricity to other jurisdictions where it could displace coal-generation. Since air quality and climate change impacts have no regard for jurisdictional boundaries, reductions in coal combustion elsewhere are of local value. Buildings constructed with electric baseboard heat will typically include natural gas boilers to provide heat to pressurized hallways and common spaces. These systems often end up supplying a large portion of the heat to units as well, effectively negating the benefits of using clean electricity.

2.2 Existing District Energy Systems

Parts of the City of Vancouver are already powered by district energy systems and have been for decades (see Figure 4). The majority of these systems use high pressure steam for distribution, limiting their potential heat sources to those that can provide sufficient temperatures for steam generation (ie. combustion). Converting steam systems to hot water can be cost-prohibitive since it requires switching out piping infrastructure and can require changes to the internal infrastructure of connected buildings (heat exchangers, etc). Conversions can be achieved over time however, and maintenance and operational costs can be reduced with newer hot-water systems. This is the rationale behind UBC's decision to convert their current steam distribution system to hot-water. New buildings attached to steam-based systems can use heat exchange units to convert steam heat to hot-water for internal distribution.

Figure 4: Map of Existing DE Systems



Source: City of Vancouver

Established in 1968, Central Heat Distribution Ltd (Central Heat) is a privately owned, publicly regulated utility that provides steam heat to over 200 buildings (35 million sqft) in the downtown core. Steam for this system is currently generated by a natural gas steam plant on the corner of Beatty Street and West Georgia Street and distributed via a 10.5 km network of high-pressure steam lines. Central Heat's proximity to the proposed redevelopment of the North East False Creek (NEFC) neighbourhood makes expansion of this system likely. A high-level review of alternative energy sources for the system is currently underway through a partnership between Central Heat, the City and BC Hydro. So far, the review has identified biomass as a promising alternative fuel source to meet base loads, though uncertainties remain surrounding fuel availability and pricing, potential steam plant location, air quality impacts, and fuel delivery and storage.

The BC Women and Children's Hospital (BCWC) and Vancouver General Hospital (VGH) each operate a fossil-fuel based steam system to supply heat and control humidity levels within their own buildings. The systems are connected via an inactive steam line and have the potential to be expanded to serve nearby properties should their capacities be increased. Integrating these systems into neighbourhood-scale district energy systems could improve their efficiency of use (by diversifying the load) and reduce capital and operating costs by sharing costs across multiple agencies. The nearby Central Broadway Corridor, where significant redevelopment is expected in the coming decades makes an integrated district energy system supplying both hospitals and surrounding commercial and residential development a very attractive opportunity. If this system were powered by renewable energy, both health authorities could avoid the costs of purchasing offsets as required under the province's Greenhouse Gas Reduction Targets Act, 2008. Biomass combustion is a potential renewable heat source for this system, though its perceived air-quality related health impacts are likely to play an even stronger role because of the hospitals' need to be exemplars of prioritizing public health.

The South East False Creek (SEFC) Neighbourhood Energy Utility (NEU) is the latest addition to the city's collection of district energy systems. Supplied in part by sewer heat recovery, this system serves the new and growing neighbourhood of SEFC including the Olympic Village. At full build-out, the system could serve as much as 6,000,000 square feet of development. The baseload heat supplied by sewer heat recovery (approx. 3.5 MW thermal (MW_{th})) is supplemented and backed up by 3 natural gas boilers.

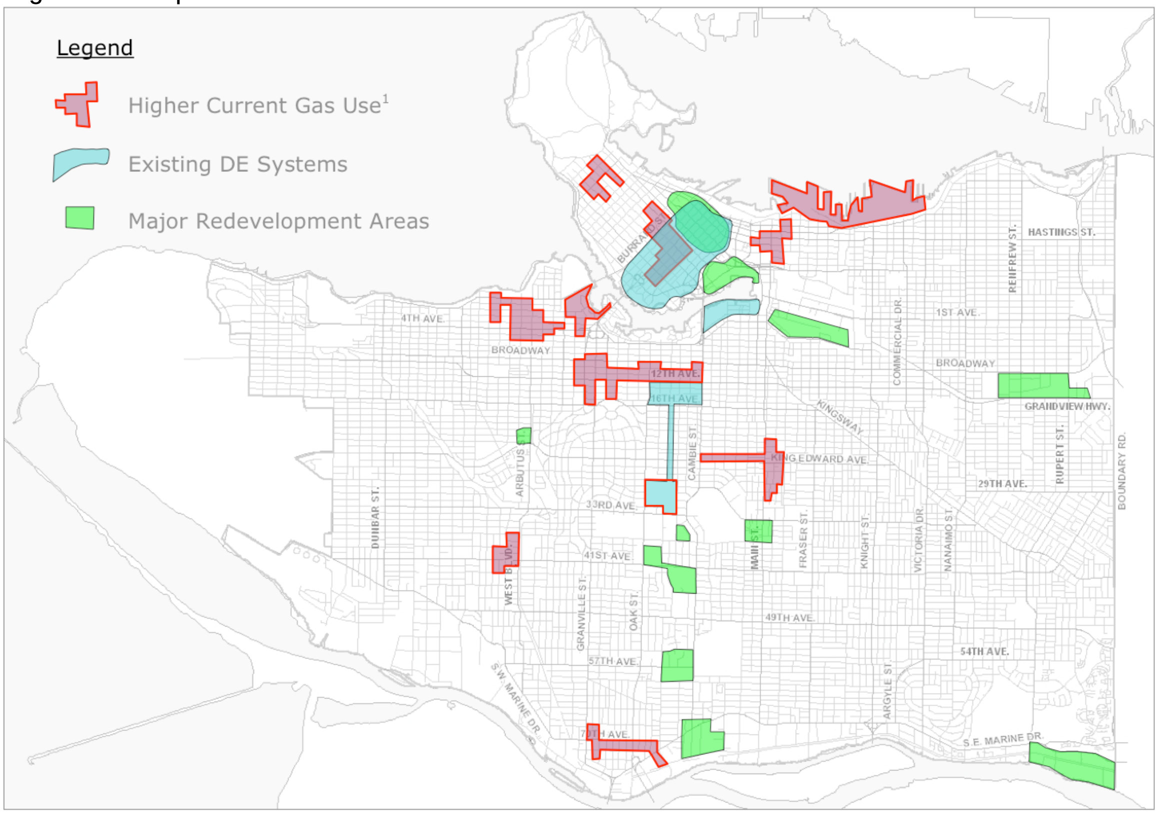
2.3 Fuel Switching, Potential Expansion & New Systems

District Energy Systems are most readily introduced in *new* development where building infrastructure can be designed for DE connectivity. Challenges of integrating existing buildings into DE systems are substantial and can include technical and economic challenges associated with converting internal infrastructure as well as political challenges related to negotiation with strata councils and the imposition of new rate structures on residents (Compass Resource Management, 2009). The greatest potential exists in areas where new high-density development is expected to have a sufficient heat load requirement to economically justify a renewable heat source. In some cases a fossil-fuel powered district energy system is the only economically achievable first step until sufficient demand exists to justify a heat source switch. Even fossil-fuel based district energy systems still have significant efficiency and GHG reduction benefits when compared to conventional, distributed heating.

The City is already exploring ways of requiring new construction in potential DE areas to be "DE ready" so that when systems are introduced or expanded, the necessary infrastructure is already in place. The City's authority over the establishment and operation of energy utilities is outlined under Section 300 of the Vancouver Charter and includes the right to compel persons to make use of an energy utility system and to establish the terms and conditions on which persons may make use of that system. Similar authority is granted to other BC municipalities under Section 8(2) of the Community Charter. A Connectivity Study prepared for the City and BC Hydro determined that connecting to a district heating system actually avoids initial capital costs for developers, so requiring that connection is not difficult (Compass Resource Management, 2009).

The City has done some mapping work towards identifying potential DE growth areas, shown in Figure 5. This map shows areas of higher current gas use (red), existing district energy systems (blue) and major redevelopment areas (green). The greatest opportunity lies where these areas overlap or where their proximity to one another would make expansion of an existing DE system possible or a new system viable. Data limitations in the identification of higher current gas use areas reduce the accuracy of this mapping. However, it is a useful starting point for discussions on DE opportunities and has a clear association with areas of higher density development and/or industrial uses.

Figure 5: Map of DE Potential



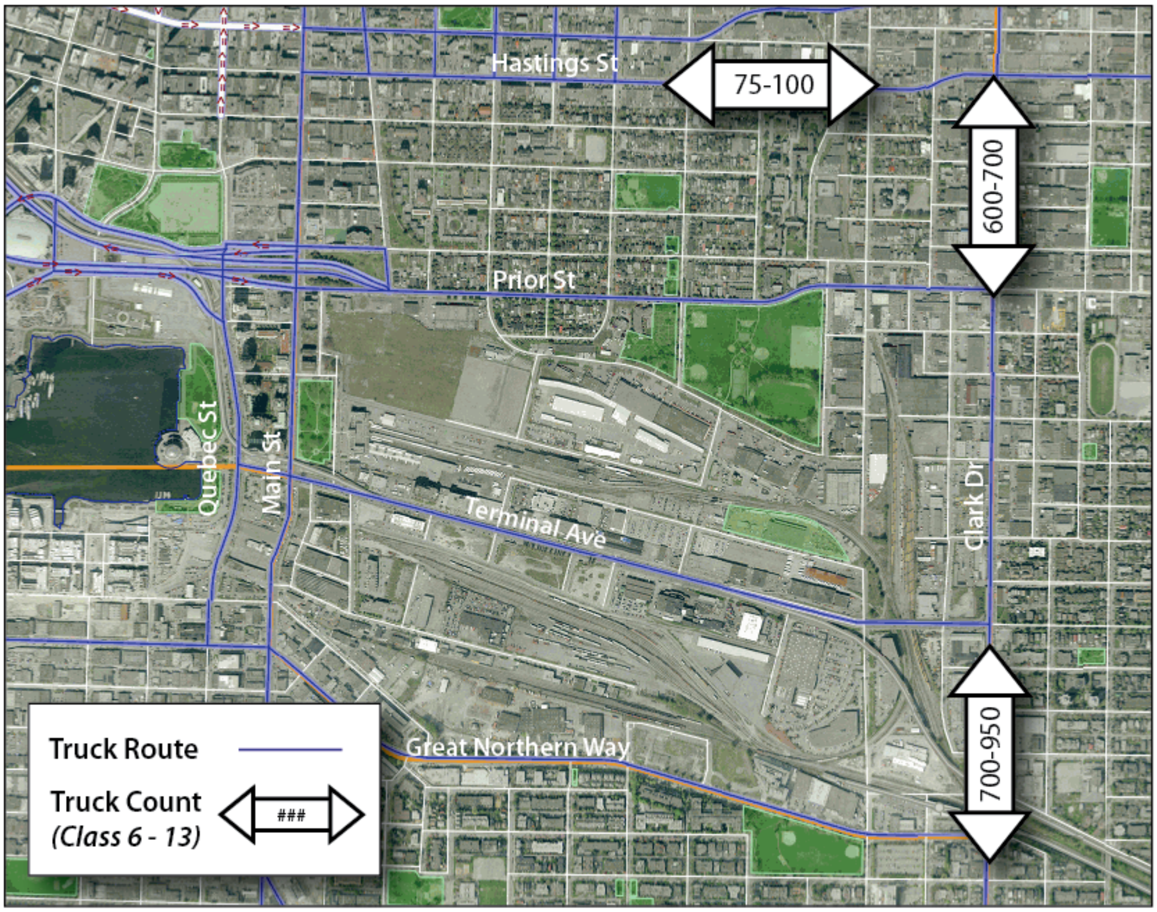
Source: City of Vancouver

Note 1: Block-level mapping of Higher Current Gas Use areas was based on incomplete data from Terasen Gas. As a result the areas identified are based on only 55% of actual usage and are thus approximations at best. Their inclusion is simply to provide an indication of opportunities for further study.

