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Fire in the *woods* or fire in the *boiler*?

A new tool to help rural communities determine if forest biomass from wildfire abatement can sustainably fuel a district heating system

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EXECUTIVE SUMMARY

Many rural British Columbia (BC) communities are at risk from wildfire, and the level of that risk is rising due to number of factors. Climate change impacts such as increased average summer temperatures and longer periods of drought, coupled with large areas of dead forests left by the mountain pine beetle epidemic, are creating fuel sources for potential fire outbreaks. The risk of wildfire damage to human property and infrastructure is also increasing as the population living in the wildland/urban interface expands.

Many of these same communities are simultaneously faced with increasing heating costs due to fuel-price hikes and rising energy demands as their populations grow. Fifty-seven communities in BC are off both power and natural gas grids, and more than 60% of the province's land base is not connected to the natural gas grid. Even if connected, communities in Vancouver Island and in the Prince George – Prince Rupert corridor pay costly premiums compared to natural gas prices paid by Lower Mainland communities.

However, surrounding these communities is an alternative, local, low-carbon heating fuel that may hold the solution: forest biomass. This paper explores the opportunity to combine community wildfire risk abatement with bioenergy development – integrating both climate change adaptation and mitigation measures. Additional co-benefits to this approach include: 1) reduced community energy expenditures; 2) the creation of local jobs; and 3) increased community energy security. Harvesting of forest biomass, however, needs to be managed to ensure ecological sustainability and thus maintain its availability over the long term.

This study involves researchers from the University of British Columbia (UBC), and two BC-based non-profit organizations, the Community Energy Association (CEA) and the Wood Waste to Rural Heat Project (formerly the Green Heat Initiative). The partnership marries forest ecology modelling with expert knowledge on alternative energy technologies and effective outreach, to help bridge the gap between planning and implementing alternative energy sources for small communities that may lack the capacity to conduct such feasibility studies themselves.

The three rural BC communities of Burns Lake, Invermere, and Sicamous were chosen as sites to conduct forest-fuel supply simulations while monitoring for ecosystem and soil health. These communities serve as representative examples of ecological regions that account for much of the forested area across BC: the Shuswap, the Kootenays, and the North Interior. Maps have been created showing each community's wildland-urban interface area with quantified estimates of the sustainable biomass generated when using three different management scenarios of varying tree density and woody debris clearing frequency. In addition, the communities were visited by members of the research team in 2011-2012 to assess the on-the-ground bioenergy potential.

At the three sites, it was discovered that using forest biomass generated from wildfire risk control would reduce energy costs, create local jobs, and reduce greenhouse gas (GHG) emissions, with the gains in each parameter depending on the area under active management. However, the dimensions of such gains depend greatly on forest type and area under management.

Ecosystem health should be closely monitored in some of the most intensive management schemes in young and slow-growing forests to prevent soil degradation, as is demonstrated for some stands in Invermere and for most of the forests surrounding Burns Lake. All things considered, the economic, social and environmental benefits of linking wildfire prevention with bioenergy generation make this option worth exploring.

Many rural communities in BC will be able to utilize the information presented in this paper to help make biomass an integral part of their energy supply profile. The results and experience gained through the work has been synthesized in a calculator tool, now freely available online, for initial screening-level assessments: the Fire Interface Rural Screening Tool for Heating: FIRST Heat. It is freely available at (http://www.communityenergy.bc.ca/) This easy-to-use Excel spreadsheet contains a vast ecological library of different forest types, conditions and forest management style data. By inputting their own site-specific economic, social and engineering parameter values, users can estimate the amount of sustainable biomass available for district heating systems from wildfire risk reduction activities. The tool combines biomass data with energy data to calculate the potential size and capital cost of the biomass boiler, potential energy savings, job creation, and reductions in GHGs compared to fossil fuels that provide the same heating capacity.

Data from FIRST Heat should be used to provide a proof of concept for a biomass district heat project, which can then serve to start a discussion inside the community about the suitability (or not) of this approach. A rigorous examination/feasibility/design process will then be required before a community can decide to proceed to install a new district heating system. The role of the tool is therefore to help community managers explore at an early stage the complexities of implementing district heating systems that would be fuelled by biomass from wildfire risk-abatement operations.

To use FIRST Heat, communities require knowledge of the following:

- A general understanding on how forest biomass heating systems work.
- The present and future wildfire risk in the surrounding forests, taking into account climate change.
- The community-wide consensus on the level of acceptable wildfire risk, which will determine the forest management approach taken in the urban/wildland interface.
- The ecology of the forests surrounding the community, as not all forest types are suitable for biomass removals.
- Information on present and possible future energy costs at a community level, and on funding available for installing district heating infrastructure.
- The main local energy consumers, and the potential future growth of community energy demands.
- The probable timescale for construction operations including below-ground systems (installation of district heating pipes, and disruption to existing infrastructure including cable TV, potable and waste water distribution systems, power and gas lines) as well as major building renovations.

1. INTRODUCTION

Carbon dioxide is the most abundant and significant greenhouse gas produced by human activities. Federal government studies suggest that the most cost-effective solutions for reducing carbon emissions from buildings involve minimizing energy usage, maximizing efficiency, and switching to lower-carbon-content fuels[1]. However, some studies suggest that fuel switching could play a larger role than energy efficiency in reducing greenhouse gas emissions[2,3]. In BC Interior communities, space and water heating are among the major contributors to GHG emissions.[4,5] By focusing on low-carbon heat sources, such communities could reduce their dependence on fossil fuels. For example, carbon emissions associated with space heating for the City of Prince George could be reduced by approximately 11%[1] by switching to low-C fuels. This would take the city one third of the way towards meeting the provincial emissions reduction target for 2020 (33% below 2007 levels). Both the city and the University of Northern British Columbia are well down this path with investments in biomass energy systems on campus and downtown.

Many BC residents and businesses, mostly in smaller communities, still heat their buildings with heating oil or propane using over 11 million GJ costing approximately $330 million per year (assuming $1.25/Litre for heating oil and $23.20/GJ for propane) and more than 60% of BC's landbase is not connected to the natural gas grid[6]. Among the regions that have natural gas access, communities connected to the Vancouver Island and Prince George-Prince Rupert pipelines have to pay a premium of 25% and 50%, respectively, above the prices paid by communities in the Lower Mainland[7,8,9], as the cost of natural gas is only about one third of the total cost with delivery, handling and midstream charges accounting for the remainder. In addition, 57 communities in BC (many of them First Nations villages) are disconnected from both power and natural gas grids[10]. Therefore, propane, diesel, and heating oil have to be transported from the main population centers to such communities, and represent expensive energy sources for heating. In contrast, wood is considerably cheaper. Under current residential prices for example, propane is two-to-three times more expensive than wood pellets (the most expensive form of biomass – see Table 1). Moreover, the long-term trend is for fossil fuel prices to rise, putting additional pressure on local economies.

Communities that border BC's interior forests are also vulnerable to natural disasters such as wildfires. Events such as the Kelowna and Barriere wildfires of 2003, the West Kelowna wildfire of 2009 (Figure 2), and the Peachland wildfire of 2012 point to a disturbing trend common to all North America: increases in both burned area and overall damage caused by wildfires. [11,12,13,14] This trend is caused not only by higher temperatures and longer dry periods, but also by the growth of suburban areas that are in direct contact with the surrounding forest, constituting what is referred to as the wildland-urban interface area. Forest, parkland, and agricultural landscapes of BC are now scattered with buildings and infrastructure vulnerable to wildfires[15], due to the growing popularity of the rural lifestyle. As a consequence, the wildland-urban interface area is growing rapidly (Figure 1).

Communities around BC (especially in the Interior) are implementing preventive forest management to reduce the risk of wildfires. However, these activities generate woody debris from the reduction in stand density, which needs to be disposed of securely.

Figure 1: Air photo showing wildland-urban interface area in rural southwestern BC. Source: UBC-CALP.

