A Preliminary Assessment of Renewable Energy Capacity in Prince George, BC.

Report Prepared for Natural Resources Canada

March 31st, 2009

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1. INTRODUCTION

In 2008, the BC Provincial Government presented their Climate Action Plan, which set greenhouse gas reductions targets for the province. These targets include an 80% reduction below 2007 levels by 2050 (Government of British Columbia, 2008). Meeting the carbon reduction targets will require aggressive changes to current energy sources for both industrial and residential users. The Prince George Community Energy and GHG Management Plan (2007) outlines broad strategies for addressing Greenhouse Gas (GHG) reduction options and energy supply systems, consistent with the current Provincial legislation. One proposed component of the Community Energy Plan, the Prince George Community Energy System (CES), a downtown district heating system for over 20 downtown civic and commercial buildings, will be able to reduce local GHG emissions if fuelled by low-carbon, renewable sources. While a range of possible alternative energy sources exist, including local biomass, geoexchange, solar, micro-hydro, and wind, such sources have not been systematically mapped at the various scales impacting downtown Prince George.

The following report outlines work undertaken by the Collaborative for Advanced Landscape Planning (CALP), UBC, to build on and add value to the City's GHG reductions and renewable energy systems work, in support of a Smart Growth on the Ground process in Prince George in 2008-2009[1]. Working with City and SGOG staff and associated partners, preliminary estimates of potential renewable energy capacity have been calculated in order to begin addressing the question of the potential renewable energy capacity from the local landscape for the Prince George region. This report presents a framework that is being developed within CALP to assess renewable energy supplies at the community scale. Spatializing this information is important for linking local energy resources to land use planning processes and policies in order to develop integrated community solutions to climate change. The purpose of the case study section of this report is to investigate the potential for renewable energy supply in Prince George by developing a method to quantify and spatialize that supply at the community scale using biomass and solar thermal hot water as demonstration cases. The biomass section looks at

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[1] Smart Growth on the Ground is a partnership between Smart Growth BC, the Design Centre for Sustainability at UBC, and the Real Estate Institute of BC. For more information see http://www.sgog.bc.ca/indexnscp.asp

the potential role of the Prince George Community Forest in a low-carbon economy, while a second application consists of a mapping methodology to begin to quantify solar thermal (hot water) potential capacity in Prince George's downtown core. While energy generation potential from biomass and solar thermal are the focus of this research, the framework for assessing renewable energy supplies at a community scale should be transferable to other sources. Thus, although the work is preliminary and exploratory, it begins to set out a community renewable energy methodology that will provide communities with a better understanding of their local renewable energy supply options.

Finally, the perceived impacts of green energy solutions can have a big influence on their implementation, as demonstrated by recent municipal decisions stalling the proposed CES biomass plant in Prince George. As a result, this report also presents an initial review of the social acceptability of alternative energy and carbon reduction measures, looking specifically at a number of barriers and suggesting approaches for addressing them.

This report is intended as a useful document both to local decision-makers, researchers and citizens in Prince George, as well as to energy and climate change mitigation researchers in other communities as communities strive to reduce GHG emissions and meet the targets necessary to achieve climate stabilization and a liveable future.

2. APPROACHES TO ASSESSING COMMUNITY RENEWABLE ENERGY SUPPLIES

2.1 COMMUNITY ENERGY PLANNING DEFINED

As concerns mount about the future supply of fossil fuels (Hirsch, 2005; Salameh, 2003) and the impacts of their use (Hoffert et al, 2002), there is a push to develop both conservation measures and renewable energy systems. In British Columbia, there has been a focus on industrial scale renewable energy sources, such as large hydroelectric dams, Independent Power Producers facilities (IPP's), and onshore and offshore windfarms. There is, however, increasing interest in more community-scale energy solutions as many renewable energy solutions, by their nature, have a local focus (St. Denis and Parker, 2008; Sebitosi and Pillay, 2008).

Community energy planning (CEP) refers to comprehensive energy planning (i.e. supply, demand, and transmission) at a community scale. Church and Ellis suggest that "the primary intent of the community energy plan is to find an optimum energy supply/demand scenario for a pre-defined location and hence identify mechanisms by which this solution may be achieved" (2007, p. 7). According to Church and Ellis (2007), what is "optimum" is dependent upon the community's vision of itself – implying both technical an*d* social components.

A similar concept is Jaccard et al.'s (1997) "community energy management", which includes land use planning, transportation management, site design, local energy supply, and delivery planning in a comprehensive plan. In both community energy planning and community energy management, there is a stipulation of a constrained geographical area, though that area may be as small as a neighbourhood (Church and Ellis, 2007), or as large as a region (Jaccard et al., 1997). Community energy planning, then, includes a spatial component.

The rise in CEP parallels the increasing recognition of a need to move to a more decentralized energy system (St. Denis and Parker, 2008). Major benefits from such a shift include increased community resiliency and efficiency by reducing waste heat energy and per capita energy consumption, enhancing scalability (increasing or decreasing system capacity and extent), facilitating fuel switching in the future, and improving compatibility with mixed-use urban forms and complete communities. Historically, energy planning has been a centralized task driven by engineering and economic models, and therefore outside the mandate of communities. For centralized energy planning, the main point of contact with local communities came as the result of facility siting (Andrews, 2008). In community energy planning, there is a need to think about energy as a system at the community scale. Thinking about energy (Ekins, 2004) and larger sustainability issues (Milbrath, 1995) as systems may be particularly important to long-term effective planning. The increasing risk of disruptions due to climate destabilisation and vulnerability to rising external energy costs argue for communities taking control of at last a portion of their energy needs in the interest of community resilience (Sheppard, Pond and Campbell, 2008).

A criticism that has been levelled at current CEP processes in Canada is that they have focused

almost exclusively on the subject of demand management (St. Denis and Parker, 2008). While there are obvious economic reasons why this might be the case, the failure to mention or explore renewable options may suggest that planners and policy makers are not yet considering energy supply at the community scale in a systemic way.

2.2 SPATIALIZING ENERGY SUPPLY

Movement towards decentralizing the energy system, and addressing energy demand and supply at the local level brings energy management into local and municipal purviews in a way that it previously was not. From a demand side, many planning-related moves to reduce energy use have significant spatial ramifications, such as the need to increase density of development for district heating and energy systems.

Supply-side changes also have significant spatial implications. First of all, by decentralizing the energy system, some energy generation happens *in* the community, making it necessary to plan spatially not only for transmission, but also for generation. Secondly, the move away from fossil fuels with high energy density to lower density alternative sources means that more area will be required to generate energy – including, potentially, area for growing biomass feedstock, collecting solar radiation, or positioning wind farms. In some circumstances, provisions for one form of alternative energy supply can lessen the impact of another form. For example, the relatively high density required to economically support a district heating or energy system can negatively impact the ability to design buildings for passive heating and cooling and to incorporate photovoltaic and solar thermal systems (Canadian Urban Institute, 2008; Miller and Cavens, 2008; Steemers, 2003). Also, conflicts may occur between renewable energy production and other land uses, e.g. biomass harvesting and scenery values for tourism.

In essence, the need to address energy demand and supply at local levels makes energy a much more spatial problem. In this context, energy mapping can provide a valuable tool for communities to assess their current energy demand and supply, and plan for development and infrastructure. As community access to spatial data and Geographic Information Systems services is improving, it is now possible for more communities to acquire or develop the data required to manage and plan for energy

locally. The purpose of this section of the report is to take a first step towards developing a conceptual framework for how communities can catalogue and map potential energy supplies for their community.

2.3 A CONCEPTUAL APPROACH TO ASSESSING LOCAL ENERGY SUPPLY

In traditional energy planning with a centralized energy system, supply requirements are calculated using econometric models that forecast demand. In the current Prince George project, energy demand and energy supply are being assessed by different research groups. Ideally, energy supply opportunities and analysis would take place in the context of recognized current demand and future demand projections.

This report outlines methods for arriving at potential local renewable energy capacity. However, mapping energy capacity is only one critical piece of the local energy system and GHG reductions puzzle, the others being energy demand, and demand reductions potential (including efficiencies and conservation, and changes to urban form). Bringing all the pieces together enables modeling of potential GHG reductions in a community energy system, an exercise which is beyond the scope of this report. Thus, this report focuses on developing methods for mapping potential renewable *capacity*, understanding that actual renewable energy supply is predicated on further refinements of technical and economic concerns, and social considerations such as acceptability, and will necessarily be smaller than capacity. Mapping capacity enables communities to begin to identify local resource opportunities, and bring such energy considerations into local community planning processes. It is this potential energy approach that is discussed here for Prince George, with recognition that future planning need also consider demand and transmission components of energy management.

Current case studies show that local renewable energy supply calculations and mapping are becoming more common. Solar Boston provides an interactive website where users can engage with a web-based map of Boston (City of Boston, 2009 http://www.cityofboston.gov/climate/solar.asp); clicking on solar rooftop icons provides pop-up displays of individual rooftop system information and photographs. Users can also click on any non-solar roof and, using a small number of changeable factors such as useable roof area, obtain a calculation of the roof's potential electrical generation for PV

(photovoltaic) panels. Thesis work in Landscape Architecture at UBC (Pond, 2008), mapped roof potential within existing residential neighbourhoods for solar thermal or solar PV, integrating the findings into a mix of local renewable energies to replace existing space and water heating demand, and meet increased electrical demand from electric vehicles. Recent work for North Vancouver (Design Centre for Sustainability, 2008) assumed multiple local energy sources, including, potentially, sewage heat recovery and waste incineration, amongst others. Work with the City of Calgary has included an energy mapping study (Canadian Urban Institute, 2008) that includes a business as usual, a high efficiency, and a renewable energy set of maps for Calgary. Thus, methodologies for assessment of the local renewable resource potential are now under development.

2.3.1 IDENTIFYING LOCAL OPPORTUNITIES

The first stage in assessing local energy resources is to apply a coarse filter to resource opportunities in order to identify potentially more viable types of renewable energy from less viable types for a given area. Some alternative energy sources are more general in their requirements, and are somewhat less limited by particular characteristics of the local environment. Geothermal exchange, solar thermal heat (for heating water), photovoltaics, passive solar or solar air heat (for space heating), and biomass are examples of energy production techniques that have less restrictive local constraints and may be found in many communities. Instead, limitations to these technologies are more likely to result from economic or infrastructure concerns. Geothermal exchange is less expensive when a horizontal loop is used (requiring more area to install), but can be installed using a more expensive vertical loop under constrained conditions. Solar technologies may have longer economic return intervals in cooler, less sunny conditions, but can still provide energy under those limiting conditions. Biomass can be shipped to combined heat and power (CHP) plants from other locations in the form of chips or pellets, with additional cost and associated GHG emissions. For such energy types, local restrictions may still be important but at a finer resolution within the community.