Natural gas consumption at Central Heat currently accounts for over 20% of downtown Vancouver GHG emissions related to space heating and hot water (Compass Resource Management, 2010). However, total emissions may have been higher if connected buildings each had their own gas boiler. This creates a remarkable opportunity: by converting this one operation to a GHG-neutral fuel source, city-wide emissions could be reduced by 80,000 tons CO_2. This would be equivalent to taking 14,500 cars off the road and would meet 12% of the City's 2020 Emission Reduction Target over which the City has influence. Integrating or expanding the Central Heat steam system to include new development in NEFC improves the business case for a fuel switch even further. A screening study commissioned by the City, Central Heat and BC Hydro suggests that baseload requirements for an expanded system could potentially be met by a 63 MW_{th} biomass boiler.

The nearby industrial lands of the False Creek Flats (the Flats) may be an ideal location for this type of a large-scale (40 MW_{th}+) biomass combustion system since conflicts with surrounding uses are minimized and access to the rail network and truck routes for fuel supply is already in place. However, air quality impacts would need to be addressed in detail in context with existing ambient (background) levels of air pollutants in the area. A 63 MW_{th} boiler would require approximately 210,000 tons/year of wood chips (at 50% moisture content), or about 20 40-foot trucks per day (actual mass and volume of fuel needed dependant upon specifics of fuel type). To better understand the relative magnitude of this increase in truck traffic on surrounding truck routes, data from a 2009 traffic count was analyzed to determine existing truck volumes (Figure 6). Wood trucks would likely access a site within the flats via Clark Drive and Prior St or Terminal Ave. Clark Drive is already a heavily-used truck route with 600-700 trucks per day so an additional 20 trucks would be insignificant. Specific truck volume data for Prior St was unavailable but it likely caries lower volumes than Clark. In addition, it passes through a residential area of Strathcona, so this potential increase in truck traffic may be of public concern. Opportunities for the use of existing rail and/or port infrastructure may exist, however their analysis was outside the scope of this project.

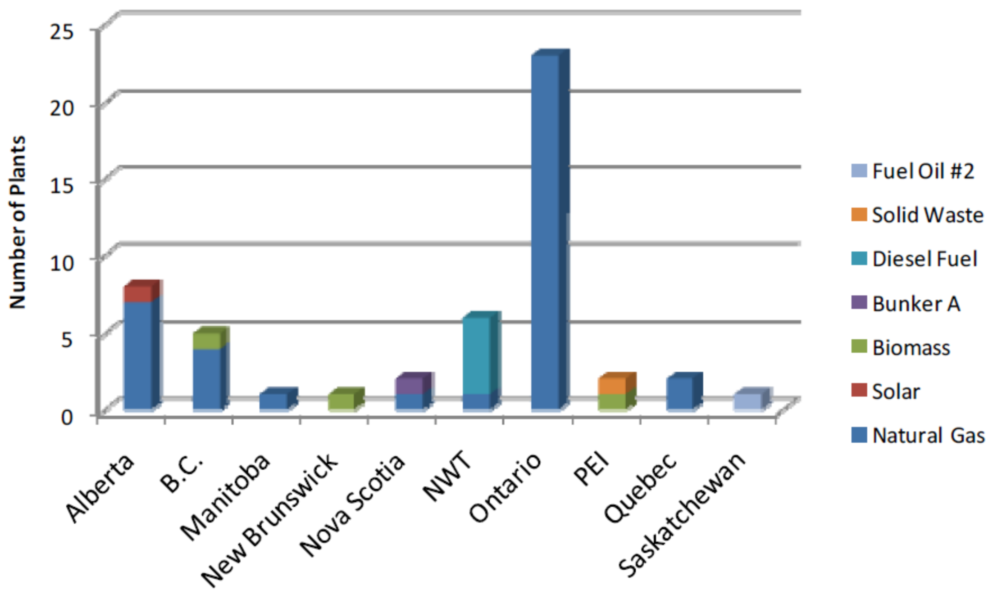
Figure 6: Truck Volume Mapping around False Creek Flats



3. Biomass Combustion for District Energy

A National Survey conducted by the Canadian District Energy Association (CDEA, 2009). identified biomass as an emerging fuel source in the industry, particularly in B.C. where large sources of residual wood waste exist from the forest industry. To date, however, Natural Gas remains the dominant primary fuel type, with biomass playing a role in only three provinces (See Figure 7).

Figure 7 - District Energy Primary Fuel Type by Region (N = 51)



Source: CDEA, 2009

3.1 Greenhouse Gases & Biomass

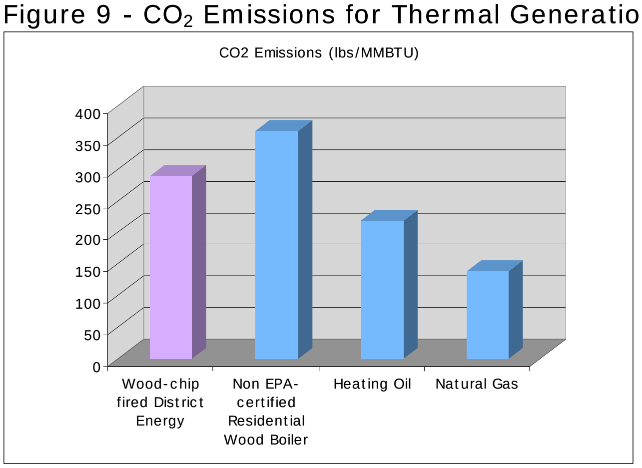
The primary rationale for adopting biomass as opposed to traditional fossil-fuel boilers is related to GHG reductions. The International Panel on Climate Change (IPCC) Guidelines consider CO_2 emissions from the combustion of biomass to be GHG neutral (IPCC, 2007). Although biomass combustion facilities do emit carbon dioxide, the greenhouse gases emitted through combustion do not exceed what would be generated through natural decomposition and are equal to the carbon sequestered over the life of the trees (See Figure 8). Effectively, the release of wood-based carbon is a natural part of the carbon cycle, though accelerated by combustion. This is desirable when compared to the burning of fossil fuels, which releases carbon sequestered from the atmosphere millions of years ago. By avoiding the use of fossil fuels, we can avoid introducing *new* carbon to the atmospheric cycle.

Figure 8: Biomass Carbon Cycle Schematic

Source: BC Bioenergy Strategy

There is however some disagreement as to the relative magnitude and timing of climate-related benefits. On a per-unit of energy basis, burning wood emits more carbon than the burning of fossil fuels since it has a lower embodied energy (See Figure 9). A study conducted by the Manomet Centre for Conservation Sciences (2010) defines these excess emissions as the *carbon debt*. This study demonstrated that in the case of newly harvested forest biomass, this debt is paid off as re-growth occurs until eventually biomass begins yielding *carbon dividends*. These dividends are in the form of atmospheric GHG levels that are lower than would have occurred from the use of fossil fuels to produce the same amount of energy. The rate at which this debt is paid off and dividends achieved depends on the specific technology employed and on forest management practices. For thermal applications, biomass was found to have effective carbon emissions 37% greater than Natural Gas and this associated carbon debt could be paid off in 17 to 37 years depending on the harvesting scenario. As the authors note, however, this analysis considered only biomass from harvesting natural forests. The use of urban waste wood or forest residues would yield more immediate dividends since carbon from these sources would enter the atmosphere anyways through decomposition.

Figure 9 - CO_2 Emissions for Thermal Generation



Source: Manomet, 2010

In the case of waste wood disposed of in a landfill, anaerobic breakdown of the wood would result in the production of methane, a much more dangerous greenhouse gas because it has a stronger forcing effect on climate (72 times that of CO_2 over a 20 year time period) (IPCC, 2004). While a portion of this methane can be captured and used as fuel or flared (approx. 70% at the Vancouver Landfill), some is still released to the atmosphere. Therefore, even from a direct GHG emission standpoint, the combustion of waste-wood biomass is preferable to its disposal in landfills. Diverting woody biomass from landfills has the added benefit of extending the useable life of the City's landfill and reducing the need for other forms of waste disposal (e.g. incineration or export).

Since biomass fuel is readily available from a number of waste streams, the energy required to produce it is usually relatively small. The transportation of biomass (typically by truck) does involve GHG emissions, so locally sourced fuels are preferable. In BC, the volume of waste wood residue from forestry far exceeds the present demand for it, and if urban waste wood and construction or demolition waste can be sufficiently screened of contaminants, then very little transport is required. In the long term, it is plausible that a larger market for biomass would develop in BC and that the supply of diverted waste wood would be insufficient to meet demand. In this case the harvesting of trees specifically for use in biomass combustion may become necessary. This suggests that harvesting and forestry practices should be carefully managed in B.C. to ensure the long-term sustainability of forest ecosystems, the biomass industry and the energy systems that depend on them. Policy implications and other considerations related to biomass fuel supply are discussed further in Section 6.1.

A number of other studies have compared biomass with alternative district energy fuels (natural gas, waste incineration, coal, etc) through life-cycle assessment (LCA). LCA, when applied to district-heat production, considers the impacts of all activities involved in the extraction, refining, transport and use of the fuels (Eriksson, 2007). A LCA study from Sweden that looked at cogeneration systems determined that, if the marginal electricity is mainly based on non-fossil sources (as is the case in Vancouver), biofuels are in general better than natural gas. The model determined that biofuels outperformed waste incineration and natural gas in terms of net environmental benefits in eight out of twelve weighted results (including all models based on existing low-carbon electricity systems). These results indicate that adopting policies to support the combined production of district heat and electricity from biofuels is an environmentally robust strategy. The authors also highlighted that the results of biomass-fueled scenarios were less sensitive than waste and natural gas to external factors such as waste management policies and fluctuations in energy markets. This has obvious implications for the long term resilience of a local energy system.

3.2 Applications of Biomass in and around Vancouver

The City of Vancouver does not currently have any major facilities that exclusively burn biomass for the production of heat energy or electricity. Within Metro Vancouver, however, there are industrial and agricultural applications of biomass combustion for process heat, though none yet serve as heat sources for district energy systems. Metro Vancouver reports that 13 commercial/industrial operations currently burn wood as a fuel (9 greenhouses, 2 sawmills, a paper mill and a plywood plant) (Envirochem, 2008). Richmond Plywood Corporation Ltd. is one such industrial application just outside the City boundary. Their biomass plant, in operation since 2008, has a capacity of approximately 30 MW_{th} and supplies heat for their plywood production equipment. The fuel source is a mixture of bark, green veneer trim, and sanderdust residuals produced on site and they operate subject to Metro Vancouver's Boilers and Process Heaters Emission Regulation Bylaw No 1087 (see Section 4.2).

At the provincial level, fostering the development of a sustainable bioenergy sector is one goal of the BC Energy Plan. In 2005, British Columbia's forest industry self-generated the equivalent of $150 million in electricity and roughly $1.5 billion in the form of heat energy from biomass (BC, 2007). The plan's 2009 report on progress states that over 800 megawatts of biomass electricity is installed in BC, enough to power 640,000 households. Actions under the province's Bioenergy Strategy include developing at least 10 community energy projects that convert local biomass into energy by 2020 and establishing one of Canada's most comprehensive provincial biomass inventories that creates waste to energy opportunities (BC, 2008).

3.3 Biomass-fired District Energy Systems

While biomass is widely adopted in European communities (especially in Scandinavian countries), there are very few examples of its use in district energy applications in North America. This is likely a result of the relative abundance and low cost of fossil fuels in North America and slower adoption of GHG emission control legislation (e.g. emissions trading schemes). There are, however, several useful case studies here in North America.

In the U.S. recent federal and state support for biomass in energy production has encouraged its application in cogeneration plants to some degree. It is frequently used in industrial applications for process heat and for electrical generation, often mixed with coal. The largest and most established district energy system powered by biomass is in Minneapolis-St. Paul.