Figure 2: Wildfire in the wildland-urban interface area in West Kelowna in 2009. Source: Community Energy Association.

The challenge for planners and local managers in rural BC then is multi-fold: how to reduce wildfire risks and keep communities safe and attractive for locals, newcomers, and visitors, while at the same time keeping energy costs low and reducing carbon emissions. These requirements are not independent of each other. It is estimated that sustainable forestry methods in BC could produce enough biomass to replace about 30% of fossil fuel energy used in the province. This estimate would be larger if the timber from trees killed by the mountain pine beetle outbreak was used, reaching a total of 28.1 million dry tonnes per year, or about 50% of the fossil fuel energy currently used in BC [16].

Although these figures are striking, BC´s biomass potential is far from being fully utilised. Challenges and possible barriers include: accessibility, operation costs, transportation costs and efficiency. In addition, ecology must be taken into account. From the perspective of a forest ecosystem, there is no "waste" biomass. All forest residues are part of the long-term nutrient budget. Recent research has shown that removing forest residues traditionally left in BC´s forests after harvesting could rapidly have impacts on fauna[17] as well as long-term effects on flora[18].

2. FIRE IN THE WOODS

Wildfires are natural or human caused phenomena that are usually associated with the words like "disaster", "calamity", or "damage". This is a normal perspective for people living in rural communities, where their livelihoods can turn to ashes when fire strikes. However, wildfires are a natural element and fundamental part of forest ecosystems, especially in the temperate and boreal forests that dominate most of BC.

2.1 The role of fire in forest ecosystems

Forest ecosystems in fire-prone areas have evolved to be adapted to fire. Forests do not disappear after fire: they just go back to the forest stand initiation stage, in which seedlings of different species establish again in the burned area. In fact, if there were no fires, many tree and plant species would not have the chance to reproduce, as growing space would already be occupied by old growth forests[19]. Fire has many effects on forest ecosystems, with the combination of site, forest type and weather conditions creating a unique set of properties affecting fire behaviour. As a result of the natural variability and randomness of forest ecosystems, fire behaviour, and weather, in any landscape around BC there is a mixture of totally burned, partially burned and unburned sections after a fire. Over time, these patches evolve differently, some keeping the pre-fire forests and others growing a new stand of trees. Animals are affected by fires too, as their habitats and food sources are altered. In addition, the forest soil is affected by fire.

Soil can become richer in nutrients from the ash that is created. The ash is rich in mineral nutrients from the burned vegetation. However, if the heat is very high, it can bake soil particles, making them water-repellent, causing rainwater to run off and fostering soil erosion. Soil is a very important part of forest ecosystems as it is the biggest reservoir of nutrients and water. For plants, most of these resources are linked to the presence of organic matter in the soil. This link is so strong that the amount of soil organic matter in forest soils can be used as a measure or indicator of site fertility[20]. Soil organic matter is in turn dependent on the amount of woody and non-woody debris that came from the decomposed dead vegetation, which is incorporated into soil. However, fires can burn these important amounts of woody debris. If a fire reaches high temperatures, organic matter already incorporated in the soil can volatize thereby reducing site fertility and water retention.

Every forest in BC has a natural history of wildfires. Forest ecosystems are adapted to a specific fire regime characterized by the average time between one fire and the next, typical fire intensity (temperature), fire season, and other factors. Some external factors (either natural or human-made) impose changes that make it difficult for plants, animals and soil to return to pre-fire conditions. Examples include excessive fire suppression or excessive tree mortality (e.g. natural, by mountain pine beetle outbreaks, or artificial by harvesting), which cause an accumulation of fuel and therefore increase in fire intensity. Another example is the increase in fire frequency caused by human-induced sparks, or by increasing summer temperatures or drier summers. The last two issues are becoming more important particularly for southern BC, as direct links between climate change and fire frequency in western North America have already been reported[21] and projected[14,22].

For communities in rural BC it is not a matter of whether there will be a fire in the forest surrounding them, but of when. Fire regimes vary by ecosystem because each has a different composition and structure determined by climate conditions, tree species present, forest age, plant biomass, and ignition sources. Each of these factors is linked to the dominant forest type that surrounds each community. In BC, forest types are systematically classified following the use of biogeoclimatic zones (BEC zones[23]).

2.2 Forest management and fire

Forest management activities can cause wildfires. Sparks from machinery or power tools can ignite fires, and harvesting operations can leave behind residues that increase the fuel load. However, these risks can be reduced by piling and burning residues generated from harvesting. In addition, forest management can be a tool to fight wildfires. For example, FireSmart guidelines[15] provide a detailed set of rules to protect homes and properties. These rules clearly show the importance of reducing the amount of vegetation biomass in the proximity of buildings (the wildland-urban interface, see Figure 3).

FireSmart guidelines also recognize the potential for different levels of management intensity depending on the fire risk acceptable in each situation. For example, the closer the trees to the buildings, the less woody biomass should be left on site and the lower the stand density (number of trees per hectare). If only low fire risk is acceptable (i.e., low likelihood of having a fire in the near future), then intensive management would remove most of the standing conifer trees, snags, logs and other woody debris on the ground. The few trees left standing should be broadleaves (which act as fire breakers due to their low combustibility, high moisture content, and lack of resin), or conifers pruned to avoid ladder fires. All the biomass generated during these activities should be removed from the site. The management effort needed depends on two main variables: 1) a decision taken by the community on the fire risk level considered acceptable in the interface area, and 2) the local characteristics of the forest in the vicinity of the community. In addition, the size of the interface (or in other words, the area under active

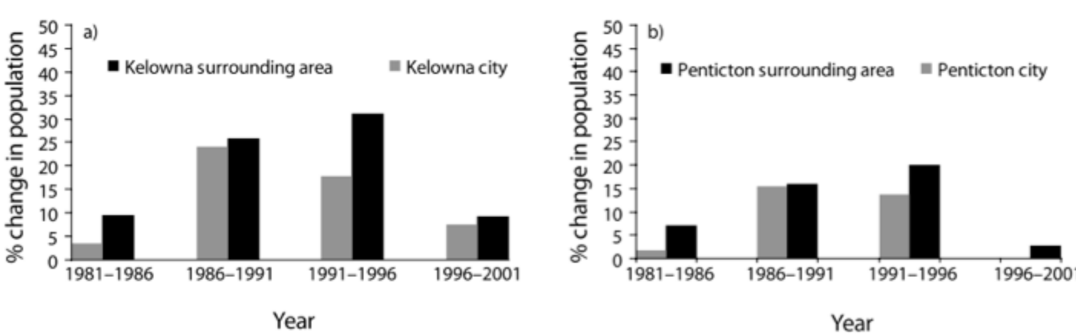
Figure 3: Example of residential area without (left) and with (right) FireSmart guidelines for managing the wildland-urban interface area[15].

management for wildfire risk abatement) depends on the forest distribution, accessibility, land ownership, interests, and capabilities of each community.

The size of wildland-urban interface has been steadily increasing over the last few years[11]. Since the census of 1981 there has been a clear trend for the population in rural suburban spaces to grow faster than city centers (Figure 4). This partially explains the increase in damage costs and evacuation orders as fires strike. As a consequence, rural community planners and fire prevention officers must take account of increasingly large areas under risk and in need of preventive forest management. It is easy to predict that this situation will also lead to an increase in biomass being removed from the forest. However, unless mature trees are removed from site, the rest of this biomass will likely have little monetary value as community safety, and not timber quality, will be the main factor in selecting trees for harvesting. Until now, such biomass has been removed from site and then burned in piles, so it will not fuel future wildfires. The result is that the potential energy available from this forest biomass has been lost.

The burning question then is: "if we have to cut trees and remove undergrowth to control wildfire risk, why not use the biomass produced to generate heat locally?" If all this forest biomass will burn naturally, why not harness the energy of the wildfire in a way that could benefit the community? We propose that the answer is to use the biomass generated by wildfire prevention activities to feed district and distributed heating systems in rural BC communities.