Other alternative energy sources have more strict local requirements. Technologies such as wind, micro-hydro, tidal, sewage heat recovery and landfill gas require more site-specific local resources in order to be feasible. While local assays will be more accurate, wind resources have been modeled across Canada and in most of the developed world. These maps can provide a general indication of whether or

not it is worth it for a community to investigate their wind generation potential. Micro-hydro (either in the form of small hydro installations, or run-of-river approaches) requires specific characteristics from any proposed water system, including slope or head potential and characteristics of the catchment area. Tidal energy, of course, is limited to coastal locations with specific tidal characteristics. Both sewage heat recovery and landfill gas installations have specific spatial requirements and may be more feasible in larger communities with their own treatment facilities and landfills. A coarse filter approach to assessing resource opportunities can identify which resources and technologies a community may be suitable for or which are simply unavailable to that community; it identifies the energy sources that the community should pursue in their catalogue or 'breadbasket' of potential energy supply solutions. These can then be assessed in a stage of analysis within the community. Spatial analysis plays a critical role in assessing how specific local renewable energy resources may be implemented in a community once the most viable options have been identified (see Figure 1, page 15).

2.3.2 UNDERSTANDING SCALES

Scale is an important consideration when assessing energy resource capacity. Scale impacts energy supply capacity in a number of different ways. Firstly, there are considerations for the measurement and modeling of energy itself. Currently, energy modeling occurs at two predominant scales – the building level, and large regional or national levels. Building level models are highly detailed engineering models concerned with the design of building envelopes and the sizing of systems, while large-scale models most often focus on the economics of energy supply and demand (Kellett et al, 2008). Increasingly, researchers, governments and private practice are trying to grapple with energy modeling at scales in between the building and large region (Kellett et al, 2008; Webster, 2009), with a focus largely on assisting planning. This can create difficulties, as downscaling of regional models may not provide data with sufficient resolution (Strasser, 2009), and bottom-up aggregation of building scale models requires either excessive detail, or some form of aggregation and generalization of data (Kellett et al, 2008). This is particularly true of demand-side modeling, but has significant ramifications for supply-side assessment of energy generation capacity as well. Decisions about how to estimate energy systems such as solar thermal, solar photovoltaics, or geothermal exchange capacity are significantly impacted by methods of aggregation from buildings into neighbourhoods and communities.

Scale also impacts the installation of energy generating technologies. Some technologies such as solar thermal, passive solar, PV, geothermal exchange, and in some circumstances wind and micro-hydro, can be installed at the individual home or building level, but can also scale to larger applications (either through district or grid buyback systems). For these systems, scale-based challenges include issues of ownership and system or grid integration. Other technologies such as district heat/energy[2] systems, landfill gas, incineration, etc. are more dependent on larger scale applications. In these circumstances, scale-based challenges revolve around technical feasibility and economic concerns.

Finally, there is the question of the scale at which a given technology can provide energy. Table 1 provides a preliminary look at the scales of energy provision for different technologies; emerging technologies may enable these systems to cross scales further in the future. Technologies that can provide electricity are perhaps more flexible than those that provide thermal energy, because of transmission concerns. Scalability of building-level installations such as PV and geothermal exchange are dependent on integration with larger systems.

Table 1. Suitable spatial scale for application of different renewable energy systems

Energy System	Building/Parcel	District heat/energy	Community/Regional Scale (grid connected electricity)
Solar PV	Yes	Yes	Yes
Solar thermal	Yes	Yes	No
Passive solar	Yes	No	No
Biomass	Yes	Yes	Yes
Geo-exchange	Yes	Yes	No
Geothermal power	No	No	Yes
Landfill gas	No	Yes	Yes
Incineration	No	Yes	Yes
Wind	Yes	Yes	Yes
Micro Hydro	Yes	Yes	Yes
Tidal	No	No	Yes

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[2] District energy systems may be either heat only, or combined heat and power (electricity)

2.3.3 JURISDICTIONAL CHALLENGES

Management of energy resources has not typically been the role of municipal governments, and while there are signs that this is changing (e.g. Ministry of Energy, Mines and Petroleum Resources, 2007), many legal and jurisdictional constraints persist (Canadian Urban Institute, 2008). In addition, many of the technologies in question, such as photovoltaics, solar thermal, passive solar, and geothermal exchange, are building-level decisions made by individual owners. Although some provincial GHG legislation exists in British Columbia and Manitoba, most energy-specific management occurs in the development of municipal and community energy plans. Many municipalities are also enacting building code requirements such as LEED standards for new buildings (Swing, 2009), and incentive programs are being instituted to offset costs for building owners. However, issues of ownership, jurisdiction and policy still need to be considered when assessing the difference between energy potential and energy supply. Constraints play a significant role in determining the difference between the energy production capacity of a community and the feasible supply, and will be discussed further in Section 4.

2.3.4 ENERGY SUPPLIED FOR END USES

While several studies give energy demand as a single number, often by m^2 (see, for example, Steemers, 2003), building energy demand actually has three end uses: space heating, water heating, and electricity for appliances. Solving the domestic and commercial energy emissions problem requires renewably sourced supplies for all three energy needs, and consideration of the different energy demands as renewable supply is assessed[3]. Not all energy is created equally, and different energy supplies are more suited to meeting different energy demands, as shown in Table 2.

Exergy can be thought of as a measure of usefulness or quality or value of energy (Dincer and Rosen, 2007). Heat, often a by-product of other forms of energy production such as burning natural gas, coal or wood to make electricity, is a low exergy energy. Thus, space and hot water heating can be met by waste heat, but heat cannot meet all energy demands. Electricity is a high exergy energy, in that it can be

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3 In BC, hydro-electricity currently supplies most of the province's electrical demand, and thus, for BC, space and hot water heating (usually supplied by natural gas) currently produce the majority of residential building GHG emissions. As imported electricity is used to meet provincial electrical demand increases, GHG emissions related to electricity could rise significantly as some of the imports come from coal-fired plants.

used for many purposes, and can convert down into other forms of energy, particularly heat.   Thus, electricity is a high value energy source. It can meet all three domestic energy needs: space heating, hot water, and running appliances (although it may best be used where heat cannot).

Table 2. Renewable energy systems supply different energy demands

Energy System	SPACE HEAT	HOT WATER	ELECTRICITY
Solar photovoltaics	No	No	Yes
Solar thermal (thermal siphon)	No	Yes	No
Solar thermal (electric pump)	Yes	Yes	
Passive solar	Yes	Yes	No
Biomass, individual house	Yes	Potential	No
Biomass district heat generation	Yes	Yes	No
Biomass cogen (CHP)	Yes	Yes	Yes
Geo-exchange	Yes	Yes	No
Geothermal power	No	No	Yes
Sewage heat recovery	Potential	Yes	No
Landfill gas	No	No	Yes
Waste incineration	Yes	Yes	Yes
Wind	No	No	Yes
Micro-hydro	No	No	Yes
Tidal	No	No	Yes

Matching of renewable supply to different demands is a critical part of building a local energy system: can you provide for your current and future needs matrix using selected technologies? Most renewables provide either heat or electricity; however, combined heat and power systems, such as district energy systems that generate electricity and use the waste heat for space and hot water heating, supply all three energy end uses.

2.3.5 ANALYSIS

Once a coarse filter identifying local opportunities, appropriate scales, and end uses has been applied, the next stage of community energy planning involves analysis of the potential energy capacity
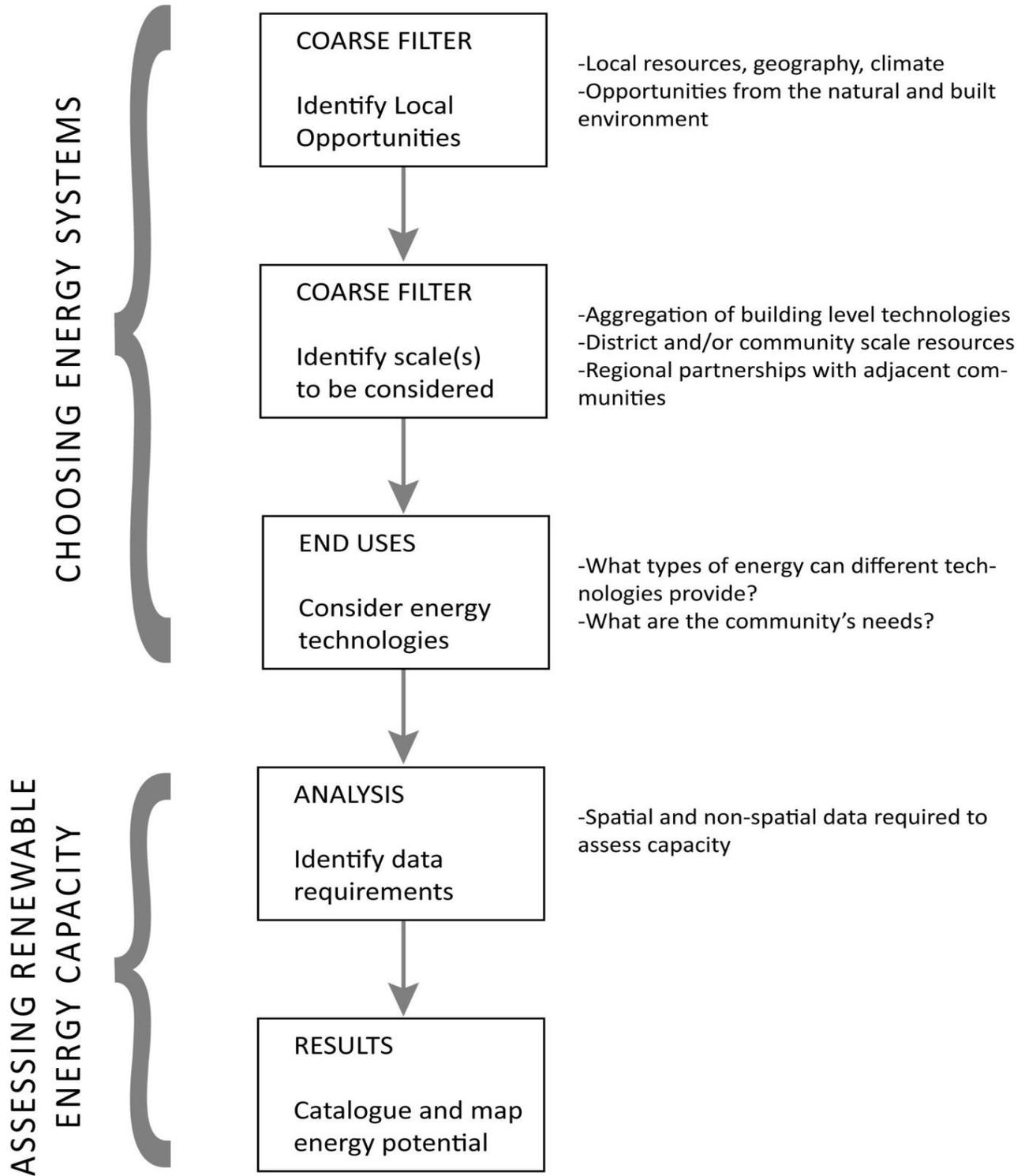
within local landscapes for differently sourced renewable energy systems. Each energy system will have different requirements; however, both spatial and non-spatial aspects need to be considered (see Figure 1). Non-spatial data includes technical considerations such as efficiencies, costs, or other modeled data such as forest productivity. Spatial data includes land area under consideration, forest cover by type, roof mapping, shading, and others. Development of GIS suitability mapping techniques is one aspect of whole landscape planning for local renewable energy that needs further development. The work on both biomass and solar thermal in this report uses spatial suitability mapping as a way of assessing renewable energy potential; conversions from spatial data to energy outputs require technical performance assumptions. Each will be discussed in the methods and results in Section 3.