In Canada, direct-fired biomass DE systems have been implemented in several communities, including: Charlottetown P.E.I. (22 MW_{th}), Revelstoke BC (1.5 MW_{th}), and Oujé-Bougoumou Québec (2.7 MW_{th}). Dockside Green in Victoria, B.C. uses Nexterra's waste wood gasification technology to supply heat and hotwater to the mixed-use redevelopment (2 MW_{th}). In B.C., post-secondary institutions are poised play a leadership role, with both UNBC and SFU considering biomass combustion plants for their own district heating systems. UBC is in the process of constructing a small-scale pilot gasification cogeneration plant on its Vancouver campus as a demonstration project that will feed into its existing natural gas-based district energy system. The system currently uses steam distribution but the University is in the process of converting it to hot water to improve efficiencies and reduce maintenance and repair costs associated with older infrastructure. As a single entity, this conversion is more feasible than in a neighbourhood where there may be hundreds of different landowners. The university is also assessing more aggressive use of low-carbon alternatives including biomass through its Alternative Energy Sources Project Feasibility Study.

A number of case studies were selected based on their relevance to energy decision-making in Vancouver and are introduced on the following page. A summary table of case study systems is attached as Appendix A and some cases are referenced again throughout this document.

Charlottetown, PEI, is home to Canada's first biomass-fueled hot water DE system. With a baseload of 22 MW_{th} and peak of 51 MW_{th}, the system now serves over 125 buildings (4.5 million square feet). The system gets heat from the combustion of a combination of sawmill residue (42%) and municipal solid waste (41%) supplemented by oil (17%) for peaking and backup. The system is considered to have contributed to the establishment of a local waste-wood fuel-supply market (NRCan, 2009).

Photo Credit: © 2010 Google StreetView

Photo Credit: Joe Mabel

Closer to Vancouver, the City of Seattle is home to the **Seattle Steam Co.**, a private district heating utility that provides steam heat to around 200 buildings in Seattle's downtown. They recently replaced one of four existing natural gas- and oil-fired boilers with a wood-fired boiler that will burn clean urban waste wood, land clearing debris, and woody fragments from composting operations.

The largest biomass-fuelled district energy system in North America is **District Energy St. Paul** in Minneapolis/St. Paul MN. The entire DE system supplies heat to 80 percent of St. Paul's central business district and adjacent urban areas. 65 MW_{th} (or 22% of total capacity) is supplied by a municipal wood waste combined heat and power plant. The CHP facility became operational in 2003 and now supplies 75% of the annual thermal energy for customers in downtown St. Paul. The system also includes two low-sulphur coal-fired boilers, four gas-fired boilers and four gas- and light oil- fired boilers. These other plants are now operated mainly to support peak periods of demand (CDEA, 2008).

Photo Credit: Andrew Ciscel

4. Air Contaminants & Regulations

The combustion of biomass can involve the emission of various health-impacting air contaminants. This section describes these contaminants, why they are of concern and how their emissions are regulated in Vancouver and abroad. Relevant regulations or permits in other jurisdictions are also summarized in Appendix B. Having an understanding of the air contaminants of concern and what regulatory systems are in place for their control is an important starting point in considering biomass as a fuel source for district energy.

4.1 Health-Impacting Air Contaminants

Particulate Matter:

Particulate Matter (PM) is the major emission of concern from the burning of wood (EPA, 2003). These emissions can, however, be reduced to a large degree through conventional technologies (see Section 5.2). PM from biomass can include soot (carbon), unburned wood dust, polyaromatic hydrocarbon compounds (PAHs), semivolatile organic compounds (e.g. tars and condensibles), or ash (minerals, dirt and dust) (Envirochem, 2008b). Modern combustion equipment essentially eliminates the first four of these by ensuring complete combustion leaving mostly ash to be collected by emission controls.

Fine particulates are so small that they can remain airborne for days or weeks and behave much like gases, getting inside homes even when windows and doors are closed. Typically, health-impacting particulate matter is divided into two groups: inhalable particulate or PM_{10}, which have aerodynamic diameters less than or equal to 10 micrometers; and respirable particulate or $PM_{2.5}$ which are the finer fraction of PM_{10} with aerodynamic diameters less than 2.5 micrometers. PM_{10} can enter the lungs causing respiratory irritation and potentially increasing the risk of heart attacks and strokes. $PM_{2.5}$ is even more dangerous as it can enter the alveoli and affect the exchange of gases within the lungs. The finest particles can even penetrate the lungs, entering the blood stream and causing other health issues. The total suspended particulate matter of all sizes is sometimes referred to as Total PM or T-PM. Depending on the fuel type, more serious carcinogenic compounds (such as PAHs and Dioxins) may be part of the PM mix. High PM levels are particularly dangerous to vulnerable populations such as the elderly, children, and people with compromised respiratory or immune systems.

PM can have environmental effects including reduced visibility (haze) and settling impacts on ground and water, including: lake and stream acidification, changes to the nutrient balance in coastal waters, depleting nutrients in soil, damaging sensitive forests and farm crops, and affecting the diversity of ecosystems (EPA, 2003).

In addition to the PM emitted directly from a variety of sources, secondary particles (usually fine) can be produced by chemical reactions involving precursor gases (including NO_X, SO_X, VOCs, and NH_3). Particulate matter is also a major contributor to smog formation (Environment Canada, 2001). Smog, or ground-level ozone (O_3), is a byproduct of atmospheric reactions involving sunlight, heat and various air contaminants (including PM, VOCs, NO_x). Smog can have adverse effects on the lungs of children, people with asthma, and people who work or exercise outdoors. It also damages vegetation and can reduce crop yields.

In Vancouver, PM emissions stem largely from non-road engines (landscaping & construction equipment), marine vessels, and residential wood smoke (Metro Vancouver, 2010). Metro Vancouver is currently conducting a Residential Wood Burning Study to better understand the impact that residential wood burning appliance emissions are having on local air quality. Since these appliances have no emission controls and often burn inefficiently, their PM emissions are significantly higher than more sophisticated biomass combustion systems employing emission controls.

Nitrogen Oxides (NO_X):

These include nitric oxide (NO) and nitrogen dioxide (NO_2) and are reported in NO_2 equivalents. NO_X emissions vary significantly among combustion facilities depending on their design and controls. The high nitrogen content of many biomass fuels makes NO_X emissions one of the top air quality concerns associated with biomass combustion.

Health concerns of NO_X are associated with the respiratory system. Atmospheric NO_X reacts with ammonia (NH_3), moisture, and other compounds to form Nitric Acid and Nitrates. These small particles can penetrate deep into the lungs and cause or worsen potentially fatal respiratory diseases such as emphysema and bronchitis. NO_X is also a precursor to ground-level ozone (smog) and can lead to acid rain, which can damage buildings and acidify lakes and streams.

NO_X emissions in Vancouver stem from a variety of sources. The primary sources are in the transportation sector (road vehicles and marine vessels) where significant decreases are expected in the coming years as a result of stricter standards on fuel content and vehicle engine technology. Non-road engines and the various commercial, institutional and residential uses of natural gas also contribute a significant proportion of NO_X emissions (Metro Vancouver, 2010).

Sulphur Oxides (SO_X):

This category of pollutant includes primarily sulphur dioxide (SO_2) and sulphur trioxide (SO_3). Ambient levels are reported as SO_2 equivalent. Atmospheric SO_X has been linked to an array of respiratory effects including bronchoconstriction and increased asthma symptoms. SO_X can react with other compounds in the atmosphere to form fine sulfate particles, which can penetrate deep into sensitive parts of the lungs, causing or worsening respiratory disease and aggravating heart disease (EPA, 2009). The sulphur content of wood is not chemically converted to SO_2 through combustion, however about 5% of the sulfur found in bark is. The emission rate amounts to 0.001-0.02 lb SO_2/million Btu energy if purely bark is burned (Oglesby et al., 1980). Because of the low sulfur content of wood, very low SO_X emissions are experienced unless the biomass fuel is contaminated by other substances.

SO_X emissions in Vancouver originate almost entirely (approx. 96%) from offshore marine vessels (Metro Vancouver, 2010). These are expected to decrease as new international emission standards and low-sulphur fuel requirements take effect in the coming years.

Carbon Monoxide (CO):

This contaminant causes health effects by limiting oxygen delivery to the body's organs and tissues. Extremely high concentrations (typically indoors) can be fatal to even the healthiest people. Low atmospheric levels can affect people with heart disease, causing chest pain and reducing their ability to exercise. At high levels, CO can affect the central nervous system. This may cause vision problems, impair a person's ability to work, learn, or perform complex tasks, and reduce manual dexterity (EPA, 2009).

CO also contributes to the formation of smog (ground-level ozone), which can trigger serious respiratory problems. The largest sources of carbon monoxide emissions in the City are non-road engines and light duty vehicles. In biomass combustion, CO is a product of incomplete combustion and can be effectively minimized by ensuring appropriate boiler design, operation and fuel preparation.

Volatile Organic Compounds (VOCs):

This is a class of organic compounds that participate in atmospheric photochemical reactions. It typically excludes methane, ethane, methyl chloroform, methylene chloride, and various CFCs (excluded because of their negligible photochemical reactivity). Their major sources are in the transportation sector and in the use of solvents, especially in paints and protective coatings. Concentrations of many VOCs are consistently higher (up to ten times higher) indoors than outdoors (EPA, 2009).

Health effects of VOCs vary depending on the compound. Some can cause a loss of coordination or damage to the liver, kidneys and nervous system. Others are suspected or known carcinogens (e.g. Formaldehyde). Symptoms of exposure include eye, nose and throat irritation, headaches, allergic skin reaction, nausea, fatigue and dizziness (EPA, 2009). VOCs also contribute to the formation of ground-level ozone by reacting with NO_X and can increase secondary $PM_{2.5}$ formation as discussed above. Polyaromatic Hydrocarbons (PAHs) are a related family of organic compounds of particular concern because they can persist in the environment and tend to bioaccumulate (increase in concentration as they move up the food chain).

In Metro Vancouver, VOC emissions stem largely from light-duty vehicles, non-road engines[1] and the use of consumer products[2] and commercial and industrial solvents (Metro Vancouver, 2010). With biomass combustion, VOCs are also a product of incomplete combustion and can be minimized with optimal boiler operation.

[1] "Non-road engines" include generators, backhoes, forklifts, lawn and garden equipment, recreational marine vessels, and railway maintenance equipment

[2] "Consumer products" include personal care, household, and automotive products such as aerosol products, household cleaners, toiletries, rubbing compounds, windshield washer fluid, polishes and waxes

Dioxins and Furans:

Dioxins and furans are extremely toxic compounds. Even in low concentrations, exposure to dioxins can cause skin problems, reproductive or developmental problems, and may even increase the risk of cancer. According to Health Canada, major sources include:

- the large-scale burning of municipal and medical waste;
- the production of iron and steel;
- backyard burning of household waste, especially plastics;
- fuel burning, including diesel fuel and fuel for agricultural purposes and home heating;
- wood burning, especially if the wood has been chemically treated; and
- tobacco smoke

While they are usually released into the air, these chemical compounds also bioaccumulate in the food chain. As a result, ninety percent of people's overall exposure to dioxins is estimated to be from their diet (Health Canada, 2005).

Salt-water contamination of biomass fuels is the major concern for dioxin formation since this provides a supply of chlorine. There is some indication that dioxin concentrations in the emissions from smaller boilers burning wood containing salt can be much higher than from large industrial boilers (Envirochem, 2008b). This is likely a result of the use of increasingly sophisticated emission controls (ESPs, Fabric Filters, etc) in larger applications. By limiting the chlorine content of the fuel and ensuring proper fuel handling, the risk of dioxin formation can be reduced.

Byproducts of Emission Controls:

Sometimes the application of one emission control will result in increases in another contaminant. This is usually because of byproducts of reactions in the flue gas or because of decreased combustion efficiency. The injection of ammonia, for example, to control NO_X emissions could lead to the formation of ammonium chloride which precipitates out in the atmosphere as flue gases cool, creating a visible haze. Thus acid gas controls are often employed to limit the availability of hydrogen chloride (HCl), which reacts with ammonium (NH_3). This speaks to the need for rigorous system design, giving special consideration to the specific components of the fuel.