Figure 4. Wildland-urban interface has grown faster than city centers in most of BC[11].



3. FIRE IN THE BOILER

Based on Statistics Canada data, 70% of the energy used in BC's homes, commercial businesses, and institutions is for space heating and domestic hot water[5]. This energy need could be satisfied with district and distributed heating systems using forest biomass. Biomass boilers and furnaces have efficiencies and particulate emissions approaching natural gas systems — but with lower net carbon emissions— and have been used widely in Europe for many years. A bioenergy system can enable locally sourced biomass from wildfire mitigation activities to be effectively and cleanly used to benefit the local community.

3.1 The pros: multiple and multiplicative benefits of biomass heating systems

Substituting fossil fuel heating systems with biomass heating systems has multiple potential benefits for rural communities:

- *Reduction in fossil fuel costs*. The cost of heating energy produced by biomass is clearly beneficial for communities not connected to the natural gas grid (see Figure 5), and also for those that are connected but pay a premium (Tables 1 and 2).
- *Reduction in carbon emissions*. The most common types of biomass energy applications reduce carbon dioxide emissions 55% to 98% compared to fossil fuels, even when transported long distances, as long as the biomass production does not cause any land-use change[24]. It is worth noting that most of these studies focus on forest biomass generated during timber production (thinning and harvesting residues, short rotation coppice plantations, etc.) but not direct management for bioenergy. Moreover, there has been very little discussion on

Table 1: Biomass and conventional energy cost for heating in BC. Here and in the rest of the document monetary units are Canadian dollars[16]. GJ = GigaJoule.

Energy type	Cost
Natural gas	$8-10 / GJ
Propane	$30-35 / GJ
Heating oil	$29 / GJ
Biomass (wood pellets)	$8-10 / GJ

Table 2: Energy content, price and cost of fuel types in BC[25].

Fuel Type	Unit Sale	Energy Content	Retail Price	Typical cost in BC	
		GJ / Unit Sale	$ / Unit Sale	$ / GJ	$ / MWh
Natural Gas	GJ	1.0	11-19	11-19	40-70
Propane	Litres	0.0253	0.48-0.63	19-25	70-90
Electricity	kWh	0.0036	0.068-0.083	19-23	70-80
Heating Oil	Litres	0.0387	0.74-0.97	19-25	70-90
Ponderosa Pine	Cord	17.9	200-250	11-14	40-60
Wood Chips	Green Tonne	11.2	35-55	3-5	10-20
Pellets (Retail)	Tonne	19.2	175-210	9-11	30-40

the use of biomass from wildfire mitigation for bioenergy production, but this concept is becoming more widely considered. In addition, reducing carbon emissions will also help communities to fulfill their commitments in the BC Climate Action Charter and their community greenhouse gas emission reduction targets in their Official Community Plans.

- *Reduction in energy revenues leaving communities*. Generally, fossil fuels originate from outside most BC rural communities. The result is that energy dollars leave the community. If the fuel were coming from the local wildland-urban interface, the revenues would stay in the community and reinforce the local economy.
- *Increase in job opportunities*. Heating from biomass is one of the most job-creating uses and forms of energy. It is estimated that six direct jobs are created per Megawatt[26]. Typically, jobs will be created in the forest operations and transportation sectors, and indirectly in the service sector. These jobs will be placed in the community, and the salaries will therefore be spent mostly in the local area, reducing flow of money out of the community. The jobs also tend to be more stable as the utilities industry is less cyclical than other sectors.
- *Reduction in energy dependency.* Nobody wants to be cut off from their heating suppliers in the middle of the winter. However, snowstorms, windstorms and torrential rain events are expected to be increasingly common in a future under climate change. These events, together with other factors that may affect fossil fuel production, may produce a less reliable supply chain in the future. Using local energy could reduce this risk.
- *Other fiscal benefits*. District heating systems can be a non-tax source of revenue for communities, funding projects that enhance the community quality of life. In addition, having a well-managed wildland-urban interface, with low wildfire risk, could also reduce insurance costs for property owners.

3.2 The cons: there is no free lunch

The implementation of a district heating system (DHS) fed by biomass is not devoid of drawbacks. Some are technical, some economic, but there are also ecological issues that must be taken into account during the planning stage.

- *Initial capital investment required.* Similar to water, sewer, or electrical utility development, the initial capital investment is significant (Table 3). In many cases the distribution grid (pipes, valves, etc.) is more expensive than the actual heat production plant (boiler, fuel storage, etc.). The challenge is how to develop a heating network cost effectively. The solution is to identify areas of high heat demand that are clustered together. Such clusters could include hospitals, schools, hotels, recreation centres, large commercial buildings, apartment complexes, or industrial parks. Also, it is important to look for 'windows of opportunity' to minimize costs. These could include building improvements and simultaneous upgrading of below-ground infrastructure such as cable TV lines, phone lines, and gas distribution networks.
- *Need for detailed forest inventories and projections of forest growth.* Inventories are a basic tool in forest management planning. The BC Ministry of Forests,

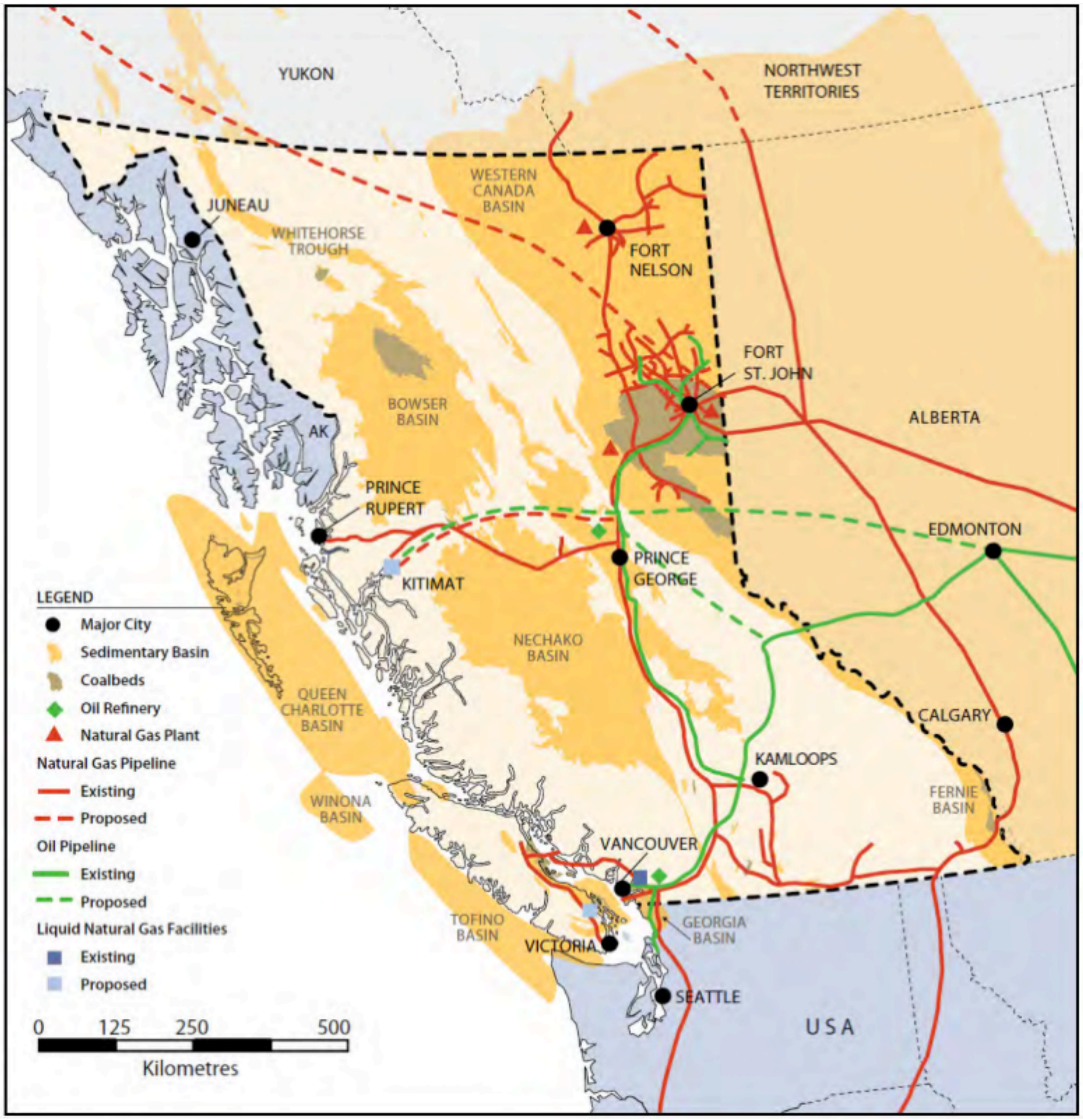


Figure 5: British Columbia sedimentary basins, natural gas pipelines and oil pipelines. Source: Ministry of Energy, Mines and Petroleum Resources.