2.3.6 SYNTHESIS OF FRAMEWORK

The first three steps in choosing energy systems are covered by the framework discussion and tables in Section 2. In Prince George, biomass for district heating, and solar thermal potential, were chosen for further study in consultation with the city and other partners including Natural Resources Canada. Section 3 covers both analysis templates and results. Once the potential capacity has been assessed in this pre-feasibility stage, further steps beyond this report would involve determining actual potential supply, demand loads, and potential GHG reductions. Integration with other research components associated with the Smart Growth on the Ground Prince George project should enable demand and supply to be aligned, for example.

A later stage fine filter assessment for energy supply siting would need to include feasibility studies, and building and infrastructure integration. As well, policy changes and addressing barriers, amongst others, may need to occur for planning these and other renewable energy supply options. This report does not cover the fine filter assessment, which is outside the scope of work, but does provide an overview of barriers and potential means of overcoming them in Section 4.

Figure 1: A framework for assessing renewable energy systems

CHOOSING ENERGY SYSTEMS

COARSE FILTER

Identify Local
Opportunities

-Local resources, geography, climate
-Opportunities from the natural and built
environment

COARSE FILTER

Identify scale(s)
to be considered

-Aggregation of building level technologies
-District and/or community scale resources
-Regional partnerships with adjacent com-
munities

END USES

Consider energy
technologies

-What types of energy can different tech-
nologies provide?
-What are the community's needs?

ASSESSING RENEWABLE ENERGY CAPACITY

ANALYSIS

Identify data
requirements

-Spatial and non-spatial data required to
assess capacity

RESULTS

Catalogue and map
energy potential

3. CASE STUDY: RENEWABLE ENERGY IN PRINCE GEORGE, BC

This section will introduce a methodology for spatial and non-spatial analysis required for renewable energy capacity mapping. Results of the analysis for biomass and solar thermal heat applied to the city of Prince George give coarse renewable energy capacity for the city that can be incorporated into further planning practices, including the Smart Growth on the Ground process.

Biomass and solar thermal were chosen for detailed analysis for several reasons:

- Prince George is often considered to be an enormous source of biomass and has access to local and regional forest resources; thus, Prince George's biomass provides an example of renewable energy supplies from a city's hinterland;

- Proposals for a biomass district heating system in Prince George have proven controversial, and necessitate further exploration building on previous studies on biomass capacity;

- Solar thermal is considered one of the more economically feasible solar energy sources;

- Solar thermal can be developed on-site within the city, and therefore has the potential to be integrated with the downtown urban design issues of the SGOG project.

3.1 BIOMASS

3.1.1 BIOMASS ENERGY AND CLIMATE CHANGE IN PRINCE GEORGE: AN INTRODUCTION

The first example of renewable energy capacity analysis concerns the potential role of the Prince George Community Forest (PGCF) and surrounding forestland in the local supply of biomass available to support a low-carbon energy economy. Building on previous studies of biomass potential, the CALP research maps and quantifies how Prince George's forest resource can be managed to ensure long-term biomass supply while maintaining forest stand health and ecosystem productivity. Several generations of forest ecosystem modeling tools at the University of British Columbia culminated with the development of FORECAST, which is used to drive the quantified asset mapping exercise. Biomass energy capacity is linked to potential land use changes in the Smart Growth downtown concept plan and the possibility of a district heat system in order to begin to understand potential biomass energy contributions to the City's energy requirements.

Bioenergy is energy derived from organic biomass sources such as trees, agricultural wastes and manure. Biomass can be generated from logging, agriculture and aquaculture, and vegetation clearing including within forest fire hazard areas. When used for energy, biomass such as organic waste, wood residues and agricultural fibre is considered low-carbon because, not including greenhouse gas emissions released during harvesting, transportation and processing, it releases no more carbon into the atmosphere than it absorbed during its lifetime. Additionally, biomass has low sulphur content, which minimizes acid rain. Use of biomass as a green energy source is an example of synergy between climate change mitigation (reducing carbon emissions), climate change adaptation[4], and community sustainability or resilience in terms of increasing local economic development from existing forest resources.

Prince George is considering a district energy system for its downtown core. District energy systems are most effective, in terms of financial and economic performance, when they serve a large number of buildings in a reasonably compact area. The Prince George Community Energy System (CES) originally considered a single stand-alone plant using local hog fuel (mill by-product) rather than harvesting directly for energy (FVB Energy Inc., 2006). The fuel budget was to be 80% hog fuel and 20% natural gas. The plan has been recently updated to use waste heat from existing local industrial facilities instead of burning waste hog fuel at a new plant located in the downtown area. The work for this project examines how the Prince George Community Forest can contribute biomass energy, through a sustainable yield, to the Community Energy System. Findings on the forest land required to meet non-downtown residential energy needs will be discussed in the results as well.

3.1.2 PRINCE GEORGE COMMUNITY FOREST

The Prince George Community Forest, bounded by the municipal boundary of Prince George, is 32,945 Ha, or almost 330 km^2. Of this, about 75% is predominantly forest cover, with approximately 5500 Ha of Crown Land that is considered the most viable land-ownership for biomass generation. Approximately 1000 Ha of the forest are municipal lands, while the largest forested area is under private

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[4] such adaptations may include vegetation clearing to reduce the increased wildfire risk due to climate change, or logging of pine beetle infested forest

control. The City is the legal tenure holder of the Probationary Community Forest Agreement, and management of the PGCF is headed by the City's Development Services Department. Individuals from the Environment Division oversee day-to-day operations, and experts on the Community Forest Committee connect the forest staff to the public. Primary objectives of resource management on Crown land within Prince George are to create "fire smart" urban wildland interface areas, to address the current mountain pine beetle infestation, and to ensure long-term forest health. The current anticipated annual cut is 5,750 m3/yr from municipal lands, specifically to conduct fire risk reduction measures, while an Annual Allowable Cut (AAC) for timber of 12,000 m3/yr is taken from Crown land.

3.1.3 BIOMASS METHODOLOGY OVERVIEW

A study on wood biomass generation potential was completed by TDB consultants (2005) to assess lands both within and outside of the PGCF. It focused on overall stand productivity, the associated costs of harvesting, and final delivered prices. It was not calibrated to sustainable harvest rates, nor to community energy planning metrics. The study did demonstrate the large amounts of waste wood residues generated by traditional harvesting practices, a by-product which would be incorporated into energy generation under a biomass for energy scenario. The work for the current paper builds on the TBD report (summary volumes in Table 3).

The current study worked with GIS maps of the forested areas in the PGCF to assess potential biomass based on ownership (municipal and Crown lands[5]), and sustainable yield by stand species. Harvest rotation times were calibrated for stand species composition using the FORECAST modeling tool that ensured that nutrients in the forest ecosystem remained consistent, allowing for continuous harvests without the need for fertilization, or loss of forest productivity. Harvests from wild fire thinning outside of the FORECAST analysed stands were also calculated. MPB salvage was examined, but without stable yields over time, was not used for final numbers. Total annual sustainable yields of biomass were calculated and then converted into a total amount of heat energy that could be generated using multiple technologies, as efficiencies across systems are similar at approximately 80%. Given available energy

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[5] Due to a lack of detailed current ownership data, an informed assumption that 1/3rd of the PGCF is either municipal or Crown land was made.

demand numbers for Prince George, as well as the proposed energy demand that could be met from the proposed Community Energy System, the sustainable yield biomass energy supply numbers can be related to current needs in Prince George. Each of these methodological stages will be discussed in detail in the following sections, with caveats noted as necessary. Results and additional considerations such as air emissions, suggested forest management strategies, and application of biosolids will conclude the biomass section of this report. Additional data and discussion is supplied in several Appendices.

Table 3: Forest productivity for stands with a site indices (SI) of 15 (lower quality sites), and 25 (higher quality sites) (TDB Consultants, 2005)

		Total Tonnes Area waste	Total Tonnes Area waste	Mean SI 15	Mean SI 25
		Total SI 15	Total SI 25	Tonnes ha	Tonnes ha
Area (ha)	168,566.02				
Residue		9,428,382.00	13,051,897.00	55.93	77.43
Merchantable		14,142,573.00	19,577,845.50	83.9	116.14
		23,570,955.00	32,629,742.50	139.83	193.57

3.1.4 BIOMASS SPECIES IN PRINCE GEORGE

The PGCF forest consists of mixed conifer and deciduous species in the Sub-Boreal Spruce (SBS) biogeoclimatic zone. The SBS zone has a continental climate with characteristic extreme temperatures. Summers tend to be short, warm and moist. There are three biogeoclimatic subzones within the community forest: the dw (dry warm), mk (moist cool) and mh (moist hot). Climate, combined with the geology and topography of an area, result in different vegetation combinations, and therefore in different stand types. Climax tree species for SBS include hybrid spruce (*Picea engelmanii x glauca*) and subalpine fir (*Abies lasiocarpa*). Early seral species, which occupy an area following a wildfire or other disturbances, are lodgepole pine (*Pinus contorta*), trembling aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) (Blanco, 2009).

Forests dominated by Lodgepole pine (P*inus contorta*), spruce (predominantly white spruce, *Picea glauca*), and aspen (*populous tremuloides*) will be the focus of this study (see Figure 2). Other species present in the Prince George region include alpine fir, *Abies lasiocarpa*, douglas fir, *Pseudotsuga*

menziesii), balsam poplar / cottonwood (*Populus balsamifera*) and paper birch (*Betula papyrifera*), as well as understory species. Biomass resources from these forests take a variety of forms, which correspond to different ideal uses. These are described in Appendix A.

Cultivated forms of forest biomass have not been studied in depth here and would require further investigation. For example, fast growth, high biomass yields and good frost hardiness render poplars (various *Populus* spp.) suitable for planting and cultivation on agricultural land in temperate and boreal climates (Weih, 2004). These species also burn longer and at higher temperatures than other potential biomass trees (US Dept of Energy, 2009). More detailed information on the relationship between stand type and energy can be found in Appendix B.