4.2 Metro Vancouver & BC Regulations

In Vancouver, air quality falls under the jurisdiction of Metro Vancouver (formerly the Greater Vancouver Regional District) and emissions are regulated under the Air Quality Management Bylaw No. 1082, 2008. Under this bylaw, Metro Vancouver can establish generally applicable emission regulations and issue specific permits to control the discharge of air contaminants. With the introduction of the Boilers and Process Heaters Emission Regulation Bylaw No 1087 in 2008, biomass boilers or process heaters with a facility capacity of 50 MW_{th} or less no longer require a specific emission permit if they satisfy the emission regulation and pay the applicable emission fees. The emission regulation limits the concentration of filterable particulate matter from biomass boilers and process heaters to 18 mg/m^3 and opacity to 5%. It also requires a fee to be paid of $300 per tonne of PM and $50 per tonne of NO_X. This regulation does not place limits on any other contaminant discussed above, however, it does require the fuel moisture content to be less than 60% and chloride content cannot be greater than 0.05 percent dry basis. This should limit emissions of products of incomplete combustion (CO, VOCs, etc) as well as acid gases and dioxins to some degree.

Facilities larger than 50 MW_{th} require an Air Quality Permit from Metro Vancouver. To date, no biomass facilities have come in under the new regulation and no new permits have been granted. Seven existing permits in the region involve some level of biomass combustion and for the most part PM is the only contaminant controlled, limiting stack concentrations to 20 mg/m^3. Exceptions are made in applications within the wood products sector where VOCs and formaldehyde limits are included because of the increased risk of burning plywood and particleboard contaminated with glues and solvents.

The BC Environmental Management Act (EMA) administered by the Ministry of Environment includes a Wood Residue Incineration Regulation that limits PM to 50 mg/m^3 and opacity to 15%. This regulation does not apply within Vancouver since Metro Vancouver has been delegated authority under Section 31 of the EMA.

Facilities producing electricity over 50 MW_e[3] in BC are required to undergo an environmental assessment process through the BC Environmental Assessment Office. A 50 MW_e electrical plant would be equivalent to a thermal plant of 150-200 MW_{th}. A project of this size is unlikely within the city of Vancouver since local electrical generation at that scale is not a municipal priority. The city or a proponent of a biomass combustion plant could always opt into an environmental assessment process, though this may lead to unwanted delays and costs.

[3] Thermal megawatts (MW_{th}) and electrical megawatts (MW_e) are not equal measures of energy input. The production of 1 MW_e usually requires the equivalent of about 4 MW_{th} due to the inefficiency of steam-turbine generators and physical limitations associated with the conversion of thermal energy into work (the Carnot Cycle).

4.3 Regulations in Other Jurisdictions

The regulatory framework in the U.S. is much more complex and well-developed than in Canada. The U.S. Clean Air Act (CAA) is the federal law that establishes ambient air quality standards and regulates air emissions from stationary and mobile sources. Its focus with respect to stationary sources is on the regulation of *major sources* of emissions. *Major sources* are defined as a stationary source or group of stationary sources that emit or have the potential to emit 10 tons per year or more of a hazardous air pollutant or 25 tons per year or more of a combination of hazardous air pollutants (EPA, 2010a). The CAA also regulates *area sources*, which include any stationary source that is not a *major source*, though the specific permitting requirements are usually set by state or regional agencies. The EPA has proposed new National Emission Standards for Hazardous Air Pollutants (NESHAP) for both *major* and *area sources* under Section 112(d) of the CAA. It is unlikely that a district energy facility would fall under the *major source* category unless it was part of a much larger scale power plant. For biomass boilers, the new *area source* standards include emission limits on PM (0.03 lb/MMBTU or approx. 30 mg/m^3) and CO, as a surrogate for polycyclic organic matter including PAHs (EPA, 2010a).

States (or Tribal Governments) have the main responsibility of ensuring air quality standards are met. In "non-attainment" areas, they develop Implementation Plans to reduce air pollutants to allowable levels. States often establish regional permitting agencies, which develop locally relevant permitting procedures and policies. These agencies usually issue Title 5 Air Operating Permits, which bring together all applicable local, state, and federal regulatory and permitting conditions for a given site or project.

In Seattle, Washington, air quality regulations are administered by the Puget Sound Clean Air Agency (PSCAA). The PSCAA issues Air Operating Permits, which bring together all National, State and local emission regulations applicable to a given emitter. Seattle Steam Ltd. has one such permit, issued in 2002, that applies to its entire steam-generating operation. In 2009 the company applied for an Order of Approval to permit the construction and operation of a fluidized bed biomass boiler as a replacement to one of four existing natural gas- and oil-fired boilers. The specific limits imposed are summarized in Appendix B, but include limits on Opacity, PM10, NO_X, SO_X, CO, NH_3 (a product of SNCR NO_X reduction), and HCl.

In Minneapolis/St. Paul, the Minnesota Pollution Control Agency (MPCA) is delegated authority from the State (Minn. R. 7007.0800) to issue Air Emission Permits that include Federal and State requirements. In 1995, District Energy St. Paul applied for a new permit allowing the addition of a biomass CHP plant to their existing facility (consisting of 3 coal-fired and 3 gas/oil-fired boilers). The modification was considered “a significant net emissions increase for PM, PM_{10}, NO_X, and CO” and therefore warranted a “new source review”. The current permit (amended slightly in 2005) regulates Opacity, Total PM, PM_{10}, NO_X, SO_X, CO, and NH_3 (See Appendix B). The company submitted dispersion modeling to the MPCA that showed compliance with all ambient standards at full potential emission rates (MPCA, 2005).

The Massachussets Department of Environmental Protection is believed to administer the most stringent emission guidelines applicable to biomass combustion (included in Appendix B). They include emission limits for SO_X, NO_X, Ammonia, CO, PM, VOCs, HCl, and toxic metals. Their emission limits are 50-90% lower than Washington and Minnesota but are presumably not so low as to deter the adoption of biomass, as four large-scale 40-50 MW_e electrical generating plants are in the process of seeking approvals in the state.

5. Biomass Combustion and Emission Control

This section is intended to provide an overview of the technology and processes involved in biomass combustion for district energy. This is important knowledge for municipal planners and policymakers to have on hand to support engagement efforts around biomass. While the specific technologies and configurations employed are technical decisions made at the design stage, being able to effectively communicate, early on, the potential for existing and well-established technologies to control emissions can go a long way to alleviating public concerns.

Biomass combustion has a long history, even predating the use of coal, and the technology for efficient combustion is well developed. As concerns over the health and environmental impacts of air pollutants rose throughout the 1900's, new emission control technologies emerged and have been continuously improved. Today, Natural Resources Canada reports that biomass should be recognized as a clean, efficient, environmentally friendly and safe energy source (NRCan, 2008). This chapter gives a broad overview of currently-available technology, though no particular technology is universally ideal and this is not intended as an exhaustive list. The specific components and system configurations are most readily determined on a project-by-project basis, taking into account capacity requirements, fuel type, plant location, etc. Emission levels from particular systems can vary significantly depending on the technologies employed, the quality of the fuel, as well as operation and maintenance procedures. For this reason, establishing "typical emission levels" would not be easy or practically useful. However, lessons can be learned from existing facilities and from detailed feasibility studies conducted elsewhere. In general, modern biomass boilers perform well within emission limits set by regulatory agencies and can have a negligible impact on surrounding ambient air quality if adequate emission control technologies are employed.

5.1 Combustion Technology

There are two approaches to the use of biomass for district energy: direct combustion and gasification. Direct combustion is a proven technology approach employed across Canada using a variety of "waste fuels", such as hog effluent, sawdust and bark, woodchips, agricultural waste, municipal waste, sewage, and processed and domestic waste (Canadian Urban Institute, 2008). A 2008 study commissioned for Metro Vancouver established that "different boiler technologies and configurations can result in very different particulate matter (PM) emission profiles (before flue gas treatment), with gasifiers currently producing the lowest *uncontrolled* emissions." (Envirochem, 2008b). However, with the adoption of emission control technologies, air contaminants from direct combustion can also be effectively limited.

Direct-Fired Systems

Stoker Boilers

The most common boilers are traditional stoker grate boilers which employ direct fire combustion of biomass fuels with excess air, producing hot flue gases. These hot gases then produce steam in a heat exchange section of the boiler. Mechanical stokers automatically feed fuel onto a grate where it burns with air passing up through it. Ash residue is automatically removed after combustion and overfire air is added to complete combustion and minimize atmospheric emissions.

There are two general types of systems—***underfeed*** and ***overfeed***, referring to where the fuel is supplied from. Fuel type, load conditions and desired capacity are important considerations in selecting the correct size and type of stoker. The most common modern system is a spreader stoker, which is of the overfeed variety and throws or spreads fuel evenly over the grate area. The finer particles of fuel combust in suspension as they fall against the upward moving air. The remaining heavier pieces fall and burn on the grate surface, with any residual ash removed from the discharge end of the grate (EPA, 2007).

Modern boilers with spreader stokers incorporate:

- Equipment that distributes fuel uniformly over the grate.
- Specially designed air-metering grates.
- Dust collection and reinjection equipment.
- Forced draft fans for both undergrate and overfire air.
- Combustion controls to coordinate fuel and air supply with steam demand (EPA, 2007).

Fluidized Bed Boilers

Fluidized bed boilers are the most recent type of boiler developed for solid fuel combustion. They offer a variety of benefits but are significantly more costly to install (2-5 times the price of stoker boiler equipment) (EPA, 2007). Unlike typical 'stoker grate' boilers, where wood chips are simply burned as they pass along a rolling grate, the fluidized-bed boiler circulates the wood chips and burns them while they are suspended in a bed of hot incombustible particles within the combustion chamber. The scrubbing action of the bed material on the fuel enhances the combustion process by stripping away the CO_2 and solids residue (char) that normally forms around the fuel particles and increasing their exposure to oxygen. These systems also generate a steadier and more controllable heat output. Because of the longer residence time and high intensity of mass transfer, the fuel can be burned at lower temperatures (760 to 870° C compared to 1,200° C for a spreader stoker boiler), resulting in lower NO_X emissions. Where sulfur contamination of the fuel is an issue (e.g. in construction debris), limestone can be added to the fluid bed to increase sulfur capture and limit SO_X emissions.

Gasification Systems

Gasification of biomass is another way of converting wood residues into useable forms of energy. Gasification is the thermal‐chemical conversion of biomass under limited oxidation and moderate temperatures into low to medium energy content synthetic biogas or 'syngas'. Compared with direct-fired biomass systems, gasification is a more recent, less established commercial technology. It does, however, have a variety of advantages making it an increasingly adopted technology. These benefits are outlined by the EPA (2007) in their Biomass CHP catalog as follows:

- "A gaseous fuel is more versatile than a solid fuel. It can be used in boilers, process heaters, turbines, engines and fuel cells, distributed in pipelines, and blended with natural gas or other gaseous fuels.
- Gasification can remove fuel contaminants and reduce emissions compared to direct-fired systems.
- Gasification can be designed to handle a wide range of biomass feedstocks, from woody residues to agricultural residues to dedicated crops, without major changes in the basic process.
- Gasification can be used to process waste fuels, providing safe removal of biohazards and entrainment of heavy metals in non-reactive slag." (EPA, 2007).

However, because of the modifications required to accommodate the lower-BTU syngas, existing natural gas turbines cannot easily be retrofitted for its use. Gas turbines designed for low-Btu biogas generally cost at least 50 percent more than natural gas turbines on a per kW basis. The biogas' low-BTU nature may also make it less desirable for use with district energy systems that use steam distribution and thus rely on high temperature boiler outputs. Gasification holds the most promise for cogeneration at small scales, where the biogas can be used to produce heat and power in reciprocating engines.