Lands and Natural Resource Operations has a detailed Vegetation Resource Inventory of forest inventories at an operational level that allows city planners to understand the forest around their communities. District heating systems are planned and amortized over 25 years but have a lifespan of over 50 years. This will be enough time for the forest to change in noticeable ways as trees grow, although changes in species composition caused by climate change would likely be slower[27]. Dominant trees will grow taller, whereas occluded trees will die. As a consequence, more biomass will be present in the forest both as standing trees and as coarse woody debris. However, estimating how much forest biomass will be available in the future is not straightforward. Trees will grow more or less depending on how many resources (water, light, and nutrients) they have available[28]. These resources will change through the operational life of the district heating system depending on how the forest is managed for wildfire mitigation. Therefore, current inventories have to be combined with an ecological model to simulate future biomass inventories under changing resource conditions (Figure 6). A suitable model for this task is FORECAST, a research tool that has been widely tested and applied in BC forests[29,30].

- *Ecological sustainability may be compromised in some stands.* From the tens of thousands of seedlings per hectare that may sprout after a wildfire, only a few hundred will reach the stage of the majestic trees that can be found in old-growth forests. The rest will die and eventually fall to the forest soil, where they will become woody debris and, after decomposing, soil organic matter. The speed at which all these processes occur (growth, mortality, decomposition, etc.) depends on the specific stand: forest type, age of the forest, climate, topogra-

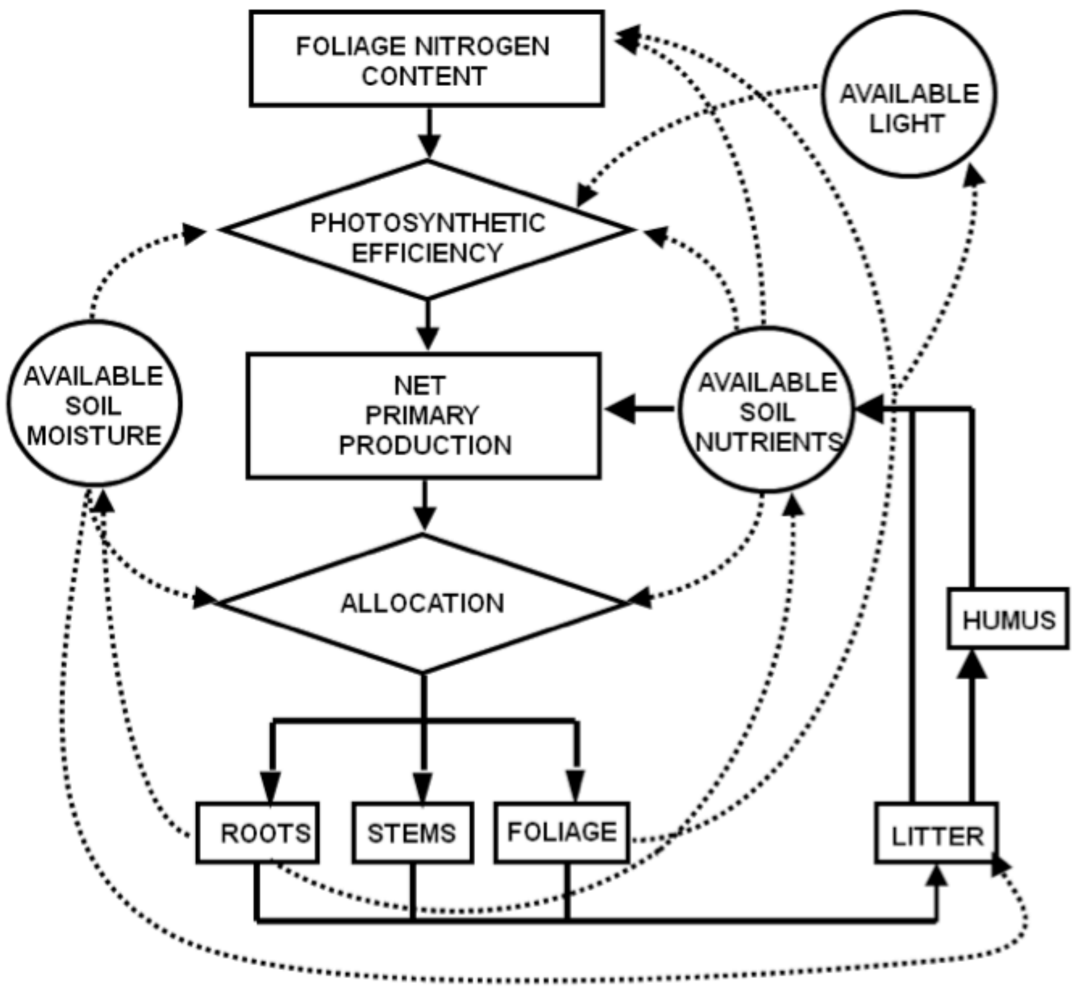


Figure 6: Main ecological processes involved in tree growth and simulated by FORECAST. Biomass flows between different pools (rectangles) at rates defined by photosynthesis and decomposition. Tree growth is limited by resource availability (circles)[29].