3.1.5 WILDFIRE AND MOUNTAIN PINE BEETLE SALVAGE

Harvesting MPB salvage and biomass from fuel reduction in areas of the PGCF that are currently at high and very high risk to wildfire (Figure 3) would increase biomass extraction (and therefore fuel supply and energy generation potential) by 6-8% annually based on applying the FORECAST sustainable harvest rates to these areas. Although the current MPB epidemic has led to an increased Annual Allowable Cut (AAC) in some areas, current mortality and harvest rates are not expected to continue in the future (BC Ministry of Forests, accessed 2009). Thus, including MPB sources would bring a short-term but unsustainable boost to biomass feedstock, and therefore is not considered as part of long-term calculations, though it might have economic benefits in the start-up of a larger local biomass industry. As well, while MPB-killed trees could be used for combustion for several years following mortality, selective harvesting of MPB killed trees is more costly than standard cut blocks with less carefully managed extraction, which harms the cost competitiveness of this fuel (see Appendix F for more costing discussion). It would likely be more cost effective to carry out traditional management strategies, which would include some MPB salvage, and leave MPB killed trees outside of cut blocks to carry out their post-mortality ecological function.
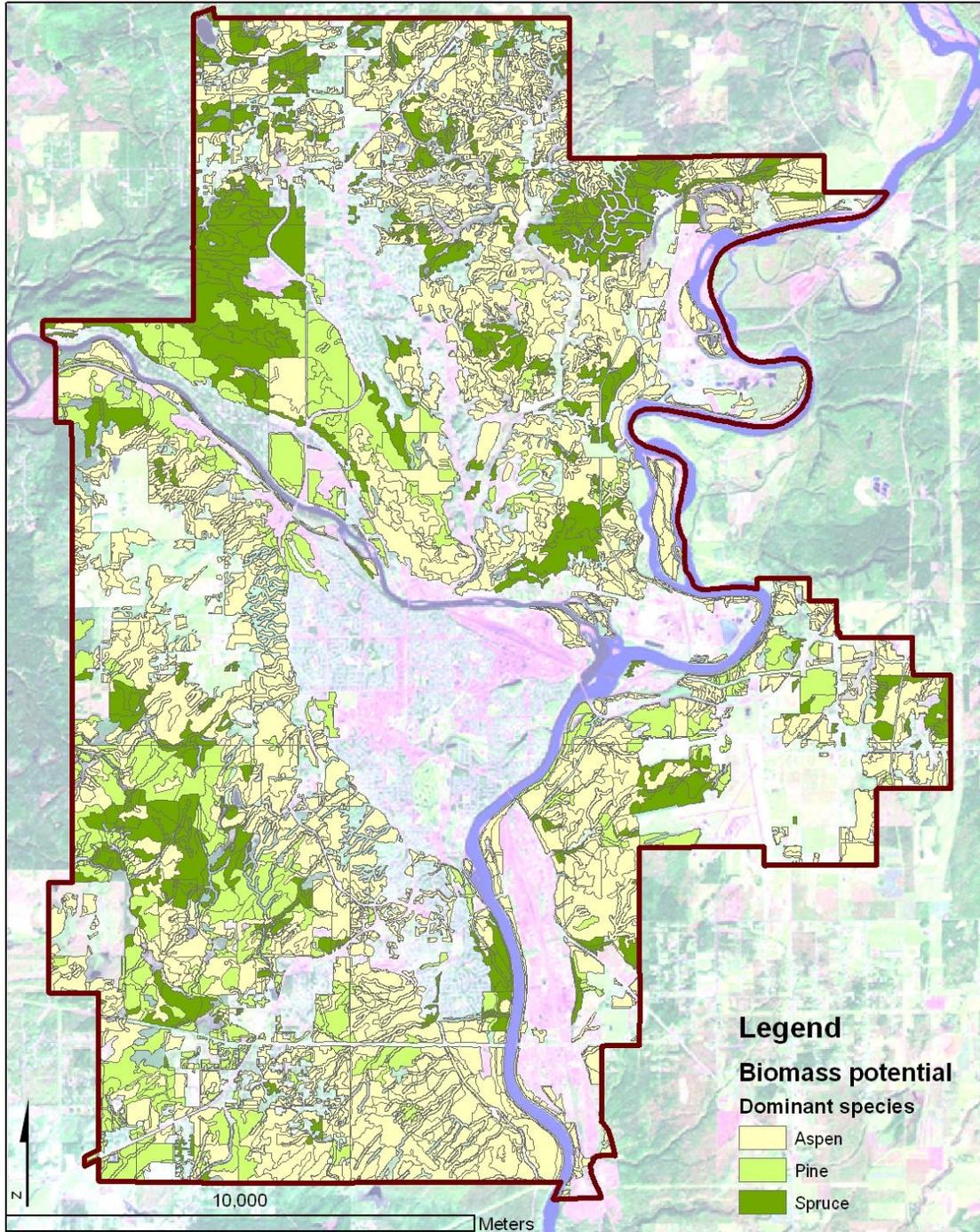
Prince George - dominant biomass species

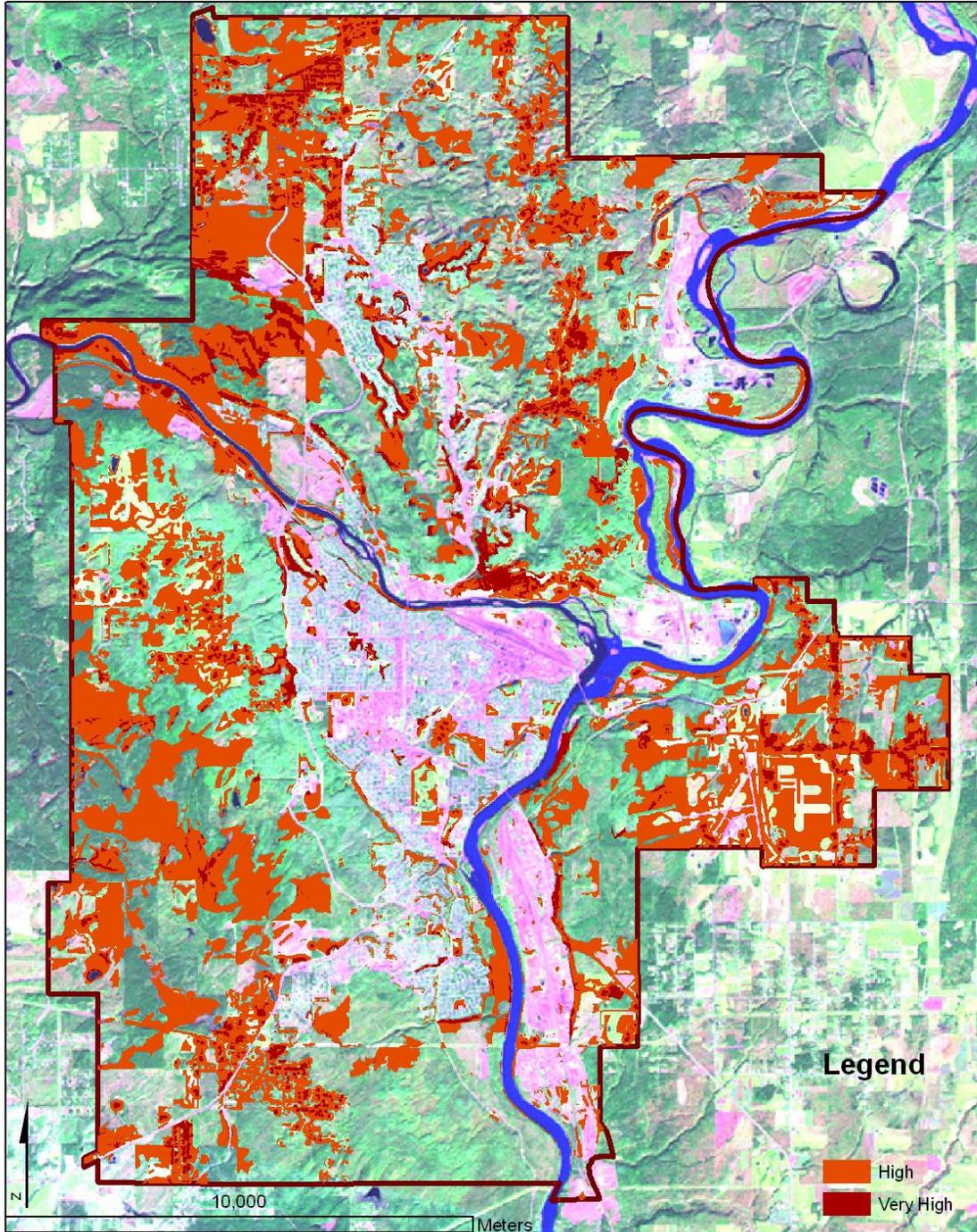**Figure 2: Biomass species in the Prince George Community Forest (UBC, CALP)**

Figure 3: Wildfire risk in the Prince George Community Forest (UBC, CALP)

3.1.6 SUSTAINABLE BIOMASS CAPACITY MAPPING METHOD

3.6.1.1 FORECAST BIOMASS SUPPLY MODELING

The modeling system used to develop estimated biomass production capacity for this study is the FORECAST model (see Kimmins, 1997, for a description of FORECAST for modeling sustainable bioenergy production, forest growth, and other resources/values). The model allows estimation of total biomass produced, as well as exploration of various management/harvesting strategies and their effects on the sustainability of the resulting ecosystem. This in turn allows researchers to address the public and scientific community's concern of over-extraction, which would result in long-term soil and ecosystem damage from harvesting.

Using BC Ministry of Forests VRI forest cover inventory, creek riparian area data, and BC Biogeoclimatic zones as inputs, we have modeled a management scenario over 150 years for the Prince George Community Forest using the FORECAST ecosystem simulation model (see Table 4). All forest polygons in the PGCF were modelled: Crown Land, municipal land, and lands under private ownership. Ten different analysis units (AU) were delineated for the PGCF, each with a unique combination of dominant and secondary species (shown under Description, Sp1 and Sp2 headings), soil quality (shown under Description heading), site quality (shown under Site Index Range heading), and biogeoclimatic zone. In general, trees are harvested at a younger age for energy than for traditional uses such as lumber. Numerous methods of prescribing the amount and type of wood harvested in each stand type are feasible, including carefully planned clear-cutting, thinning and a "two-pass" system described by Welham et al, (2002). Biomass production does not necessarily entail clear-cutting, as shown by the two-pass harvest system.

In the two-pass system, the aspen pioneer species is harvested early, at around 15 years, followed by a second harvest once the slower-growing coniferous species reaches the ideal age for harvest 15 – 35 years later. The two-pass harvesting system is similar to partial thinning in that any given stand always has standing biomass remaining after a harvest, which may serve to mitigate some of the social barriers to large-scale biomass harvesting. Used with the FORECAST model, the two-pass system included an assumption of 100% removal of overstory tree species for any particular harvest, allowing

calibration of the model. The model then leaves understory species to develop for subsequent 100% removal once they become overstory (see Table 4). In this manner, reducing or increasing the amount of biomass extracted from a stand could be achieved by decreasing or increasing rotation length, rather than reducing or increasing the percent of thinning in that stand. Four stand types were so productive that some thinning of understory was possible while still achieving indicators for sustainable harvest rates. Aspen stands tend to regenerate without significant replanting effort, whereas spruce and pine stands will likely require monitoring and replanting to ensure consistently high stem densities (Figure 4).