Gasification is the technology used at the Dockside Green development in Victoria, BC. There, the boiler provides approximately 2 MW of thermal heat. It is also the technology being piloted at UBC's proposed cogeneration facility with a 2 MW electrical output. Because of Vancouver's abundant supply of relatively cheap hydro electricity, the local business case for cogeneration through gasification is not very good. Therefore any biomass district energy system proposed in Vancouver is likely to be based on direct combustion.

5.2 Emission Controls

Biomass boiler systems are complex installations with many components. The full system may include fuel storage, preparation and handling equipment, the boiler itself, induced and forced air fans, controls, water treatment systems, and varying levels of emission control equipment. Almost all installations will include cyclone separators to capture large fly ash and a baghouse for fine particulate matter (PM). NO_X emission control is usually provided by a selective non-catalytic reduction (SNCR) system using urea or ammonia that is installed in the top of the boiler. Other control equipment could also be included as well as the stack, ash handling equipment, and continuous emissions monitoring equipment if required (EPA, 2007).

The significant cost differential per unit of energy of wood versus natural gas leaves a fairly large margin to accommodate emission cleanup costs for boilers. There is, however, a diminishing rate of return on investment in emission controls. While it is technically possible to achieve very low emissions from wood combustion (e.g. <10 mg/m3 PM), the increased capital costs of emission controls and the need for full-time supervision to continuously maintain these levels limits their application. This section summarizes the emission control technologies available, how they work, and their financial implications. Technologies are also referenced by target contaminant in Appendix C – Quick Reference Guide: Biomass Air Contaminants & Emission Controls.

While only North American emission data are referenced in this study, European biomass combustion technologies and control systems are generally the same as those available here. For example, reported particulate emission rates for biomass-fired boilers in Denmark, where there is a well-developed biomass energy industry, are similar to comparable systems available in North America (Resource Systems Group, 2001).

Particulate Matter Controls

The technology employed for particulate removal depends heavily upon the capacity of the system and desired/necessary reductions. While the vast majority of total particulates can be removed through mechanical collectors, the remaining fraction becomes increasingly fine and more difficult to collect, driving up the cost per unit of collected particles. Based on manufacturer data, this area of rapid cost increases starts to occur at levels below about 30 mg/m^3 for ESPs (Envirochem, 2008b).

Mechanical Collectors:

Cyclones can be applied to separate particulate from gas streams using centrifugal force. A multiple cyclone is an array of many small cyclones in parallel. These collectors can remove as much as 90% of PM10 but have limited success (~70%) in removing the finest particulate (PM2.5) since they rely on the weight of the particles (ICAC, 2010). Their efficiency is also dependent on gas flow rates and their use requires regular cleaning to avoid plugging and preventative maintenance to avoid leaks. Because of the extremely fine nature of particulates from wood combustion, the success of mechanical collectors is limited in biomass applications. Cyclones are typically used as a pre-cleaning stage before flue gases pass through a fabric filter or electrostatic precipitator.

Fabric Filters:

Fabric filters or baghouses are widely applied in the combustion of both solid and liquid fuels. Essentially, they involve a collection of tightly woven fabric 'bags' through which the flue gas passes. With the correct design and choice of fabric, particulate control efficiencies of over 99% can be achieved even for very small particles (1 micrometer or less). The only limiting factor is maintaining appropriate stack pressures and ensuring continual maintenance (cleaning of bags).

Electrostatic Precipitators:

Electrostatic Precipitators (ESPs) use electrical fields to remove particulate from the flue gas. The electric field ionizes the gas, which subsequently ionizes the suspended particles. The electric field drives these charged particles to collecting electrodes, which are rapped mechanically (in dry ESPs) or sprayed with water (in wet ESPs) to dislodge collected particulate into hoppers for removal. Determinants of efficiency include gas velocity, proper design and timing to avoid re-entrainment, and the resistivity of suspended particles (their resistance to the flow of electric current). Overall collection efficiencies of ESPs in excess of 99.5% are common. Wet ESPs can also help remove acid gases and mists in addition to fine particulate, reducing opacity.

NO_X Controls

The goal of NO_x controls is the reduction of oxides of nitrogen (NO_X) to nitrogen (N_2) and water (H_20) vapour.

Selective Non-Catalytic Reduction (SNCR)

SNCR is a simple chemical process that uses a reducing agent (usually ammonia or urea) to reduce NO_x to molecular nitrogen. The reagent is injected into the combustion gases and at suitably high temperatures (1,600 -2,100 degrees F), the desired chemical reactions occur. Given the simplicity of this process, installation of SNCR is relatively easy. NO_x reduction levels ranging from 30% to over 75% have been reported (ICAC, 2010).

Selective Catalytic Reduction (SCR)

SCR uses a catalyst bed (usually involving base metal catalysts) to catalyze the reaction of NO_x with ammonia (NH_3), which is injected upstream of the catalyst bed. There are no moving parts, and other than spent catalyst, the SCR produces no waste products. By catalyzing the reaction, SCR improves efficiencies to meet control targets of over 90% in many cases (ICAC, 2010).

Acid Gas & SOx Controls

Scrubbers are systems that use absorption to remove pollutants from the gas stream. Sometimes referred to as flue gas desulfurization (FGD) systems, scrubbers rely on chemical reaction with a sorbent to remove sulfur dioxide and other pollutants including acid gases (e.g. HCl and HF), fine particulates and other air toxics (e.g. mercury).

Dry Scrubber

In a dry scrubber, particles of an alkaline sorbent (usually lime or sodium based) are injected into the hot flue gas. Pollutants come into direct contact with the atomized sorbent and are absorbed. The resulting dry material is collected in a downstream particulate control device (see above). Depending on their configuration, dry scrubbers are sometimes referred to as spray dryers, circulating spray dryers, or dry injection systems. These systems commonly provide removal efficiencies of 70-95%, >90%, and 50-70% respectively (ICAC, 2010). Dry scrubbers generally involve simple designs and low capital and maintenance costs.

Wet Scrubber

In a wet scrubber, a liquid sorbent is sprayed into the flue gas. Pollutants are dissolved into the liquid sorbent and a wet slurry waste or by-product is produced. New wet scrubbers routinely achieve SO_2 removal efficiencies of 95% (ICAC, 2010). According to the EPA, wet and dry scrubbers have been shown to reduce HCl emissions by 95% or more. Wet scrubbers also provide significant removal of HF, arsenic, beryllium, cadmium, chromium, lead, manganese, and mercury from flue gas (ICAC, 2010).

The recent conversion at **Seattle Steam** involved the installation of multiple emission controls. These included a fabric filter particulate collector, a selective non-catalytic reduction system for the control of NO_X, and limestone injection for control of SOx. An additional spray dryer was added when fuel tests revealed higher levels of chlorine than expected in the supplied wood chips. This alleviated concerns over HCl emissions reacting with Ammonia slip from the SNCR process, which would create a visible haze of ammonium chloride. Though not regulated, the company also injects activated carbon into the flue gases to remove any trace organic compounds such as dioxins & furans. While the system has not been operational long enough to evaluate its emission performance, the company is confident that the system will have no visible emissions and meet all the regulatory requirements set by the PSCAA (See Section 4.3 & Appendix B).

5.3 Effects of Fuel Type & Quality

There are a number of options when it comes to sources of biomass fuels. Table 1 provides a summary of available fuel sources in Metro Vancouver as well as air quality and environmental concerns associated with them. Because of variations in physical and chemical properties of the various fuel types, combustion and emission control equipment should be designed for the specific fuel to be used. This should include taking into consideration the fuel's moisture, ash, and chlorine contents as well as the fuel's physical characteristics (e.g. dry chips, sander dust, wet hog fuel, species, etc.) (Envirochem, 2008b). The properties of a given fuel source may vary because of poor quality control by the fuel supplier, changes in fuel availability, or swapping of fuel sources in response to price variations. In order to maintain consistently low levels of emissions, ongoing and high levels of operational monitoring and control are required as well as fuel management system that ensures fuel properties (sizing, moisture, ash and contaminant contents) are in line with the combustion and emission control process. For a discussion of the relative availability of these different fuel types, see Section 6.1.

Table 1: Summary of Available Biomass Fuel Sources

Source Type	Description	Air Quality Concerns	Other Environmental or Sourcing Concerns
Mill Residuals & Hog Fuel	Mostly used internally by wood industry. Wood chips are made from clean wood (bark-free). Hog-fuel is made up of regular-sized wood chunks from wood slabs, ends and other wood debris. Off-spec or contaminated wood chips are often downgraded to hog-fuel.	Moisture content can vary significantly. Hog fuel can be contaminated by sea salt, leading to dioxin emissions. Can have varying degrees of non-wood contamination depending on source.	
Construction Waste	Non-reusable wood ends and debris from building construction. Often grouped as Construction & Demolition Waste (CDW) since these streams are not currently separated.	Some residual wood may be pre-treated and/or otherwise contaminated.	The use of wood in building construction is decreasing as manufactured/engineered alternatives become cheaper.
Demolition Waste	Waste wood from building demolition that can't be recycled, often contaminated with non-wood material (nails, plastics, paint, dry wall, etc)	Non-wood material contamination can have serious health-impacting pollutants (eg. arsenic, mercury, lead).	Issues around quality control, contamination, proper characterization, and handling and combustion challenges make CDW a problematic fuel source. It is also legally considered municipal solid waste, so a handling license and burning permit would be required from MV.
Urban Forest Residue	Derived from land-clearing (for roads, infrastructure, construction, agriculture, etc.) and landscape maintenance (eg. tree clippings) .	Relatively clean source free of contaminants. May have varying moisture content.	This is a fairly limited fuel source, largely from suburban areas where new construction involves substantial land-clearing.
Manufactured Fuels (Wood Pellets)	Developed in an effort to commodify biomass fuel, wood pellets are produced (through drying and compression) to have standardized moisture-content and densities.	The content and characteristics of manufactured fuels are much more uniform. This allows for more efficient burning with lower operating costs and lower emissions.	Wood pellet exports from BC are rapidly increasing (mostly to European markets). As this market matures any fuel users in Vancouver would have to pay prices determined by international markets. The cost of pellets can preclude the use of advanced emission control equipment (e.g. beyond cyclones) for smaller units.

Data Source: Envirochem, 2008b

Regulations and permits dealing with emission controls often include fuel type limitations and specific definitions for what can and cannot be considered “biomass”. In Minneapolis/St. Paul for example the MPCA limits fuel use to untreated wood waste and agricultural waste (MPCA, 2005). Concerns related to contamination of C&D waste can be addressed through appropriate wood fuel quality control, sampling and testing procedures to ensure adequate removal of treated wood components, as well as conservative design of the emission control systems.

5.4 Varying Boiler Capacity

Smaller burners are especially sensitive to cost increases associated with air pollution controls. In some cases the capital cost of the emission control equipment can exceed that of the combustor itself. In addition, the operational requirements and fire-hazard posed by high-performance flue-gas cleaning equipment (e.g. ESPs and fabric filters) can require full-time supervision, precluding its use for smaller applications (Envirochem, 2008b). For this reason, the use of biomass in urban areas is best suited in larger-scale facilities (40+ MW_{th}) that can afford to install the best available control technology and thereby achieve the lowest economically achievable emission levels (see Table 2). Larger facilities also trigger more comprehensive regulatory processes (see Section 4.2), which, if they involve a public process, can lead to a greater sense of accountability and transparency.

5.5 Achievable Emission Levels

A 2008 study for the BC Ministry of Environment found that PM emissions from industrial sized wood fired combustors across the province ranged from 4 to 310 mg/m^3 with a median of 30 mg/m^3. This study identified the current range of PM emissions for boilers of various sizes and determined an "economically achievable limit" for each based on the cost of implementing air pollution control measures (See Table 2). What is “economically achievable” clearly varies depending on the end use of the heat energy and on market rates of biomass fuels relative to fossil fuels. The authors noted that lower limits may be desirable for facilities sited in urban centres or sensitive air sheds, but that such stringent requirements may require public funding or other subsidies (Envirochem, 2008b).