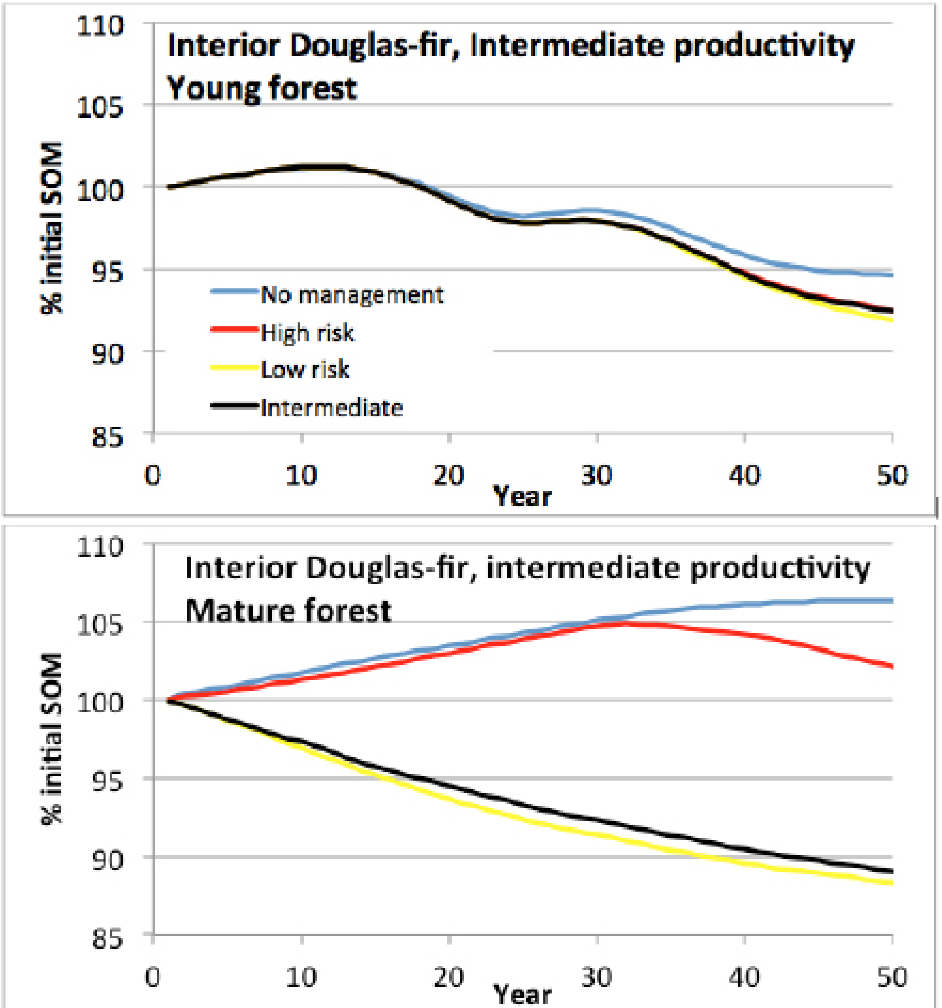


Figure 7: Relative change in soil organic matter (SOM) content in a young forest (upper panel) and a mature forest (lower panel), under different wildfire control plans for three different levels of wildfire risk corresponding to maximum, medium and minimum recommendations by FireSmart.

phy, etc. Forest management will affect these features, altering the ecological processes (i.e., reducing the amount of biomass that goes back to the forest soil, reducing its decomposition rates, etc.)[31,32,33]. In wildfire risk abatement plans, the main objective is to reduce the amount of fuel present in the forest. This reduction of biomass also results in the extraction of mineral nutrients (primarily nitrogen, phosphorus and potassium). In some circumstances, this could lead to a reduction of site fertility[33]. If that happens, trees will grow more slowly, produce less biomass, and generate less organic soil matter and the forest would become less productive. This deterioration process is very dependent on the particular circumstances of each site[18], as illustrated in Figure 7. In a young forest, where trees are small and produce small amounts of dead roots, branches, leaves and coarse woody debris, soil organic matter naturally decomposes faster than is created. Hence, the reduction in forest soil organic matter is normal, and expected for any type of management. On the other hand, in mature forests, removing many trees and most of harvesting residues (intense management to allow only low wildfire risk) reduces the amount of dead plant biomass that goes into the forest soil, disrupting the natural trend to accumulate soil organic matter, and causing important differences among management scenarios. When applying a wildfire risk control plan for the wildland-urban interface, the community planner needs to know which stands may be more sensitive to potential fertility loss, and adapt the plan accordingly.

4. THE "FIRST HEAT" TOOL

Given all these complexities, it is difficult for a rural community to decide if linking wildfire abatement plans with district heating systems is worthwhile. Toward this end, a joint undertaking by the University of British Columbia, the Community Energy Association, and Wood Waste to Rural Heat Project (formerly the Green Heat Initiative) has developed an intuitive tool to generate a rank of values for different ecological, economic and engineering variables involved in DHS planning. The tool is called the Fire Interface Rural Screening Tool for Heating (FIRST Heat) and it takes the form of a Microsoft Excel® spreadsheet in which users can select different options, and input parameter values specific to their communities (or select among the default values). It is freely available at the Community Energy Association website: http://www.communityenergy.bc.ca/resources-introduction/first-heat. The tool provides estimations of annual biomass generated during forest fire risk management activities using data provided by the user on the forest dominant type and age, and the type of preventive management used. Then, using data on capital costs, energy use and basic parameters defining district heating, the tool calculates savings in energy costs, job creation, and reductions in greenhouse gas emissions relative to the combustion of conventional fossil fuels used for space and hot water heating.

4.1 The making of the tool

Three rural communities in Interior BC were selected based on their small size, lack of existing district energy systems, and locations (difficult access to the natural gas grid, surrounded by forests prone to wildfires and situated in different biogeoclimatic zones, so as to provide a diversity of forest types). These communities are:

- Burns Lake – Northern BC, in the Interior plateau surrounded mainly by forests in the sub-boreal spruce eco-region, connected to the natural gas grid but with a gas price 50% higher than the rest of BC;
- Sicamous – Shuswap Valley, Interior cedar-hemlock eco-region, not connected to the gas grid; and
- Invermere – The Kootenays Mountains, in the mountain spruce eco-region, not connected to the gas grid.

A review was carried out in each community in 2011-2012 to gather information on local wildfire protection plans, management recommendations, ecological surveys and other related information. This information was used to design three different types of management approaches based on FireSmart guidelines:

- Minimum tree density: removing conifer trees from the stands until only 61 conifers / ha (in Sicamous) or 122 conifers/ha (in Invermere and Burns Lake) remained at the end of the first ten years. All tree regrowth and woody debris is removed from the stands every five years. Such management would minimize wildfire risk but would be expensive and have more impact on the ecosystem.
- Intermediate tree density: Removing conifer trees from the stands until 122 conifers/ ha (in all sites) remained after the first ten years. All tree regrowth and woody debris is removed from stands every 10 years.
- Maximum tree density: removing conifer trees from the stands until only 286 conifers/ha remain at all sites, and removing all tree regrowth and woody debris from stands every 10 years. This management will keep wildfire risk to its maximum acceptable level but would also be cheaper and less impacting on the ecosystem.

These three scenarios were simulated for each community with the ecosystem-level management-oriented forest growth simulator FORECAST[29]. This model simulates forest growth attending to the resources available for trees (light, nutrients and moisture). The model was calibrated for the different forest types present in each community. Libraries of yearly values of ecological variables (stem and other aboveground tree biomass, stem volume, aboveground understory biomass, nutrient availability, soil organic matter) were generated and maps of forest biomass were created that linked the ecological libraries with GIS-maps for each community. Finally, we estimated the yearly production of forest biomass for each community for the next 50 years. The information obtained through this process was used to create the FIRST Heat tool, which modifies different values in the biomass libraries depending on the site-specific economic, social and engineering parameter values inputted by the user.

4.2 Examples of communities studied: Sicamous, Invermere and Burns Lake

Below are three examples of the FIRST Heat tool applied to three different communities – Sicamous, Invermere and Burns Lake. Users of the tool should note that changing the input values produces changes in the economic, ecological and social target variables. As a demonstration of the capabilities of the FIRST Heat tool and without pretending to provide detailed feasibility studies for the pilot communities, the corresponding amount of energy generated from forest biomass was estimated (Table 3). The same assumptions for biomass, district energy systems, and labour were used for the three communities (see the most important assumptions in Appendix 1). These variables permitted estimation of the size, capital and operating costs over 25 years for a district heating network. The Levelised Cost of Energy (LCOE) was calculated, which expresses the lifecycle cost of energy from a system per unit of energy delivered. The LCOE takes into account the capital cost, discount rate, expected years of system utilisation, annual energy production, and all ongoing operation and maintenance costs. It allows the cost of energy from different systems to be directly compared.

Following guidelines by Partners in Protection[15], the first 10 years of the management plan were dedicated to reducing stand density in the fire-prone areas. To avoid problems of excessive windthrow losses among the remaining trees after suddenly reducing stand density, thinning operations were designed in two steps (removing 50% of harvestable trees in each step), separated by 10 years. As a consequence, during the first 11 years of management a large amount of biomass is generated (Appendix 2). These amounts are mostly large merchantable stems, which would be more suitable for sawmills than for bioenergy generation, and therefore this biomass was not included as energy source. The analysis for economic sustainability was made using the annual biomass generated by the operations to remove conifer regrowth (years 12 to 50), and assumes that none of it will be suitable for sawmills. To test the tool, a 25-year investment return and 50-year life span for the three sites was calculated.