Involving municipal Registered Professional Foresters, and specially trained or experienced timber cruising and falling teams are critical to successfully implement a two-pass strategy. Another vital aspect of successful implementation is on-site care to minimize damage to the understory during overstory extraction. The two-pass strategy is only one of several for achieving sustainable extraction rates, and requires more careful on-site assessment and care, but fewer re-planting efforts. More discussion of management strategies for the PGCF is found in section 3.8.1.3.

Table 4: Site condition for stand types identified and assigned management scenarios. (Source: All FORECAST modeling was conducted by Juan A. Blanco, UBC Dep. Forest Science)

AU	Description	Site Index Range	Plant Density	Sp1	Sp1%	Sp2	Sp2%	Aspen Regen Density	Aspen Regen year	Aspen rotation length	Conifer rotation length	Understory biomass harvested
401	At medium - poor	<18	500	Sx	-	100	-	1400	4	75-75	150	-
302	At rich	>=18	500	Sx	-	100	-	1200	3	15-30-30-30-30-15	30	50%
303	At Pl all sites	All	1000	Pl	-	100	-	1050	3	15-30-30-30-30-15	30	-
304	At Sx all sites	All	1200	Sx	-	100	-	720	3	15-30-30-30-30-15	30	-
305	Pl all sites	All	1500	Pl	-	-	-	-	-	-	50	50%
406	Pl Ss medium - poor	<18	2000	Pl	Sx	70	30	-	-	-	150	-
307	Pl Ss rich	>=18	2500	Pl	Sx	60	40	-	-	-	15	50%
308	Sx At medium - poor	<18	2100	Sx	-	100	-	900	4	75-75	150	-
309	Sx At rich	>=18	1000	Sx	-	100	-	400	3	8-15x9-7	15	50%
310	Sx Pl all sites	All	1250	Sx	Pl	60	40	-	-	-	50	-
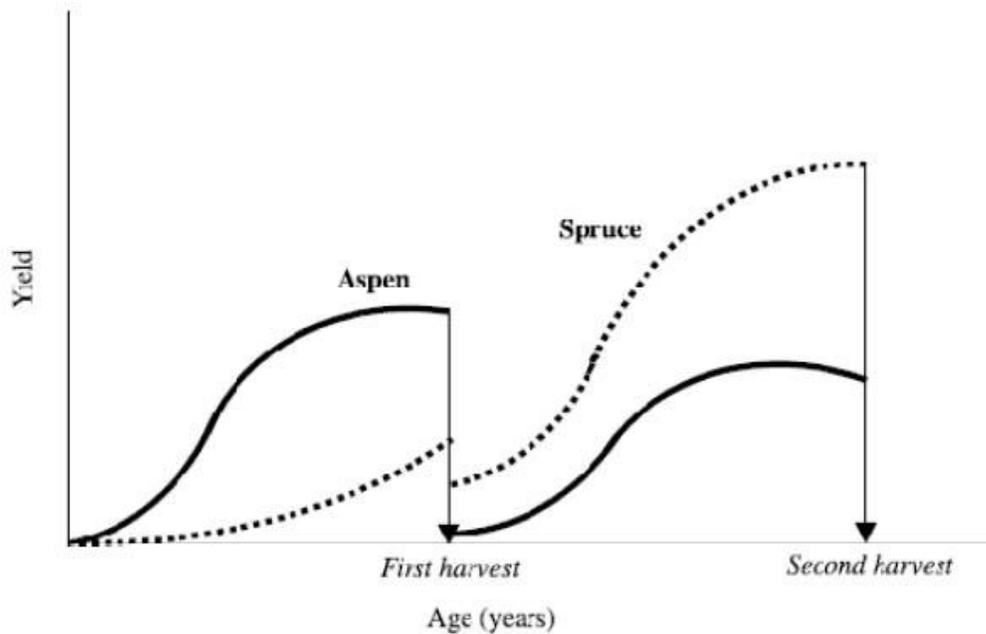
Figure 4: The yield curves of a two-pass harvesting system is shown where Aspen is cut first, preserving the Spruce understory to be cut later (Source: Welham et al, 2002).

For the FORECAST simulations of the Prince George Community Forest, soil organic matter and total ecosystem organic matter, specifically measured by carbon content, were used to assess the long-term sustainability of the forest stands. Organic carbon was chosen as the indicator because recent research suggests that soil organic matter, or organic carbon, C, is an effective indicator of soil quality and fertility, and therefore sustainable forest management practices. Organic carbon is beneficial for site productivity through its positive influence on many soil characteristics, and it facilitates key biological processes and nutrient release for tree growth (Seely et al., in press). Two scenario simulations, one with total above ground (stand) organic matter (Figure 5), and the other with soil organic matter (Figure 6) were run. In an iterative process, the FORECAST model was run with variable stand rotation lengths to achieve a management strategy that maintained no net change for these two variables after 150 years of management simulation. Due to its implications on a forest's performance as a carbon sink, ecosystem stored carbon was also modeled (Figure 7).

3.1.6.2 FORECAST MODEL RESULTS & DISCUSSION

Figure 5 shows that although peaks and troughs occur following the removal and regrowth of trees (and hence organic matter in the vegetation), the peaks in organic matter demonstrate sustained levels over the long term. Similarly, Figure 6 shows fluctuations over time that reflect litter decomposition and species competition, but no net loss in soil organic matter. Figure 7 demonstrates that stands with more intensive harvesting achieve a stable, although lower, overall level of carbon sequestration, whereas stands with intensive harvesting increase their stored carbon by the end of the 150 year simulation. Soil organic matter levels indicate that only aspen stands with poor/medium quality soil suffered from a small net reduction in soil carbon in the simulation, the result of only one harvest over 150 years (see Figure 6).
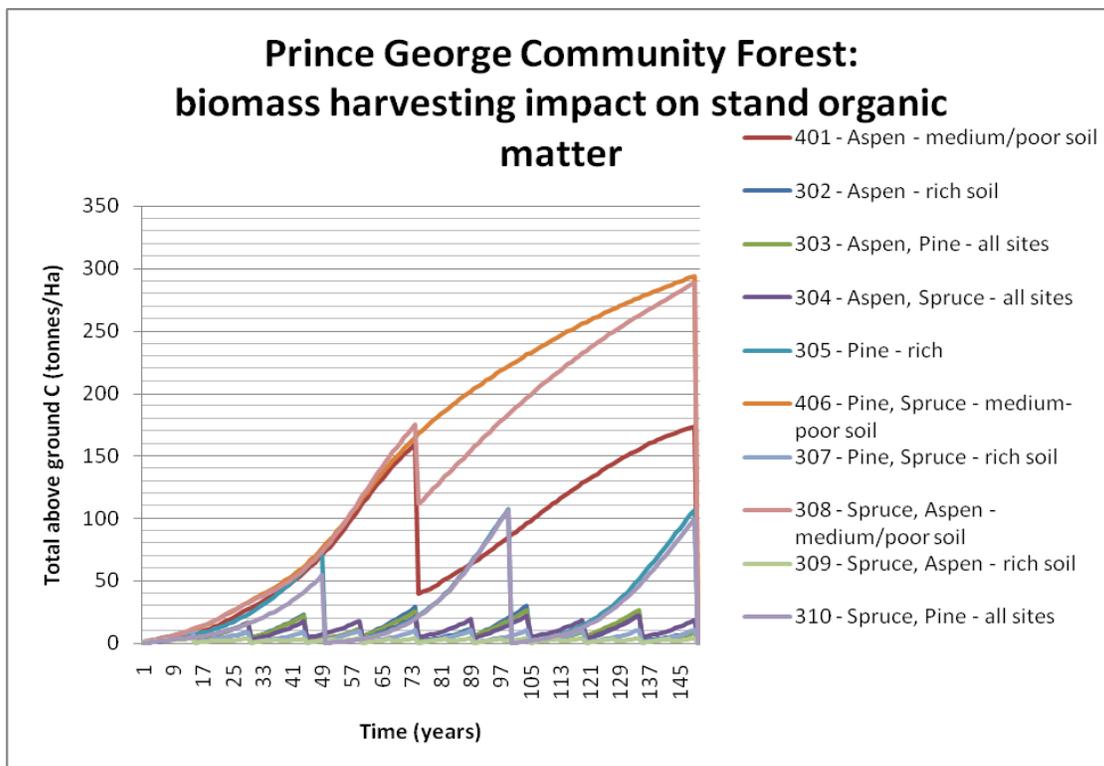

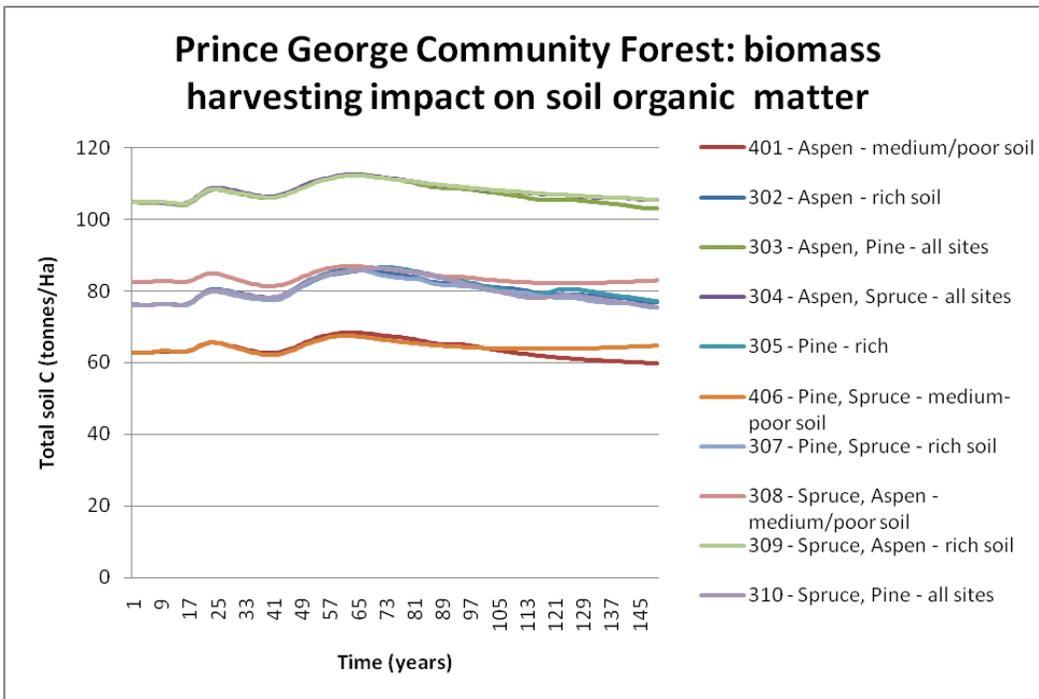**Figure 5: Harvest impact on stand organic matter**