Table 2: Economically Achievable Emission Limits (2008 costs and technology)

Boilers and Furnaces				
Heat Input:	**40+ MW_{th}**	**3-39 MW_{th}**	**1-3 MW_{th}**	**<1 MW_{th}**
A.P. Controls	**ESP**	**ESP / Fabric Filter**	**ESP / Fabric Filter**	**Cyclone / Uncontrolled**
Current Range[1]	3 - 47 mg/m^3		59 - 221 mg/m^3	216 - 5,000 mg/m^3
Economically Achievable Limit	20 mg/m^3	35 mg/m^3	50 mg/m^3	120* mg/m^3
Rationale for E. A. Limit	Large units are less sensitive to higher cleanup costs. Achievable with a 3-4 field ESP.	Emission control equipment costs as much as boiler at about 5 MW size. Achievable with 2-3 field ESP.	Can be achieved with cyclone and 1-2 field ESP, but emission control costs may exceed combustor	Feasible with cyclone or two-stage combustor.
Even lower limits?	Technically feasible, but control cost starts to increase sharply below this limit.	Would require technology demanding constant supervision.	Would require technology demanding constant supervision.	Would discourage use of wood as a fuel. *If gasification technology or pellets are used then 70 mg/m^3 is achievable.
Note: Emission controls such as ESP and baghouses usually include cyclones as precollectors. The higher cost of pellet fuel relative to raw wood reduces opportunity to fund enhanced emission controls (e.g. beyond cyclones) out of the fuel cost savings at current natural gas / pellet price differentials.				

Source: Envirochem, 2008b

These "achievable emission limits" were identified in 2008 and used as the basis for Metro Vancouver's 20 mg/m^3 limit. Because of growing interest in biomass as a fuel source for electrical as well as thermal energy across North-America, technologies are improving rapidly and the cost of emission control equipment is going down. Information gathered by the City of Vancouver suggests that new biomass installations in the region are achieving much lower PM emissions, in some cases as low as 2.0 mg/m^3 (H. Haley, personal communications). Typically, emission control equipment manufacturers design systems to achieve significantly lower emissions than the specified permit limit in order to guarantee the required performance even under worse than design conditions. For example, measurements of PM emissions for wood combustors with ESPs in BC averaged 40% less than the permitted level (Envirochem, 2008b). Biomass plants are now in operation across the continent under much stricter emission limits than in Metro Vancouver (See Section 4.3). This suggests that lower emission levels are achievable without compromising economic viability.

The scale of the system strongly influences what emission control technologies are economically feasible. Thus capital costs are a consideration in defining the best available control technology (BACT) for a specific application. The total cost per unit of pollutant removed declines with increasing facility size, so a technology may be BACT for a large plant but not for a smaller one (Resource Systems Group, 2001). Consequently, concentrations of stack emissions from small process heaters and wood stoves are usually much higher than those of larger-scale boilers.

5.6 Effects on Ambient Air Quality

Stack concentrations, discussed above, refer to the concentration of contaminants in the flue gas coming out of the stack. Ambient concentrations, on the other hand, refer to the level of pollutants in the air around us. Local ambient air contaminant levels are the primary population health concern associated with emissions since they reflect the level of exposure experienced by residents. While health experts agree that there is no "safe threshold" for many air contaminants, standards and targets are set to avoid serious health impacts. Some level of air contaminants would exist in the atmosphere even without anthropogenic sources and lower levels have no measurable impact on the health of most residents. In the U.S., National Ambient Air Quality Standards are set and updated periodically by the EPA.

The impact of biomass emissions on local air quality can be influenced by the siting of the system, local wind patterns, and the pre-existing, background, air pollutant concentrations. Vancouver is fortunate to have significant air mobility and emitted pollutants are dispersed relatively quickly. A study commissioned by Metro Vancouver predicted that any appreciable change to ambient air quality would occur relatively close to a biomass emission source (within a couple of kilometers) (Envirochem, 2008a). The same study analyzed the potential ambient air quality impacts of biomass heating in the greenhouse industry throughout Metro Vancouver. Maximum predicted ambient concentrations remained well below Metro Vancouver objectives, with NO_X values of 72 μg/m^3 (MV Objective: 200 μg/m^3) and PM concentrations of 27 μg/m^3 (MV Objective: 50 μg/m^3).

The contribution of dispersed point sources (which may not be subject to emission control regulations) to ambient levels often dwarfs that of large-scale emitters that employ emission controls. PM emissions, for example from a single plant are minor compared to the aggregate impact of residential wood stoves, diesel trucks, etc (See Section 4.1).

5.7 Natural Gas vs. Biomass Pollutant Emissions

The conversion of existing fossil-fuel-based district energy systems to biomass is the simplest approach to incorporating biomass DE since the heat load is already in place to justify the capital costs of conversion. Opportunities for such heat source switches exist in Vancouver as outlined in Section 3.3. While the specific implications of a heat source switch should be established through detailed project-specific analysis, this section attempts to compare the contaminant emissions of biomass combustion against those of natural gas.

While natural gas does burn more cleanly than wood, its combustion still produces emissions of NO_X, CO, CO_2, VOCs, trace amounts of SO_2 and Particulate Matter (EPA, 2003). As in biomass combustion, emissions will increase with poor maintenance, however the increase in emissions as a result of poor maintenance is not as great for gas as it is for wood (Envirochem, 2008). Table 3 compares emission factors for two combustion systems, a natural gas low-NO_X boiler and a biomass system burning bark and wet wood employing an ESP. Emission factors are estimates based on averages of available data as of 2003 and do not necessarily represent the emissions from employing best available control technologies. Recent test data of wood-fired boilers operating in Metro Vancouver revealed significantly lower emissions of NO_X (30 g/GJ) and PM (9 g/GJ) (Envirochem, 2008b). While the actual emission rates will vary considerably depending on specific fuel and system characteristics, the relative magnitude of emissions is a useful starting point when comparing the two fuel sources.

Table 3: Comparison of Emission Factors

Contaminant	Emissions in g/GJ of Energy Input	
	Natural gas, commercial boiler, low NOx burner	Wood, (bark and wet wood), electrostatic precipitator
CO	35.4	258
NO_X	21.1	94.6
PM_{10}	3.2	17.2
$PM_{2.5}$	3.2	15.1
SO_X	0.3	10.8
VOC	2.3	7.31
CO_2	50,588	83,850

Source: EPA, 2003

To get a sense of how the heat source decision for a district energy system might influence emissions of these contaminants, the emission factors were applied to a hypothetical 50 MW_{th} input system. The results are shown in Table 4 and indicate that the use of biomass could have an appreciable effect on contaminant emissions, particularly with respect to PM, NO_X and SO_X. In the context of community-wide contaminant emissions this contribution is relatively small, though still signicant. The percent increases for NO_X and SO_X are inflated due to a lack of city-specific data on the impact of marine vessel emissions. As stated above, these estimates are based on *average* emission factors. New systems employing best available control technology consistently perform much better. Thus these values can be considered as upper bounds on potential emissions. Also, consistent with the discussion in Section 3.1, actual CO_2 stack emissions are higher for biomass combustion. However if we exclude these emissions because of the carbon-neutrality of biomass (as is suggested by the IPCC and EPA), selecting biomass over natural gas would avoid CO_2 emissions of 79,768 tonnes/year, which is just over 3% of city-wide emissions. These are avoided emissions of *new* CO_2 to the carbon cycle, whereas the CO_2 emissions from biomass combustion are already part of the atmospheric cycle (see Section 3.1).

Table 4: Potential Impact of 50 MW_{th} Biomass Boiler on Contaminant Emissions

Contaminant	Annual Emissions of 50 MW Boiler (Tonnes/Year)[1]		Increase from selecting Biomass (tonnes/year)	2005 City-Wide Emissions[2] (tonnes/year)	% Impact on City-Wide Emissions	Metro Vancouver Emissions (tonnes/year)	% Impact on Metro-Wide Emissions
	Natural gas, commercial boiler, low NOx burner	Wood, (bark and wet wood), electrostatic precipitator					
CO	55.8	406.8	**351.0**	71,339	**0.49%**	321,526	**0.11%**
NO_X	33.2	149.2	**115.9**	6,246	**1.9%**	44,156	**0.26%**
PM_{10}	5.1	27.1	**22.1**	937	**2.4%**	7,757	**0.28%**
$PM_{2.5}$	5.1	23.7	**18.7**	602	**3.1%**	4,699	**0.40%**
SO_X	0.4	17.0	**16.6**	117	**18%**	5,381	**0.31%**
VOC	3.7	11.5	**7.9**	10,233	**0.08%**	54,325	**0.01%**
CO_2	79,768	132,215	**52,447**	2,609,237	**2.01%**	14,685,350	**0.357%**

[1] based on EPA emission factors, assuming 8,760 hrs/yr operation at full capacity
[2] city-wide values do not include marine vessel emissions which are major contributors to levels of SO_X (~1800 tonnes/year) and NO_X (~2,000 tonnes/year) in the City
Source: EPA, 2003

6. Other Considerations

6.1 Fuel Supply & Availability

Uncertainty around the long-term availability and quality of biomass fuels is one of the deterrents to its use in DE applications. Cities are only beginning to tackle the challenge of waste-stream diversion and much of the urban waste wood that is potentially available could also be reclaimed or repurposed for reuse (e.g. for mulch, compost, etc). As yet, this is a relatively untapped local resource and its use could also create more local jobs (in waste stream diversion, for example). However, long-term availability of urban waste wood may be limited by a number of factors including the increased use of non-wood construction materials, a decline in land-clearing for development, or by competing uses.

Envirochem's 2008 study for Metro Vancouver analyzed the current availability of biomass supplies in the Region and throughout the Lower Mainland. The results are shown in Table 5, and demonstrate that demolition and construction waste is the largest local source of biomass. This is currently a relatively unexploited source, with most being disposed of in landfills. A Preliminary Study on Biomass Resources for Northeast False Creek District Energy System analyzed a Metro Vancouver inventory of the City's waste stream and determined that about 97,000 wet tones/yr were available (un-recycled and un-diverted). This would be enough to supply space heat and hot water to just under 10,000 homes (Flanders, 2010). The existing flow of manufactured wood fuel to international markets (currently 500 times the amount purchased in the Lower Mainland) suggests that the availability of this type of fuel is much higher.

Table 5: Biomass Fuel Source Availability in Metro Vancouver (2008)

	Annual Fuel Source Availability (2008)					
	Metro Vancouver			Lower Mainland		
Source Type	**Volume (m^3)**	**Mass (Tonnes)**	**Energy Content (MWh)**	**Volume (m^3)**	**Mass (Tonnes)**	**Energy Content (MWh)**
Mill Residuals & Hog Fuel	330,000	99,000	200,000	470,000	141,000	280,000
Construction Waste / **Demolition Waste**	1,880,000	265,000	1,190,000	2,000,000	282,000	1,270,000
Urban Forest Residue	196,000	176,000	44,000	1,100,000	100,000	250,000
Manufactured Fuels (Wood Pellets)	3,077,000	2,000,000	10,200,000	15,385	10,000	51,000
	estimated BC annual production (currently exported to Asia & Europe)			estimated pellet use (currently purchased in the Lower Mainland)		

Source: Envirochem, 2008a

While there is always likely to be substantial waste wood from the lumber, furniture, plywood and pulp industries, the quantity is dependent on the output of those industries and on industrial practices. For example, new methods of barking logs and producing pulp have reduced the quantity of forest byproducts available for fuel in recent decades. That being said, the renewable nature of biomass means that wood fuel can be continually replenished through proper forest management, leading to a sustainable and dependable supply. The maturing market for manufactured wood pellets, largely driven by European demand, is likely to encourage relative stability.

6.2 Public Engagement & Awareness

Perhaps the greatest barrier to implementing biomass combustion systems, particularly in urban areas, stems from negative public perceptions and associated political pressure. Public concerns are usually centered on air quality but may also include aesthetics, noise and traffic concerns. Emission factors for wood combustion are often cited without recognizing the ability of modern emission control technologies to reduce these by as much as 99.5% (See Section 5.2).