Sicamous: this community is surrounded by mostly mature forests, many of them are under high wildfire risk. Therefore, forest operations will produce a stable flow of biomass and an energy source for a district heating system during the stand density maintenance period. In addition, the district system would create an important number of direct jobs and provide the community with significant energy savings and reductions in GHG emissions. The ranges in energy savings and GHG reduction are due to the different mix of energy sources in communities and the energy sources that may be used to supplement biomass during peak demand in the district energy system. More importantly, the risk of soil fertility losses in the 50 years of management is estimated to be low. This indicates that using biomass generated by wildfire risk reduction does not overexploit the ecosystem capacity to sustain tree growth in the medium to long term.

Invermere: As less forest land is under high wildfire risk than in Sicamous, annual biomass production is also lower. However, a biomass system in Invermere still compares favourably (approximately 40% lower cost) against conventional energy prices in the range of $19-35/GJ (Tables 1 and 2), not including the capital or maintenance cost of equipment for the conventional energy sources. If the area under active management is extended to forest stands available (but not under high wildfire risk), biomass production could be multiplied by 10, reaching similar numbers to Sicamous for energy, job creation, and economic returns (assuming that demand for all the available biomass exists). An important fact to take into account is the higher sensitivity of forest soils in Invermere to degradation caused by biomass removals. If intense management is carried out to keep stand density at the lowest range recommended by FireSmart guidelines, there is a moderate risk of losing too many nutrients from Invermere forests, which may jeopardize tree growth in the medium to long term. However, given the small differences in biomass production between keeping the highest stand density allowed (minimum management) and the lowest (maximum management), there is no need for such intense forest operations, and the risk of losing forest productivity can be easily avoided.

Burns Lake: Given the combination of small forest area under wildfire risk, forests dominated by young stands, and a sub-boreal climate that makes trees grow slowly, this community has the smallest potential for biomass production. As a consequence, feeding a district heating system with biomass coming only from the stands with high fire risk cannot be justified either economically or ecologically. If however a cluster of buildings can be found that allows for a more compact heating network, the levelised cost would improve. Optimizing the heat load relative to length of distribution pipe is critical in designing an economically viable system. Extending the management area further than the stands currently under high wildfire risk could also be recommended as a climate change adaptation strategy, as the wildfire risk in this region and ecosystem types is expected to rise as a consequence of drier and longer summers[9,20]. Managing all the forest stands available in the 25-km radius around Burns Lake would bring the biomass production to values similar to those of Invermere. This fact clearly shows the need for further detailed studies before making long-term decisions on energy systems in any community.

Table 3. Examples of results obtained with FIRST Heat for the three communities studied under the three types of management designed using FireSmart guidelines, combined with the assumptions described in Appendix 1 and other default values in the tool. Ranges for values are due to the different energy sources that could be used for peaking periods (electricity, propane or heating oil). GJ = GigaJoule.

Community (forest area with high fire risk) Dominant forest age	**Parameter**	**Lowest stand density** (lowest fire risk)	**Intermediate stand density** (intermediate fire risk)	**Highest stand density** (highest fire risk)
Sicamous	Biomass generated (tonne/yr)	29,618	26,525	31,723
(70,963 Ha)	Capital costs ($)	5.570.000	5,260,000	5,780,000
Mature forest	LCOE ($/GJ)	8.75 – 11.55	8.86 – 11.66	8.69 – 11.48
	Energy savings ($/yr)	0 – 2,167,616	0 – 1,921,976	0 – 2,334,860
	GHG reduction (tonne/yr)	8,615 – 10,536	7,715 – 9,436	8,908 – 10,895
	Total jobs created (FTE)	58	53.7	59,6
	Ecosystem degradation potential	Low	Low	Low
Invermere	Biomass generated (tonne/yr)	2,888	2,827	3,020
(8,866 Ha)	Capital costs ($)	1,750,000	1,750,000	1,800,000
Mature forest	LCOE ($/GJ)	14.75 – 16.10	14.71 – 16.24	14.46 – 15.99
	Energy savings ($/yr)	96,959 – 125,729	92,288 – 120,451	103,518 – 133,604
	GHG reduction (tonne/yr)	840 - 1027	822 – 1,006	878 – 1,074
	Total jobs created (FTE)	12.3	13.2	12.4
	Ecosystem degradation potential	Low	Low	Moderate
Burns Lake	Biomass generated (tonne/yr)	793	963	646
(12,984 Ha)	Capital costs ($)	1,250,000	1,250,000	1,180,000
Young forest	LCOE ($/GJ)	25.13 – 26.66	22.10 – 23.63	27.88 – 29.41
	Energy savings ($/yr)	-20,039 – -27,943	-5,342 – -14,937	-27,869 - -34,300
	GHG reduction (tonne/yr)	231 - 282	280 - 343	188 – 230
	Total jobs created (FTE)	8.6	8.8	7.5
	Ecosystem degradation potential	Moderate	Moderate	Need for detailed research

4.3 Lessons Learned

The scenarios illustrate that implementing different levels of stand density control as recommended by the FireSmart code[13] may not produce large differences in biomass production in the regrowth control period (years 12-50) (Appendix 1). However, density control may have important ecological consequences. Increasing tree and coarse woody removal in the intermediate and intense management scenarios does not produce a similar increase in biomass production. In fact, biomass production could be reduced as more intense biomass removal also removes nutrients from the site, therefore decreasing site quality and tree productivity. This phenomenon is more important in areas with slower growth rates, such as the mountainous stands of Invermere and especially in the sub-boreal forests surrounding Burns Lake. At this site, implementing the more intensive harvesting scenario could cause an average drop of 22% of the initial soil organic content over 50 years (Figure 7), which could lead to permanent site degradation and fertility losses[20]. On the other hand, implementing the minimum FireSmart guidelines could reduce soil organic matter by 12% after 50 years.

If management in forests with the most sensitive soils lasts longer than 50 years, fertility loss could be irreversible. To avoid this, intensive thinning should be eschewed, and the areas prone to soil organic matter losses should not be managed for some time after the life span of the district system ends to allow replenishment of nutrient reservoirs[16]. Alternatively, other fuel sources such as forestry and sawmill residues, wood waste re-directed from municipal solid waste streams, and processed woodfuels, could fuel the district energy system for the period of time needed for forest recovery.

Over the last 10 years, there has been a wide variation in community views on bioenergy systems in BC, from positive to negative with concerns often focussing on air emissions, pollution, and noise. During this study, no negative perceptions arose, though some communities were more in favour than others. The economic development and wildfire mitigation aspects of the project approach were socially positive.

5. CONCLUSIONS AND RECOMMENDATIONS

In BC communities off the natural gas grid, a significant proportion of residents' space and water heating requirements could be realized with district heating systems fed by forest biomass. In each case, energy substitution will depend on the business case for the proposed district energy system, which is also linked to other factors such as the heat demand density, current energy cost, etc. Where a district energy system is implemented, buildings connected to it would become mostly independent of fossil fuels (apart from the energy required during times of energy peaking demand, or as backup). Buildings not connected to the district energy system would continue using their current fuels. Once the fuel delivery/supply system is established, other buildings not originally suitable for connection (because they were too far away and therefore too expensive to connect) might then be in a position to implement their own standalone systems.

This research has shown that linking ecological, geographical, financial, and energy models can produce estimates of the ecological and economic feasibility of bioenergy production in different rural communities under different circumstances. It demonstrates the possibility of implementing multi-objective management by linking a reduction in wildfire risk and energy production in an ecologically sustainable way, provided the local conditions for forest productivity and health are taken into account. Communities wanting to take the next steps for implementing a district heating with sustainable management for wildfire risk abatement can use FIRST Heat as the first step towards their goal. To use FIRST Heat, communities require knowledge of the following:

- A general understanding on how forest biomass heating systems work. A good initial introduction can be found in the "Step by Step Guide to Biomass Heating Systems and Local Renewable Fuels" developed by the Green Heat Initiative[35].
- Wildfire risk in the surrounding forests. Knowing where wildfires are most likely to occur will help community planners to define safe areas for community development. This risk analysis should take into account future climate change.