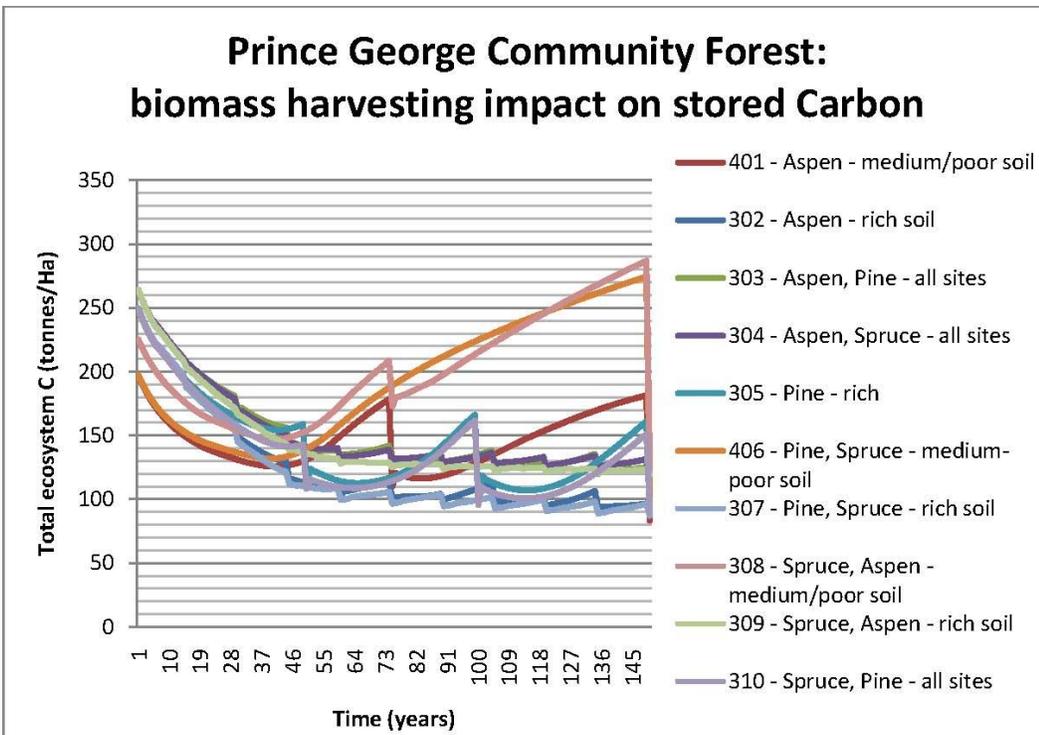**Figure 6: Harvest impact on soil organic matter**

Figure 7: Harvest impact on ecosystem stored carbon

Figures 8 and 9 map the sustainable yield biomass capacity, by forest stand within the PGCF, given in Bone Dry Tonnes[6]/hectare/year (BDT/Ha/yr). High and very high wildfire risk areas that are outside of these analyzed biomass production stands are included in the maps. The 30m riparian areas for all creeks are excluded. The areas without classification where the underlying air photo is visible consist mainly of urban areas without significant tree canopy, or agricultural areas that lacked a dominant tree species in the GIS vegetation inventory. Biomass yields varied according to stand type, but ranged from 1 to 3 BDT/Ha/yr. Averaged across all stand types throughout the PGCF, the sustainable harvesting rate suggested by FORECAST simulations would be 1.2 BDT/ha/yr. The majority of forest stands are in the mid- and upper production potential class (2 – 3 BDT/Ha/yr), compared to the lower productivity stands (<=1 BDT/Ha/yr). Site conditions and quality varies between stands, as does management strategy (i.e. harvesting rotation lengths) as well as the means to achieve these rates of extraction (eg. thinning, selective removal, two-pass harvest system, etc.). The actual biomass harvested each year will be variable, depending upon management harvesting strategies.

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[6] Bone Dry Tonnes (BDT) is the mass of wood once all water has been removed by a drying process such as air-drying, oven-heated by biomass or natural gas.
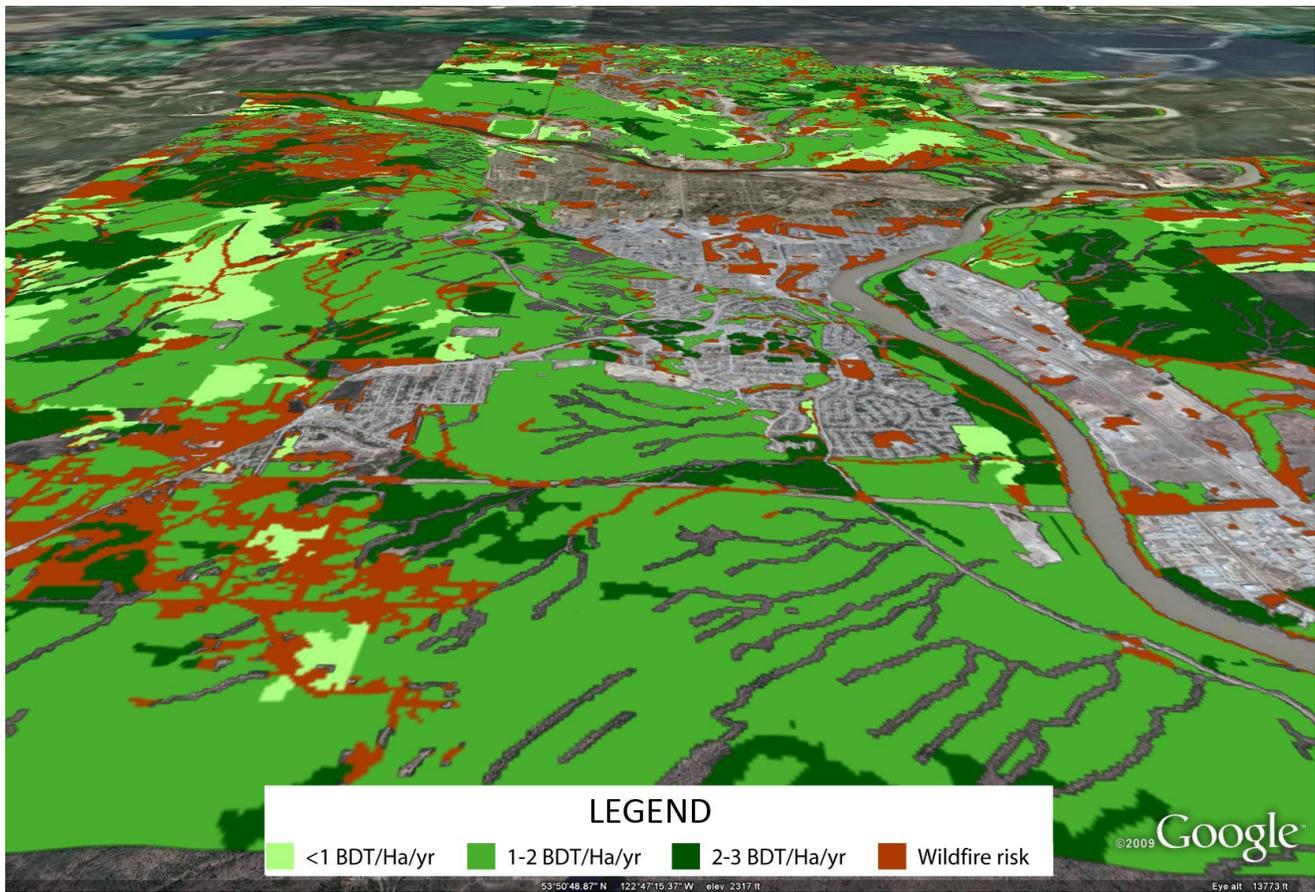
Figure 8: Biomass production potential of forest stands in the Prince George Community Forest, perspective view rendered in Google Earth
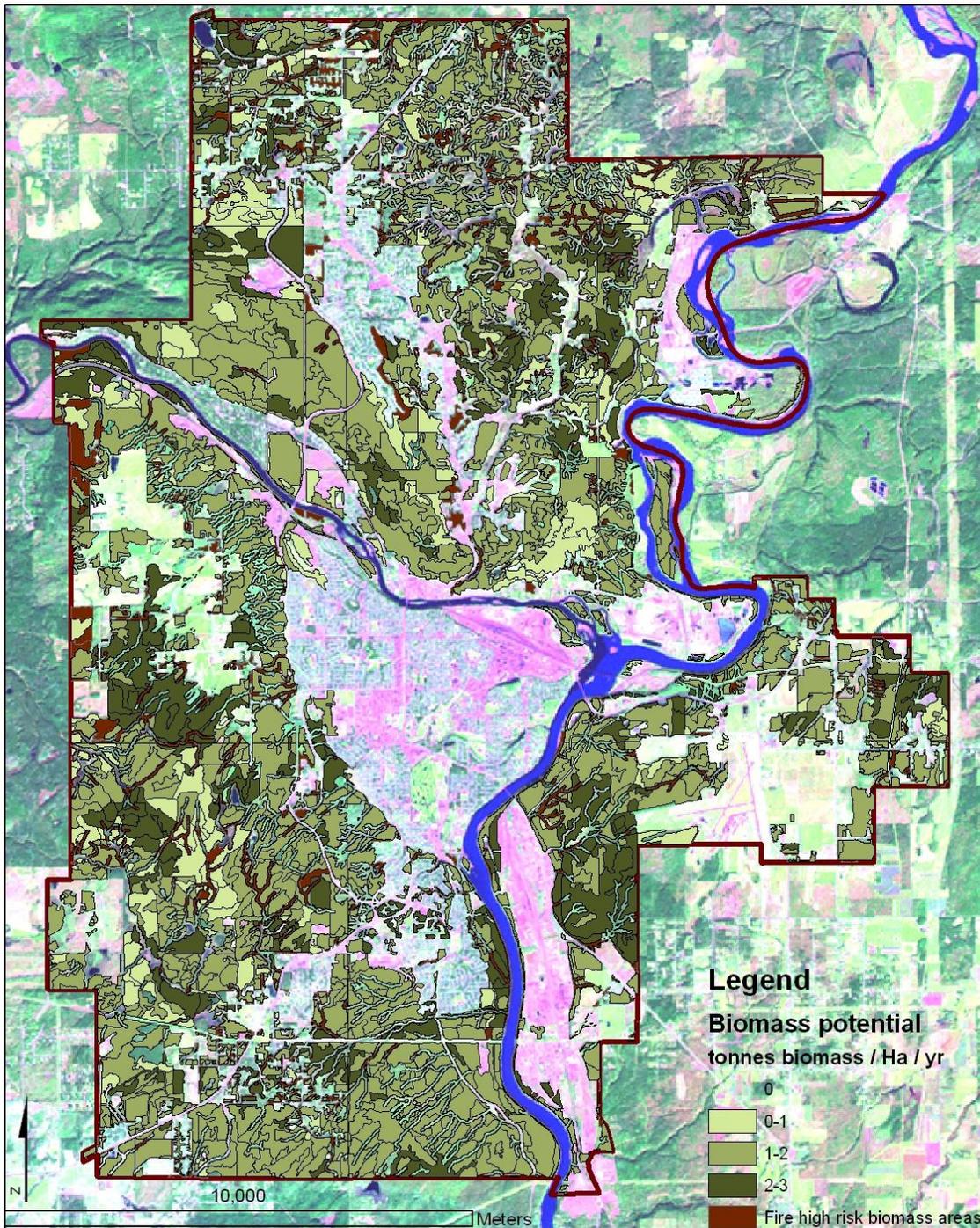
Prince George - biomass generation potential

Figure 9: Biomass production potential of forest stands in the Prince George Community Forest

Based on the forest types and conditions prevailing in the Prince George Community Forest, the sustainable yield modeling described above suggests that the PGCF has the capacity to sustainably produce 23,300 BDT of biomass each year over the long term[7]. Most harvesting and thinning is presumed, for the purposes of this study, to come from Crown and municipal land. 19,500 Ha of the PGCF is forested with a dominant overstory tree species, approximately one third of which are Crown and municipal land. Thus the biomass potential available for use for the Community Energy System from the PGCF is approximately 7,700 BDT/yr. This translates to over 20,000 m3 of harvested wood (trunk, stems, foliage for all species and understory where harvested), significantly higher than the current AAC of 12,000 m3 for Crown lands in the PGCF. This is in part due to biomass harvesting including all above-ground biomass across all species, not just extracting for lumber. An additional 1750 BDT/yr of biomass would be available from sustainably harvesting within high and very high fire risk areas on lands outside the FORECAST analysed stands, bringing the total amount that could be sustainably harvested annually to 9,450 BDT or 29,250 m3.