In 2007, City of Vancouver staff recommended biomass combustion as the heat source for the new SEFC Neighbourhood Energy Utility that would supply district heating to this new neighbourhood, including the Olympic Village. This recommendation was based mainly on the improved greenhouse gas emission performance of biomass and relatively low technical risk. At that time, this size of facility (5 MW_{th}) still required an air quality permit from Metro Vancouver, so the City initiated a public consultation process by filing a permit application. Advertisements were placed in local newspapers, the surrounding community and specific stakeholders received direct notifications and a series of open houses and information sessions were held over the course of a month. The results of this brief consultation assured staff that gaining permit approval on the project would not be possible within the schedule constraints of the SEFC project. The main concerns were identified in an April 13, 2007 council report as the:

- perception that wood combustion generates harmful emissions;
- perception that truck delivery of wood pellet fuel would have undesirable impacts; and
- concern that environmental impacts have not been adequately assessed.

Some concerns that were raised pre-empted staff knowledge at that stage in the project's design and implementation. These included:

- concern about appearance of the energy centre/stack;
- lack of detailed design information for the proposed equipment; and
- concern about lack of certainty of source and quality of fuel supply (CoV, 2007).

These are all concerns that have been discussed throughout this document and would likely be raised in any proposed biomass DE system. A study by UBC researchers analyzed the decision-making process at SEFC based on multiple criteria and the view points of different stakeholders. The results showed that with credible communication on variables (trucking volumes, particulate emissions/air quality, local fuel sourcing, secure fuel supplies, technology costs and ash disposal), the "best" energy source for the district energy system was different for different stakeholders (Ghafghazi et al. 2010). This was because of the varied weighting applied to each criterion, representing the values of each stakeholder. While the hypothetical stakeholders "Developer" and

"Community Group" both settled on biomass with natural gas ranking second, the "Environmental Group" preferred sewer heat recovery followed by geothermal. However, the study also determined that addressing concerns through efficient inter-stakeholder communication would result in a general consensus on biomass as the best energy alternative. This result points to a knowledge deficit and deficient communication as being key factors in the rejection of biomass in SEFC and the subsequent decision on sewer heat recovery.

Public involvement and engagement from an early stage is clearly critical to the success of a biomass-based DE project. A proactive approach to addressing anticipated impacts and committing to the use of best available control technologies can go a long way to alleviating concerns around air emissions. This was the case in Seattle, WA when Seattle Steam converted one of their 4 natural gas and oil boilers to biomass from urban wood waste. Concerned about opposition from residents and businesses in the surrounding high-density core, the company adopted technologies that went above and beyond what was regulated. One regulator described their approach as using both belt and suspenders. The result was almost no public opposition to the switch. This public indifference could be partially attributed to Seattle Steam's history of successful operation at this location and to the firmer, more encompassing emission control regulations in place (see Section 4.3). However, their commitment to the use of best available emission controls and communication with stakeholders before even approaching regulatory bodies is sure to have played a role.

In the case of SEFC, the compressed time-line associated with Olympic preparations made a full and thorough public process impossible. For future biomass DE proposals in the City, allowing sufficient time for a comprehensive public dialogue as well as possessing and sharing clearer information on the implications of the various heat sources under consideration can help to ensure balanced and informed decision-making.

6.3 Design & Land Use Considerations

Decisions about the location and design of a biomass facility can play a significant role in the level of public support or opposition for a project, and therefore its viability. Early integration of the following design considerations should be a priority at the planning stage:

Aesthetic Characteristics of the Plant and Associated Infrastructure

By virtue of its location within an urban area, the physical attributes of any industrial-sized facility can be severe. Integrating attractive elements such as public art pieces, transparent components, colour, etc. can reverse the perception of a biomass facility from that of a scar on the neighbourhood to a treasured piece of the urban fabric. Integrating engaging features such as portholes, displays or other visual communication of the facility's operations can add interest to a neighbourhood and help educate and connect people to the energy they use.

The design of the NEU facility in **SEFC** includes elements that engage pedestrians with the system. Portals allow a view of underground piping and extensive glazing exposes the boiler system. The design also features five finger-like stacks tipped with led panels that light up and change colour to reflect current energy production (blue for low, red for high). Built under a bridge, the facilty adds interest to a previously undesirable space and encourages the passer-by to reflect on energy use and production.

Implications on Neighbourhood Permeability and View Corridors

Even the most well designed combustion facility with no visible emissions will involve a fairly massive building and a stack of some type. How these impact the day-to-day experience of surrounding residents and visitors is another important consideration. Designing the site with some level of pedestrian permeability can also add to the potential level of engagement and education.

Impacts on Traffic and Transportation Infrastructure

As a solid fuel, biomass requires additional on-site storage and transportation infrastructure, usually involving trucks. As discussed in Section 2.3, increases in truck traffic on surrounding streets can be substantial. When located in a built up urban area, this can be a major barrier to acceptance. Having full understanding of a facility's potential impacts and well developed strategies for mitigating conflicts is vital. This could include timing deliveries to avoid peak traffic volumes, designing the site to accommodate varying levels of fuel, or locating it near alternative transportation networks (e.g. rail, port, etc).

Seattle Steam's recent conversion to biomass involved the construction of a new fuel handling and storage facility on a property across the street from the actual combustion unit. An auger system transports fuel from a silo in this facility under the street to the boiler. While this does have cost and maintenance implications, it also helped break up what would otherwise be a land-intensive facility, retaining street mobility and allowing people to essentially walk through the system. If the facility had been designed with more transparent components or viewing areas, engagement could have been further improved.

Conflicts with Neighbouring Land Uses

Noise and vibration concerns need to be addressed as well as air quality concerns. Since the majority of air quality impacts occur within close proximity to a plant (See Section 5.6), locating it further away from vulnerable populations may be preferred if possible. Noise impacts can be mitigated through a variety of design elements: enclosing equipment, using vegetation, etc.

Through thoughtful site design of their new wood handling facility, **Seattle Steam** was able to contain on-site truck movement and mechanical transport of the fuel to the interior of the newly constructed building. This effectively eliminated noise and dust impacts. Municipal support was needed in the form of a variance to allow wider curb-cuts and reduced setbacks.

7. Conclusions and Recommendations

If cities are to adequately address the challenge of climate change and transition towards a post-fossil fuel future a new approach to the provision of energy is needed. Ensuring a sustainable supply of energy based on a diverse set of renewable resources must be the foundation of this approach and may require tradeoffs with other livability objectives. The development and expansion of district energy systems are quickly becoming central strategies of community energy planning efforts across the continent because of their capacity to improve efficiencies and reduce the energy intensity of local economies. Woody biomass combustion has the potential to effectively reduce the carbon-intensity of these energy systems: lessening our reliance on fossil fuels and curbing emissions of fossil fuel-based carbon.

Public perceptions surrounding the impacts of biomass combustion have the potential to dissuade its adoption as a fuel source for district energy systems. This is particularly true in urban areas, where conflicting land uses may exist and where ambient air quality may already be impaired. However, from a community-wide greenhouse gas emission standpoint, the use of biomass in place of natural gas can have significant long-term GHG reduction benefits, helping cities achieve mandated and/or voluntary emission reduction targets. This leaves policymakers in a potentially contentious area where benefits and drawbacks need to be carefully assessed and communicated. Key to this challenge is being able to evaluate and communicate the relative magnitude of impacts and necessary tradeoffs.

This study looked at the experiences of implementing biomass district energy facilities in other North-American cities as well as technical and regulatory information related to air quality impacts and other considerations both locally and abroad. Based on this, the following conclusions, applicable to energy planners and policymakers across Canada, were established:

1. While there is some controversy over the carbon-neutrality of biomass combustion, it is at least a sustainable, renewable, carbon-lean fuel source. Biomass-related CO_2 emissions represent an acceleration of the carbon cycle but they avoid the release of new, sequestered fossil fuel carbon. Since these carbon emissions are not counted in GHG emissions inventories, the potential of biomass to take large chunks out of community emissions makes it a very attractive energy solution.

2. Climate change-related benefits are increased through the use of urban waste wood that would otherwise go to a landfill. Landfilled wood decomposes in an anaerobic environment, releasing methane. Even when captured to a large degree, methane that escapes from a landfill can have a much stronger climate forcing effect than the equivalent CO_2 emissions from combustion.

3. Through the use of modern boiler and emission control technologies, emissions of health-impacting air contaminants from biomass combustion systems can be drastically reduced to the point where even localized impacts on ambient air quality are minimal.

4. Burning biomass as opposed to natural gas is not *always* the best solution. Much depends on what type of biomass is burned, what type of combustion system is used, what emission controls are employed, how forests are managed and how the industry is regulated.

5. The current regulatory framework applicable in Vancouver limits only the emission of particulate matter from biomass boilers. While PM is the primary health concern, other jurisdictions also set limits for NO_X, SO_X, CO, and products of emission controls (NH_3). The strength and breadth of regulations may influence perceptions of public safety and accountability.

6. Addressing legitimate stakeholder concerns and misconceptions at an early stage can help to ensure a balanced decision-making process when selecting a heat source for a district energy system. This can be achieved through:
    a. effective communication of expected impacts (both in terms of GHG reductions and air quality impacts), including methods of evaluation and assumptions as well as the need for tradeoffs;
    b. assurances that strong regulatory, management and monitoring systems are in place;
    c. allowing sufficient time in the planning process for a thorough public dialogue and technical analysis of potential impacts; and by
    d. being able to point to real-world success stories, where emissions have been effectively controlled and a dependeble fuel market has emerged (e.g. Minneapolis-St. Paul, Charlottetown, Seattle).

Recommendations:

Based on the above conclusions it is proposed that the City:

1. Continue to monitor and assess the success of biomass applications in other communities including achieved emission levels, public support, and impacts on local waste streams and biomass resources;

2. Develop relationships with industry and regulatory agencies to stay up to date on best available emission controls and emerging technologies;

3. Work with Metro Vancouver to improve ambient air quality monitoring across the city in the interest of identifying areas where actions are needed to improve air quality and/or where additional point sources (such as a biomass plant) may be inappropriate;

4. Pursue opportunities for increased regulatory influence over biomass-powered district energy systems that would include emission limits for more than just particulate matter through:
    a. partnerships or negotiations with Metro Vancouver to establish an alternate regulatory structure or strengthen conditions of applicable air quality permit(s);
    b. the adoption of self-imposed policies for systems operated by the City of Vancouver under the Vancouver Charter; or
    c. contractual obligations with private utility operators;

5. Package proposals for biomass combustion with bylaws to support the reduction of non-point source emissions that contribute a larger portion of city-wide emissions (e.g. banning older wood stoves, regulating non-road emission sources, requiring retrofits to older diesel truck engines on city streets, etc). This would help demonstrate the City's commitment to maintaining good air quality while putting biomass-related emissions in context with other, more significant sources of contaminants;

6. Support the development of a stronger waste-wood fuel-supply market through:
    a. improved diversion rates of combustible wood waste;
    b. the support of biomass-based pilot projects; and by
    c. increasing the integration of policies for solid waste management and the provision of neighbourhood energy in the interest of achieving mutual benefits;

7. Acknowledge the long-term supply constraints on waste-wood and uncertain environmental impacts of manufactured wood pellets by prioritizing other low-carbon solutions (e.g. sewer heat recovery, geoexchange, etc) in locations where they are economically feasible;

8. Conduct a formal or informal survey of residents to gauge public awareness and opinion regarding future energy needs, alternative energy solutions (including biomass combustion and district energy) and perceptions of air quality impacts. This could be part of broader consultation initiatives related to sustainability, energy planning, or the Greenest City initiative;

9. Approach any proposed district energy project in a way that engages the surrounding community at an early stage in decisions on the heat source, location, and design of the facility; and

10. Encourage and support the development of a sustainably-managed and well-regulated biomass fuel-supply market in BC.

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Appendix A - Quick Reference Guide: Case Studies