- Community-wide consensus on what level of wildfire risk is acceptable. Residents, fire authorities, and forest managers should decide the extent to which they are willing to live with the risk of forest fires, and how much area surrounding the community should be managed for fire risk abatement.
- The ecology of the forests surrounding the community. Not all forest types are suitable for biomass removals. In some specific forest stands, although wildfire control risk measures should be taken, biomass may have to be left on site to reduce adverse ecological impacts.
- Present and possible future energy costs at a community level, and on funding available for implementing district heating. Such information will provide an economic framework for decisions on fuel switching affecting the community. The guide "Funding your Community Energy and Climate Change Initiatives" compiled by Community Energy Association[36] is a good starting point to explore funding possibilities.
- Identification of the main energy consumers in each community, and the potential future growth of community energy demands. Knowing where heating needs are concentrated will help community planners to have a better understanding on the dimension of the district heating system.
- The probable timescale for construction operations including below-ground systems (installation of district heating pipes, and disruption to existing infrastructure including cable TV, potable and waste water distribution systems, power and gas lines) as well as major building renovations.

6. ACKNOWLEDGEMENTS

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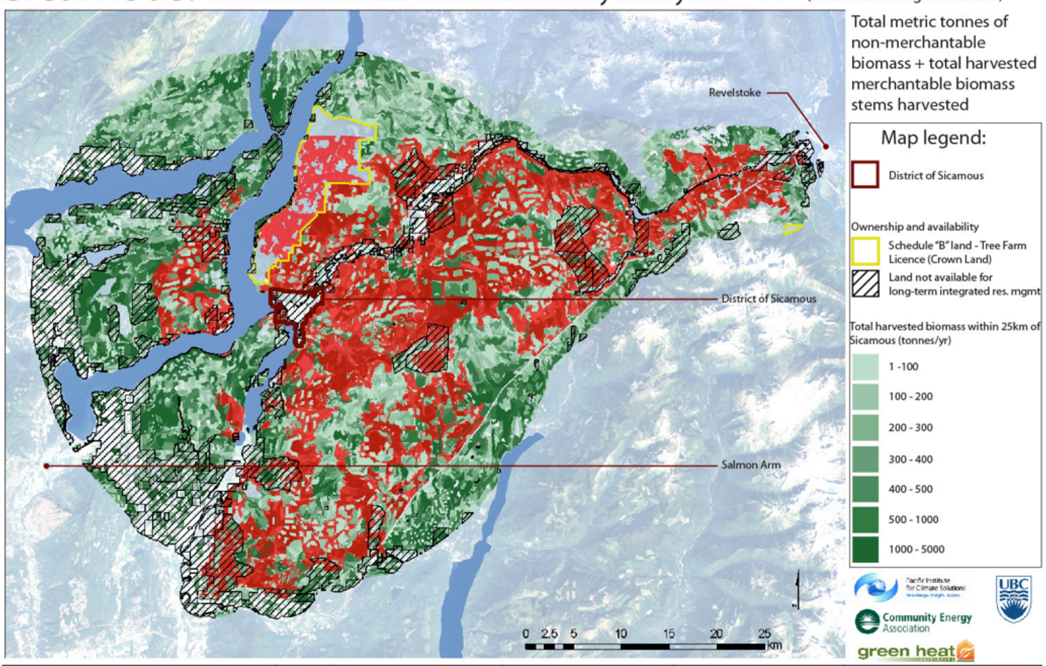
APPENDIX 1: ASSUMPTIONS FOR PARAMETERS USED IN BUSINESS CASES

All heating network assumptions are illustrative and not configured to specific buildings in any of the communities. For ease of comparison only, identical assumptions were made for each of the three communities. For specific community applications, assumptions tailored to each community must be made.

Biomass available	**Value**	**Observations**
Non-harvestable Material	0%	
Harvested material not available at roadside	15%	
Harvested material left at roadside	15%	
Biomass fuel sent to plant	70%	
Energy content of wood	20.32	GJ / oven-dry tonne
Moisture Content (x)	45%	Wet basis
Higher Heating Value	11.17	GJ / Tonne
District energy system analysis		
Operational life	50	years
Investment return period	25	years
Operational Hours at full Load	4,000	hours / year
Biomass plant efficiency	85%	
Peaking plant efficiency	85%	propane
Total district energy system efficiency	75%	
Total district energy system output from biomass	90%	
Cost of commercial buildings	$350	/ ft^2
District energy grid length	700	m
Cost of trenching	$500	$/m
Additional cost for district heating pipe	$200	m
Labour		
Estimated jobs from DE system construction phase	6.220	jobs/$1,000,000 capital
% biomass mechanical fall & removal	80%	
% biomass hand fall & removal	20%	
People power required for mechanical fall & removal	0.12114	person days / tonne
People power required for hand fall & removal	1.60658	person days / tonne

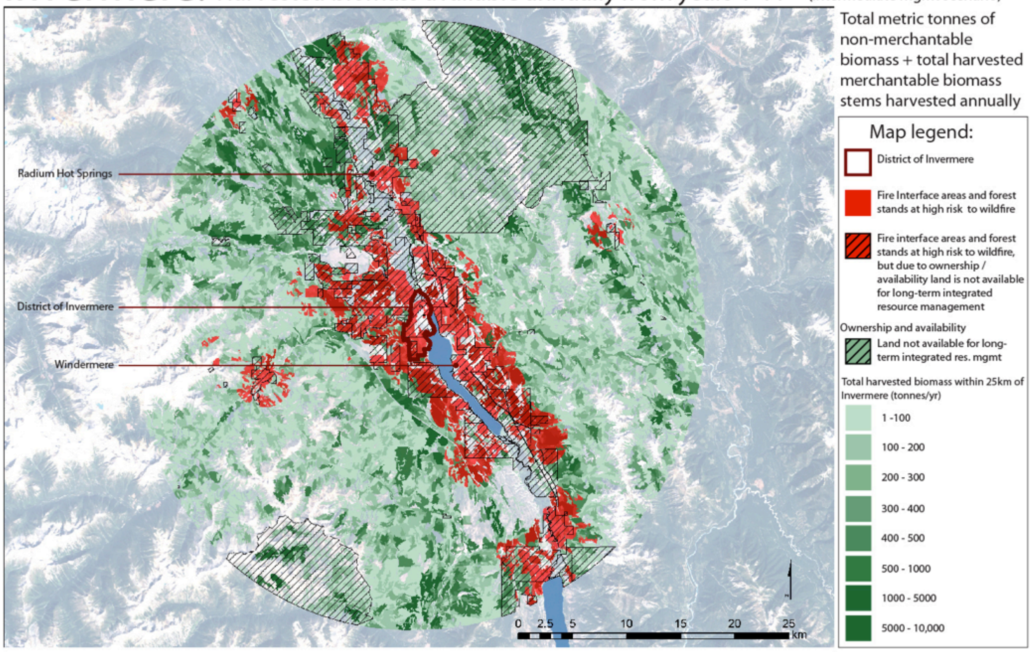
APPENDIX 2: BIOMASS GENERATION MAPS & FIRST HEAT SCREENSHOT

Sicamous: Harvested biomass available annually from years 1-11 (intermediate mgmt scenario)