3.1.7 FROM BIOMASS TO ENERGY CAPACITY

3.1.7.1 RESULTS AND DISCUSSION

Table 5 summarizes the sustainable harvest yields and resulting energy capacity from the PGCF. Total biomass yields, assuming all forested lands were to be harvested, results in potential heat energy generation, not including losses due to system inefficiencies, of 419,700 GJ/year given a conversion rate of 18 GJ/BDT across hardwood and softwood species (Magelli et al., 2009). Crown and municipal lands, identified as the most viable option from an ownership/management perspective, would yield about one third of that, at 138,500 GJ/year. An additional 31,500 GJ/year is available from additional forested lands that require thinning for wildfire management purposes. Thus, depending on management and policy decisions, the available biomass is variable: with wildfire areas included, the energy capacity in the PGCF is 170,000 GJ/year. However, approximately half of this biomass (12,000 m3 or 4500 BDT) is currently removed by the AAC. If the AAC continues to be

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7 Based on averaged annual biomass harvesting; actual harvest rates may vary while still meeting long-term sustainable harvest goals

used for timber production rather than energy use, the potential energy capacity would be reduced to 89,100 GJ/year. For the purposes of this study, the calculations of potential energy supply use the sustainable biomass yield from Crown and municipal land. Thus, it is assumed that 138,500 GJ/year is the potential energy capacity from the PGCF. The realized energy capacity, which accounts for system efficiencies of 80%, would be 110,800 GJ/year.

Table 5: Summary of potential biomass and energy production for various management scales

Sustainably harvested biomass from:	Biomass Production (BDT/yr)	Potential Heat Energy Capacity[1] GJ/yr	Realized Heat Energy Capacity[2] GJ/yr	Number of dwelling units that could be supplied heat and hot water[3]
All forest lands within PGCF	23,300	419,700	335,760	4330
Crown and municipal lands in the PGCF	**7,700**	**138,500**	**110,800**	**1430**
Fire risk thinning on forested lands not in Crown and municipal lands in the PGCF	1,750	31,500	25,200	325
Crown land, municipal land, fire risk thinning on forested lands in the PGCF minus the Crown Land AAC	4,950	89,100	71,290	920
Approximate 20km forest buffer around Prince George[4]	129,105	2,775,750[5]	N/A	Meets existing residential heating demand, assuming 80% efficient systems

[1] The total energy potential contained in the biomass (includes energy that would be lost due to conversion inefficiencies)

[2] This accounts for 80% system efficiency as a result of the conversion of biomass to usable heat (James et al., 2006; Bolhàr-Nordenkampf et al., 2003). The conversion of biomass to electricity would be approximately 25% (Bolhàr-Nordenkampf, 2003).

[3] Assumes average annual heat/hot water energy demand of 97 GJ/yr per residential unit for Prince George (Hyla, 2009), with assumed efficiencies of 80% (i.e. actual energy used is 77.6 GJ/year/unit). New multi-family dwelling units in the downtown area could minimally have between 20 – 50% reduced space heat energy demand due to improved building design and shared walls; thus the number of future units supplied could be larger than the numbers given here.

[4] This does not include an assessment that these lands are forested and harvestable, and serves only as a beginning point for discussion purposes – further analysis, including a FORECAST model simulation, would be required to determine a more accurate sustainable yield buffer.

[5] The residential energy consumption in Prince George was 3,701,000 Gigajoules in 2002 (Sheltair, 2007). Assuming that approximately 75% of the energy consumed was used for space heating and hot water (Pond, 2008; Webster,

unpublished), the total heating demand is calculated at 2,775,750 GJ/year.

The Community Energy System's proposed demand is 162,500 GJ/year (FBV, 2006). Eighty percent of the supply energy is proposed to come from waste heat from existing industrial sites, leaving the remaining 20% or 32,500 GJ/year supplied by natural gas. The PGCF has enough biomass, sustainably harvested, to meet and exceed this remaining demand. However, a more efficient use of this energy would be to provide for additional base heating loads. As shown in Figure 10, base heating loads are around 1/3rd of peak heating requirements for a district energy system, and sizing equipment to provide for this is ideal, as this load represents 80% to 85% of the system's energy needs. Peak loads are therefore 2/3rds of system capacity, but only 15% - 20% of its energy needs. As peak loads often require rapid ramping up and subsequent downsizing of system capacity, they are better met by energy sources such as natural gas or hydropower. Thus, the PGCF realized biomass energy capacity of 110,800 GJ/year would enable the CES to increase its baseload supply from 130,000 GJ/year to 240,800 GJ/year, adding 85%.
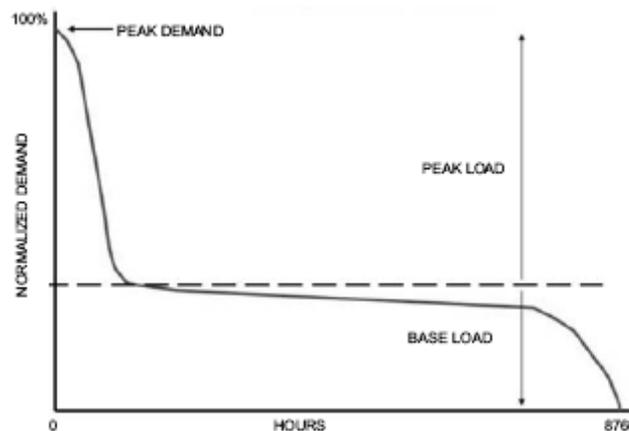
Figure 10: Typical load duration curve for district energy systems (Church, 2007)

If the heat energy generated from sustainably harvested biomass on Crown and municipal lands in the PGCF was applied to the residential sector instead, it would satisfy about 5% of the annual heating and hot water demand for the whole of Prince George's residential stock[8]. Using the FORECAST model's sustainable harvesting rates of 1 – 3 BDT/Ha, with an average extraction around 1.2 BDT/Ha, the energy

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[8] based on total residential demand of 2,775,750 GJ/year, and 138,500 GJ/year of PGCF biomass energy

available per hectare is 21.5 GJ/Ha/yr.   Thus, 129,105 Ha would thus be required to satisfy Prince George's 2002 residential heating demand of 2,775,750 GJ. This is 25 times more energy production than what is available from PGCF Crown and municipal lands. If all of the forest land outside of its municipal boundary was harvestable, a buffer of approximately 20 km around the city would be the land base required to harvest forest stock for residential heat, as shown in Table 5[9]. Bringing all residences off of natural gas would achieve about a 12% reduction in total community GHGs (based on Sheltair's 2007 community emission inventory and the BC Community Energy and Emissions Inventory (Hyla, 2009)). Such a reduction would achieve one third of the 2020 provincial emissions reduction target. For more discussion on GHG reductions potential from biomass, see Appendix D.

A last note: if private land and woodlot owners were to be involved in the production of biomass within the PGCF, the estimate for biomass energy capacity would be significantly increased due to the expansion of the total harvestable area increase. Also, yields of intensively managed biomass plantations have been found to reach from 8 to 18 BDT/Ha/yr although this would be require management practices outside of what has been modeled in this study as being sustainable. A thorough review of such research findings is presented in Powell, 2007. This potential has not been studied in depth for this phase of the study.

3.1.8 ADDITIONAL BIOMASS CONSIDERATIONS

3.1.8.1 AIR EMISSIONS

Air quality is a major concern in the Prince George area, particularly dust particles such as ash, smoke and soot. The proposed CES energy technologies (discussed in Appendix C) differ significantly in the amount of particulate emissions they produce compared to current particulate sources around Prince George. Currently, wildfires are the highest particulate emitters, followed by slash pile, beehive and silo burning. Industrial combustion processes can significantly reduce particulate emissions using numerous

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[9] As stated in footnote 4 for Table 5, the 20km buffer does not include an assessment that these lands are forested and harvestable – further analysis using VRI GIS data and a FORECAST model simulation, would be required to determine a more accurate sustainable yield buffer.

technologies such as complete burning, carbon burnout, flue gas cleaning and electrostatic precipitators which remove particles from emissions using an electrostatic charge. Smaller combustion systems may rely on electrostatic precipitators, scrubbers (including a variety of technologies which use fibrous filters, liquids or solvents), and baghouses (filters out an airstream like a vacuum cleaner), the latter being most effective if volumes and temperatures are moderate (ENVINT, 2008). Costs for these systems vary greatly, from \$3000 – \$172,000/m3/sec (EPA, accessed 2009). Pellet stoves, which are considered to have good emissions, emit 0.45g of $dust_{(PM10)}$ (particles up to 10 micrometers in diameter) per kWh, whereas gasification reduces particulate emissions to levels similar to natural gas at less than 0.01g of $dust_{(PM10)}$ per kWh.   Thus the CES would produce a total of .1076 tonnes of $dust_{(PM10)}$ from burning sustainably harvested biomass from Crown and municipal lands in the PGCF. As a comparison, the same amount of particulates would be emitted by one average low-sulphur diesel bus traveling a distance of 31,647 kilometres[10]. Particulate emissions from coal are 10 – 30x higher (ENVINT, 2008). In 2001, 30,580 tonnes of $dust_{(PM10)}$ were estimated to be emitted in the Prince George airshed (PGATMC, 1996). It is recommended that if biomass is to be used for energy production in the Prince George area, then gasification be employed and carefully monitored in the biomass conversion process to minimise any additional air pollution while reducing the community's carbon emissions.