Case Study / Source	Seattle Steam	Charlottetown, PEI	Minneapolis-St. Paul	Dockside Green, Victoria, BC	Richmond Plywood, Richmond, BC
Year Completed	2010	1997	2003	2009	2008
Biomass Boiler Capacity	25 MW	22MW	CHP (33 MWe, 65 MW thermal)	2 MW	30 MW
Boiler Type	Fluidized bed	Direct Combustion	Vibrating Grate	Gasification	Wellons Green Fuel Combustion Cell
Distribution System	Steam (converted to hot water for some buildings)	Mainly Hot-water, Steam for Hospital	Hot-Water	Hot Water	n/a
Estimated Cost:	$25 million	$25-30 million	$75 million	$6 - $8 million	
Physical Size / Appearance:	biomass boiler installed in existing downtown steam plant + storage structure behind Four Seasons Hotel	Large, plain industrial building on river front in existing industrial area	Built into existing 1906 brick power plant downtown	"small architecturally designed and aesthetically pleasing building"	Large steel-clad industrial building within existing facility
Buildings Served	~200 buildings	125+	180 downtown buildings + 300 single-family homes	2,500 residents	n/a
Fuel Input:	91,000 tons (250/day) 20 truckloads/day	66,000 tonnes (municipal waste & wood waste)	250,000 tons [14,000 truckloads/year] 40-50 truckloads per day	3000 tonnes	
Fuel Type:	Wood Chips (sourced from land clearing, clean urban wood waste, and composting debris "wooden bits")	Combined system: 41% waste incineration, 42% waste wood	Urban Waste Wood Chips (occasional forestry residue) Ground and screened in Wood-Recycling Centre	Urban Waste Wood Chips (construction demolition wood and tree trimmings)	mixture of bark, green veneer trim, and sanderdust residuals produced on site
Emission Controls:	SNCR (NOx), limestone injection (SOx), fabric filter (PM), spray dryer (HCL), injection of activated carbon (Dioxins/Furans)		SNCR (NOx)	gasification results in very low particulate emissions (20 mg/scm)	Dry Electrostatic Precipitator (DESP)
Emissions Info:	NO_X - 11.7 lb/hr CO - 11.7 lb/hr SO_2 - 4.0 lb/hr PM_{10} - 2.9 lb/hr	levels of NOx & SOx reduced relative to fuel oil system		20 mg/m^3 PM	20mg/m^3 PM
Regulatory Authority	Puget Sound Clean Air Agency				Metro Vancouver (Permit)
Neighbourhood Context/Public Process	Located in urban core. Existing steam plant consulted neighbours early and worked to address concerns with emission control measures.		Displaced coal-generated power, had existing plant site		Existing industrial facility
Challenges to Implementation	No real opposition. Need to educate whole supply chain to be quality concious. Some trouble with fuel management system (auger jamming)	access to right-of-ways	Resource supply partnerships, chipping and screening equipment, trucking logistics		

Appendix B - Quick Reference Guide: Regulations

		Metro Van	BC MOE	US EPA	Seattle, Washington	Minneapolis/St. Paul	Massachusetts
	Type of Regulations:	Regulated through Air Quality Management Bylaw No. 1082 and Boiler Emission Regulation No. 1087. Boilers >50MW must apply for permit.	Waste Discharge Regulations under the Environmental Management Act require a permit for the "burning or incineration of wood residue" (outside of GVRD) The Wood Residue and Incinerator Regulation	Clean Air Act [Code of Federal Regulations, Title 40, Volume 6, Part 60]	Permit issued by Puget Sound Clean Air Agency	Permit issued by Minnesota Pollution Control Agency	Emission Guidelines for Biomass
	Applies to Boilers of Capacity:	< 50 MW	> 50 tonnes/hour*	>29MW	Specific Permit for Seattle Steam Plant (25MW biomass & 3 Natural Gas/Oil boilers) updated by Notice of Construction Worksheet in 2009	Specific Permit for District Energy St. Paul facility (3 coal-fired, 3 oil/gas fired and 1 biomass CHP)	
Primary Polutant Category	**Maximum Opacity**	5%	15%	20%	20% for any 6-minute period or 5% for any 1-hour average	20% on a 6-minute average, except for one 6-minute period per hour of not more than 27%	5%
	Total Particulates (PM)	18 mg/m^3	50 mg/m^3	13 ng/J heat input or 1% of the potential combustion concentration	n/a	0.03 lbs/MMBTU (31 mg/m^3)	0.012 lb/MMBTU (~12mg/m3)
	Inhalable Particulates (PM_{10})	n/a	n/a	n/a	0.010 gr/dscf (23 mg/m3) AND 12.8 tons for consecutive 12 months	0.03 lbs/MMBTU (31 mg/m^3)	n/a
	Fine Particulates ($PM_{2.5}$)	n/a	n/a	n/a	n/a	n/a	n/a
	Oxides of Nitrogen (NO_x)	n/a	n/a	129 ng/J heat input	85 ppm (160 mg/m^3) 24 hour ave. AND 51.1 tons over 12 month period	0.15 lbs/MMBTU (155 mg/m^3) AND 1.6 lb/MW hour, based on a 30 day rolling average	0.015 lb/MMBTU (~15 mg/m^3)
	Sulphur Oxides (SO_x)	n/a	n/a	340 ng/J heat input	16.0 ppmdv (42mg/m^3)	1.2 lbs/MMBTU (1237 mg/m^3) AND 39 tons/year , based on a 12 month rolling sum	0.02 lb/MMBTU (~20 mg/m^3)
	Carbon Monoxide (CO)	fuel moisture content < 60%	n/a	n/a	92 ppmdv (105 mg/m^3) over 24 hours AND 51 tons over 12 month period	0.3 lbs/MMBTU (309 mg/m^3)	0.01 lb/MMBTU (~10 mg/m^3)
	Volatile Organic Compounds	n/a	n/a	n/a	n/a	n/a	0.01 lb/MMBTU (~10 mg/m^3)
	Polyaromatic Hydrocarbons (PAH)	n/a	n/a	n/a	n/a	n/a	n/a
	Dioxins/Furans	fuel chloride content < 0.05%	n/a	n/a	n/a	n/a	n/a
	Ammonia (NH_3)	n/a	n/a	n/a	25.0 ppmdv (17.4 mg/m^3)	25.0 ppmdv (17.4 mg/m^3)	2 ppm at 3% 0_2 (~0.51 mg/m^3)
	Hydrogen Chloride (HCl)	n/a	n/a	n/a	0.004 lb/MMBtu of heat input	n/a	20 ppm at 3% 0_2 (~1.08 mg/m^3)
	Fuel Source Regulations/Guidelines	permit required for the burning of demolition waste or other municipal solid waste containing materials other than uncontaminated wood waste	n/a	n/a	Wood fuel monitoring plan required as condition	Fuel use limited to untreated waste wood & agricultural waste.	metals testing required if fuel contains construction & demolition (C&D) wood
	Enforcement & Monitoring	emission testing of filterable particulate matter once each calendar year; maintain accurate records of the type, source and amount of fuels burned	continuous stack monitor required for total particulates/opacity and manual sampling once per year for PM_{10} and CO_2	enforced by regional/state authorities	Continuous Emission Monitoring System for CO, NOX and O2. Monthly visibility/opacity inspections Quarterly Facility-wide inspections Annual PM test	Continuous Emission Monitoring System for Opacity, SOX, NOX, O2, CO, and NH3. Various reporting and performance test requirements.	Continuous Emission Monitoring System for Opacity, SOX, NOX, O2, CO, and NH3. Annual PM. Metal testing if using C&D wood.
	Other Notes:		"wood residue incinerator" is defined as a combustion facility which includes combustion controls and particulate collection equipment for the destruction of wood residue but does not include a pulp mill wood-fired boiler, a wood-fired boiler that generates electricity, a beehive burner or an unmodified silo burner * Facilities larger than 50MW would also require an environmental assessment		G20HCl is likely from contamination from ocean air & municipal water sprinklers All emission limits corrected to 7% O_2 1lb/MMBTU assumed equivalent to roughly 1031 mg/m^3	These emission limits apply to Boiler 7 (the CHP boiler) when burning biomass specifically. Required to have an Operation and Maintenance Plan for all air pollution control equipment. 1lb/MMBTU assumed equivalent to roughly 1031 mg/m^3	Toxics - arsenic, antimony, beryllium, cadmium, chromium III, chromium VI, copper, lead, mercury, nickel, and selenium (wood containing C&D wood): 85% removal of mercury and 99% removal of the other metals, or reduce emissions below the detection limit. 1lb/MMBTU assumed equivalent to 1031 mg/m^3
	Info source:	MV Air Quality Management ByLaw No. 1083 MV Boiler Emission Regulation No. 1087	BC Environmental Management Act, Wood Residue Incinerator Regulation, 1995 (B.C. Reg. 519/95) Envirochem, 2008. Emissions from Wood-Fired Combustion Equipment		Notice of Construction Worksheet Reg. No. 13786	EPA 40 CFR 60 Minn. R. 7007.0800 MPCA - Air Emission Permit No. 12300063-003	Envirochem, 2008. Emissions from wood fired combustion equipment.

Appendix C - Quick Reference Guide: Air Contaminants & Emission Controls

Primary Polutant Category	Key Components	Key Characteristics / Health Concerns	Emission Control Measures	Goal of Emission Control Measures
Particulates (PM_{10} & $PM_{2.5}$)	Carbon (soot) Unburned Wood Dust Polyaromatic hydrocarbon (PAH) compounds Semi-volatile organic compunds (e.g. Tars and Condensibles) Ash (minerals, dirt and dust)	PM_{10} - "Inhalable" $PM_{2.5}$ - "Respirable" - Fine particles, capable of pentrating deep into the lungs Major contributor to smog (heart and respiratory problems) and acid rain Can be bound to by caricinogenic compounds (eg. Diesel fumes) or include hazardous air pollutants	Cyclones Electrostatic precipitators (EPS) Fabric filters (baghouses)	Filter/precipitate out particulates
Oxides of Nitrogen (NO_x)	Primarily NO and NO_2	Respiratory concerns related to the formation of nitric acid and nitrates Cause or worsen potentially fatal respiratory diseases such as emphysema and bronchitis	Staged combustion Flue gas recirculation Selective (non-)catalytic reduction [S(N)CR]	Reducing flame temperature without compromising efficiency. Reduction to elemental N_2 through reaction with ammonia or urea.
Sulphur Oxides (SO_x)	Primarily SO_2 (minor amounts of SO_3)	An array of adverse respiratory effects Wood has an inherently low sulphur content (so SOx is only an issue if fuel is contaminated)	Scrubbing (may be counter-productive by reducing combustion efficiency thereby increasing emissions of NOx and VOCs) limestone injection (fluidised bed only)	Almost never applied (wood is an inherently low-sulphur fuel)
Carbon Monoxide (CO)	CO	Indicator of incomplete combustion Limits oxygen supply to organs and tissues Cardiovascular effects Central nervous system effects	Good combustor design Fuel preparation (drying & sizing) Good operation (bed mixing, etc) Good air supply and distribution	Ensuring adequate air-supply & fuel-air contact Maintaining combustion temperatures (avoiding quenching)
Volatile Organic Compounds (VOCs)	Class of organic compounds which participate in atmospheric photochemical reactions	Various health concerns depending on specific compound: e.g. damage to liver, kidneys, and nervous system; carcinogenic; eye, nose and throat irritation; headaches, allergic skin reaction, nausea, fatigue and dizziness; Contribute to the formation of Ground-Level Ozone (Smog)	Various operational controls (see CO)	Ensuring complete combustion & breakdown of organic components
e.g. Polyaromatic Hydrocarbons (PAHs)	Various two or three ring aromatic compounds	Persistent in environment and tend to bioaccumulate		
Dioxins/Furans	75 cogeners of polychlorinated dibenzo dioxins 135 cogeners of polychlorinated dibenzo furans	Skin problems Reproductive or developmental problems May increase the risk of cancer	Fuel source controls (limiting salt-contant)	Reducing chlorine content of fuel source