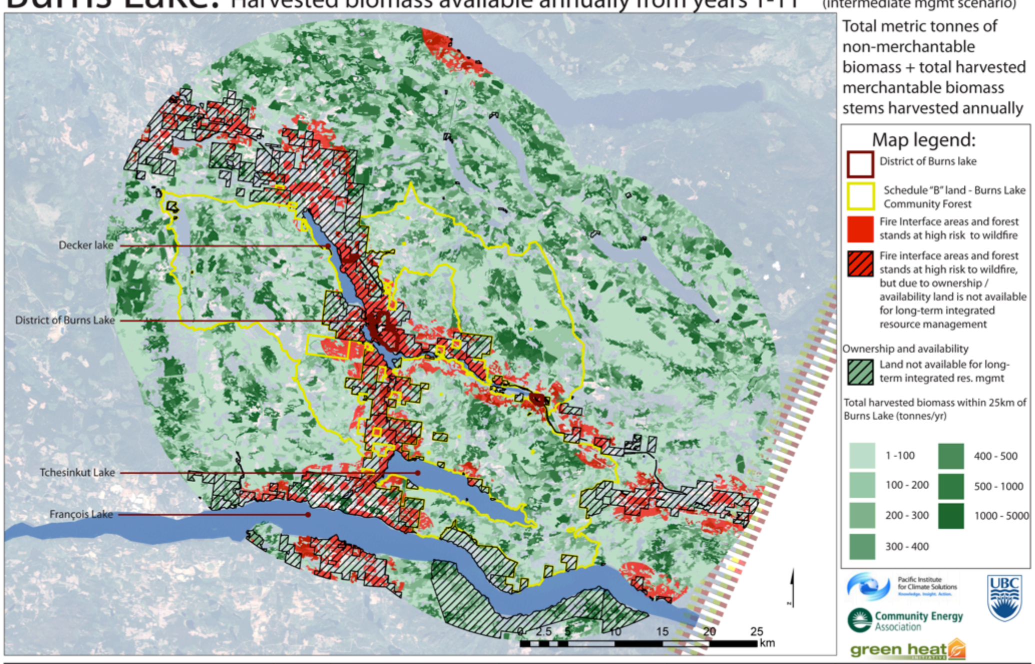
Study area	Legend	Min. mgmt (tonnes/yr)	Int. mgmt (tonnes/yr)	Max. mgmt (tonnes/yr)	Area under mgmt (Ha)
All forest stands <25km from district of Sicamous		Year 1-11: **1,842,999** Year 12-50: **102,868**	Year 1-11: **3,266,118** Year 12-50: **106,914**	Year 1-11: **3,382,763** Year 12-50: **123,057**	**291,939 Ha**
All forest stands <25km from district of Sicamous excluding land not available for long-term integrated resource management		Year 1-11: **1,541,069** Year 12-50: **89,384**	Year 1-11: **2,641,481** Year 12-50: **88,486**	Year 1-11: **2,742,819** Year 12-50: **100,073**	**231,878 Ha**
Stands at high risk to wildfire <25km from district of Sicamous, excluding land not available for long-term integrated resource management		Year 1-11: **590,966** Year 12-50: **29,618**	Year 1-11: **1,060,770** Year 12-50: **26,525**	Year 1-11: **1,097,874** Year 12-50: **31,723**	**70,963 Ha**

Invermere: Harvested biomass available annually from years 1-11 (intermediate mgmt scenario)

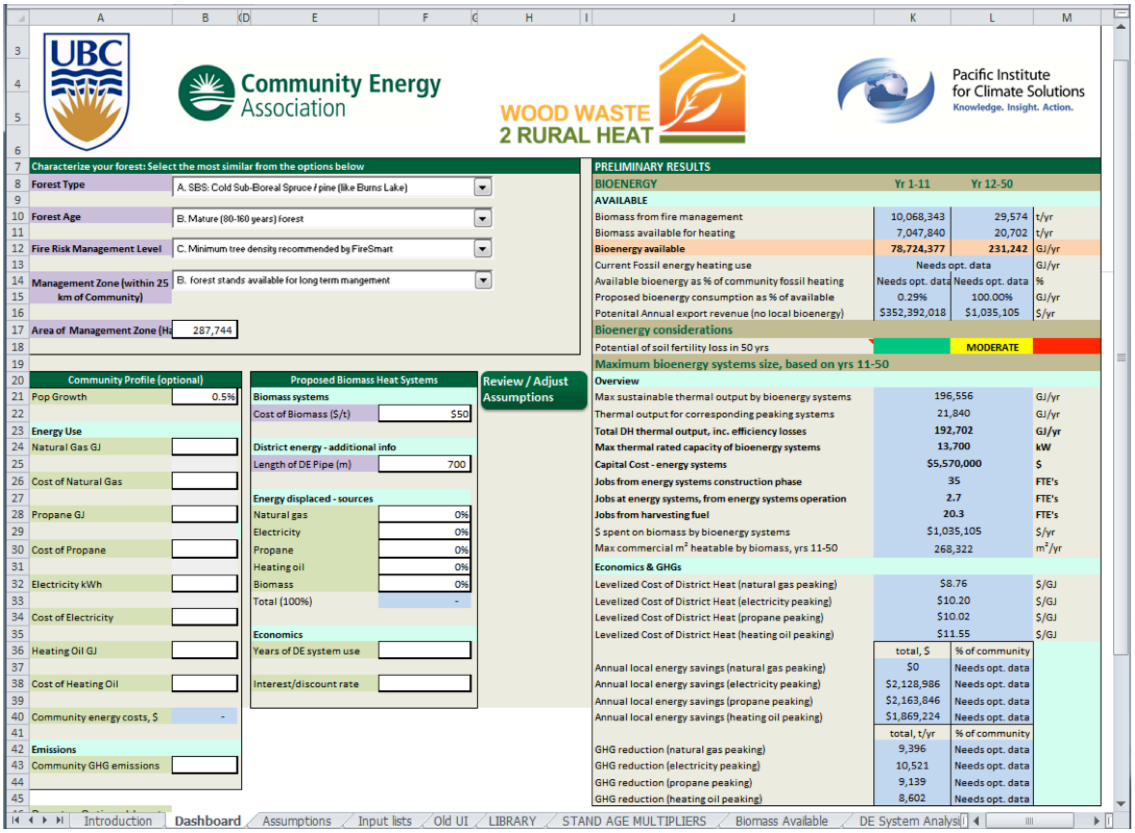


Study area	Legend	Min. mgmt (tonnes/yr)	Int. mgmt (tonnes/yr)	Max. mgmt (tonnes/yr)
All forest stands <25km from district of Invermere		Year 1-11: **1,488,260** Year 12-50: **40,952**	Year 1-11: **1,706,168** Year 12-50: **45,441**	Year 1-11: **1,616,185** Year 12-50: **51,203**
All forest stands <25km from district of Invermere excluding land not available for long-term integrated resource management		Year 1-11: **1,048,038** Year 12-50: **29,687**	Year 1-11: **1,206,834** Year 12-50: **33,694**	Year 1-11: **1,191,635** Year 12-50: **38,421**
Stands at high risk to wildfire <25km from district of Invermere, excluding land not available for long-term integrated resource management		Year 1-11: **119,248** Year 12-50: **2,888**	Year 1-11: **134,664** Year 12-50: **2,827**	Year 1-11: **118,254** Year 12-50: **3,020**

Burns Lake: Harvested biomass available annually from years 1-11 (intermediate mgmt scenario)



Study area	Legend	Min. mgmt (tonnes/yr)	Int. mgmt (tonnes/yr)	Max. mgmt (tonnes/yr)	Area under mgmt (Ha)
All forest stands <25km from district of Burns Lake		Year 1-11: **1,263,592** Year 12-50: **18,965**	Year 1-11: **1,930,010** Year 12-50: **21,930**	Year 1-11: **1,906,916** Year 12-50: **16,197**	**339,459 Ha**
All forest stands <25km from district of Burns Lake excluding land not available for long-term integrated resource management		Year 1-11: **1,121,269** Year 12-50: **17,020**	Year 1-11: **1,704,136** Year 12-50: **19,619**	Year 1-11: **1,683,845** Year 12-50: **14,553**	**287,744 Ha**
Stands at high risk to wildfire <25km from district of Burns Lake, excluding interface land and land not available for long-term integrated res. mgmt.		Year 1-11: **57,746** Year 12-50: **794**	Year 1-11: **94,009** Year 12-50: **964**	Year 1-11: **92,918** Year 12-50: **646**	**12,984 Ha**



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