3.1.8.2 APPLICATION OF MUNICIPAL BIOSOLIDS TO BIOMASS PRODUCTION

In order to maintain and improve the sustainability of long-term biomass harvesting, city biosolids could be applied to poor quality soil which the FORECAST modelling suggests could otherwise suffer from long-term declines in soil organic matter. Application of treated "Class B" municipal wastewater solids, mixed with pulp mill sludge and ash from combustion has been shown to increase forest productivity from 50 to 400%, along with improvements to soil quality, habitat, water quality and aesthetics (Sylvis Environmental, 2003). Fertilization of forested areas with this material has been applied in King County by Weyerhaeuser, in Metro Vancouver, and on Vancouver Island by Malaspina University College and the City of Nanaimo. Prince George has traditionally recycled their biosolids in the fertilization of agricultural land, and has since seen successful results using this waste material in gravel pit, road and landings

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[10] An average low-sulphur diesel bus emits 5.5g $dust_{(PM10)}$ per mile (0.0000034 tonnes/km) (Lowell et al., 2003).

reclamation projects, similar to many other jurisdictions for decades. Testing on water quality following biosolid application in the Prince George area showed a lack of contamination in surface and well water (Sylvis Environmental, 2003). Further forest fertilization research conducted by Sylvis Environmental experimental trials showed the positive impact of biosolid application on local stand types (2003). Tree height and diameter were measured for lodgepole pine stands after successive years of fertilization and fertilized trees were found to have significantly greater volume growth, largely through increases in diameter. Needle weight also increased dramatically, with significant increases in nitrogen, phosphorus, sulphur, zinc and iron.

Therefore, there is an opportunity to recycle municipal biosolids onto forest lands managed for renewable biomass energy production that will improve forest production while reducing the risk of long term productivity decline. Issues such as availability of biosolids for both agricultural use and forest biomass production, and public acceptability issues surrounding this, would need to be studied further. Preliminary investigations by Prince George municipal staff suggest that the city produces around 4250 m3 of class B biosolids annually. Given that approximately 0.023 dry tonnes/yr of biosolids are produced per person in North America (USEPA, 2009), approximately 1633 BDT should be available annually for Prince George, which, if fully committed to forest biomass stands, would allow for fertilization of at least 91-217 Ha[11].

3.8.1.3 PROPOSED GUIDELINES FOR PGCF MANAGEMENT

Based on the FORECAST analysis, the following preliminary management guidelines are proposed for consideration by the City and relevant stakeholders in planning for future biomass production for forest stands with native species:

1. Sites with rich soils can sustain more intensive management with short rotation (15-30 years for coniferous stands, 8-30 years for deciduous stands), and in many cases moderate understory harvesting (50% thinning).

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[11] This range is based on the lower application rates in King County of 7.5 tonnes/Ha, and the Sylvis Environmental study application rates of 18 tonnes/Ha (2003).

2. Sites with poor soil have very low productivity and require long rotation lengths (75-150 years for coniferous stands, 30-75 years for deciduous stands), offering a limited relative contribution to biomass volumes. There is potential for these stands to be either supplemented with non-fossil fuel derived fertilizers such as biosolids, or considered for other uses such as conservation areas. Poor soil quality sites mapped in this study comprise 2300 hectares within the whole PGCF.

3. A representative multi-stakeholder PGCF working group or other task force could be struck to consider, plan, communicate, monitor, and help manage the biomass production activities for local energy use. For sustainable forest biomass system development in an urban area, the role of the Community Forester to the community is critical in informing the public and landowners, conveying and resolving concerns or questions, and providing the necessary range of expertise to manage a new local energy resource that is produced, processed and consumed within Prince George for the benefit of its citizens.

3.1.4 CONCLUSIONS ON BIOMASS ENERGY AND PRINCE GEORGE

Biomass in the PGCF can be harvested in a manner which doesn't degrade ecosystem quality and is congruent with current land-use and industrial needs. A Community Energy System has been previously envisioned for Prince George, and this concept presents an opportunity to incorporate local biomass into community planning. Technologies exist to reduce the impact of biomass combustion on local air quality while also reducing community carbon dioxide emissions. Enough biomass can be sustainably harvested from the PGCF to provide an additional 85% to the proposed baseload coming from waste industrial heat. The additional sustainable yield biomass heat energy could be used to expand the proposed Community Energy System to more civic and commercial buildings, or provide low carbon heat for a significant number of additional homes in the downtown area to form the basis of a compact, lower-carbon downtown community.

3.2 SOLAR THERMAL ENERGY

The second example of renewable energy capacity analysis is solar thermal heat. This form of renewable energy uses the sun's energy to heat water which may be used for hot water or space heating needs. Although elements of the following analysis could be applied to solar photovoltaic energy (the production of electricity from solar energy), and solar air heat (using heat from the air outside of a building, we will focus on solar thermal heat.

3.2.1 SOLAR THERMAL IN PRINCE GEORGE

Solar thermal hot water generation is a renewable energy success story, with demonstrated effectiveness and a relatively short payback period (CANMET, 2004; NRCAN, 2003). Of primary importance to all solar energy generation (hot water, photovoltaic electricity, passive solar heating or solar air heating) is the incoming solar radiation at the site of collection. Table 3 provides the mean annual solar insolation for various cities in Canada, based on 1974 -1993 data from meteorological stations; the data thus accounts for aerosols and cloud cover (Canadian Forest Service, 2009). Regway, Saskatchewan has the highest mean annual solar insolation in Canada, while Prince Rupert, BC has one of Canada's lowest solar insolation levels. Prince George's mean annual solar insolation is midway between these levels at 11.5 MJ/m^2. Solar insolation is variable throughout the year, and cities in northern latitudes have significantly higher insolation values during the summer months (see Table 6).

Table 6: Mean annual solar insolation for various Canadian cities. Data courtesy of the Canadian Forest Service (Canadian Forest Service, 2009).

	Regway, SK	Elkford, BC	Vancouver, BC	Prince Rupert, BC	Prince George, BC
Mean Annual Solar Insolation (MJ/m^2)	13.9	13.3	11.9	9.3	11.5

Most manufacturers, energy agencies, and guides suggest that solar thermal hot water systems should be sized primarily for summer use, both to maximize efficiency, and to prevent problems from

summer overheating due to excessive winter capacity (CANMET, 2004)[12]. Table 7 provides an estimate of potential energy generation at an evacuated tube solar collector in each of four Canadian cities during the shoulder months of April and October, and the peak summer month of July.

Table 7: Solar insolation data for Prince George for different surface orientations. All values in kWh/m2. Data courtesy of the Canadian Forest Service (Canadian Forest Service, 2009).

	South-facing vertical (tilt=90°)	South-facing, tilt=latitude	South-facing, tilt=latitude+ 15°	South-facing, tilt=latitude-15°	Horizontal (tilt=0°)	Two-axis sun-tracking
January	2.1	2.0	2.1	1.8	0.7	2.4
February	3.0	3.1	3.2	2.9	1.6	3.7
March	3.9	4.5	4.4	4.4	3.0	5.8
April	3.7	5.1	4.7	5.3	4.5	7.4
May	3.1	4.9	4.2	5.3	5.4	7.6
June	3.2	5.2	4.4	5.7	5.9	8.5
July	3.3	5.3	4.6	5.8	5.9	8.7
August	3.5	5.2	4.6	5.4	4.9	7.8
September	3.5	4.4	4.2	4.4	3.3	6.0
October	2.7	3.0	3.0	2.9	1.8	3.7
November	2.2	2.1	2.2	1.9	0.9	2.5
December	1.6	1.5	1.6	1.4	0.5	1.8
Annual	3.0	3.9	3.6	3.9	3.2	5.5

The values were calculated as:
System contribution (KWh/m2) = monthly insolation (KWh/m2) x system efficiency

The calculations were for a 3m^2 Thermomax Mazdon evacuated tube solar hot water collector. System efficiency is difficult to calculate, because it is dependent on the relationship between the heat of the system and the heat of the ambient air. Evacuated tube systems are the most efficient (when compared to unglazed and glazed flat plate systems), and show the lowest losses in colder environments. For the purpose of these calculations, a conservative estimate of 40% system efficiency was used.

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[12] A system sized for full winter demand would be so large as to be economically unviable.

Table 8: An estimate of energy generated at a 3m^2 south-facing, tilted at latitude evacuated tube solar hot water collector for select Canadian cities during the months of April, July and October, assuming 40% system efficiency.

	Estimated energy generated at solar thermal collector (kWh)		
Location	**April**	**July**	**October**
Regway, SK	215.76	226.92	182.28
Elkford, BC	197.16	215.76	171.12
Vancouver, BC	163.68	197.16	119.04

Calculating solar thermal hot water needs and system sizing for individual buildings is a relatively straightforward exercise, and several tools have been developed to facilitate this process. NRCan's RETSCREEN software (CANMET, 2004) is in use around the world, and can predict system requirements and costing based on relatively simple load and building data. For the Prince George project, however, energy demand and energy supply are being addressed concurrently in separate projects and load numbers (as well as building uses) were not available for assessing solar thermal hot water potential in time for this report. It was necessary, therefore, to develop a methodology for assessing solar thermal hot water capacity at a broader spatial scale. The broader scale method also serves the research goal of energy capacity assessments for community energy planning, in this case, assessing community energy capacity for Prince George's downtown core.

3.2.2 METHODOLOGY

The essential characteristic required to calculate or estimate solar thermal hot water generation capacity is the amount of solar insolation hitting the collector panel (for accurate assessments, system losses are also required). In order to make that calculation, you need to know the solar insolation values for the site in question, and an approximation of the collector area. While more accurate methods for calculating site-specific solar radiation are being developed (see e.g. Gasper, 2009; Pavlovski, 2009;

Tooke, 2009 and pers. comm.[13]), the Canadian Forest Service has developed useful indices of solar insolation values for many Canadian municipalities (Canadian Forest Service, 2009). It is these indices of solar insolation for Prince George that were used for the calculations in this analysis. Given the CFS solar insolation values, the goal of this analysis was to develop a methodology for approximating solar hot water collector area at a neighbourhood or community scale for Prince George.

In order to make the analysis manageable, it was necessary to define a subsection of Prince George to analyze. Coverage of the entire city would have required automation – a step that was beyond the scope of the current study. Dr. Brad Bass from Environment Canada and colleagues at University of Toronto and UNBC constructed a 3-dimensional SketchUp model for the Smart Growth on the Ground Study Area (a portion of the downtown of Prince George). This SketchUp model provided the opportunity to evaluate inter-building shading, and therefore it was decided to conduct the solar thermal hot water capacity analysis for the same spatial area.

The overall study area was 530,591 m^2, of which 159,746m^2 was made up of building roofs (see Table 9). This table provided the gross roof area for the calculations of available roof for solar collector installation. While other collector options exist (ground-based, wall mounted, sun tracking, etc.), it was decided to evaluate only fixed, roof-mounted, south facing collectors to eliminate variables, and because of the significant number of flat roofs in the study area.

There are 255 building footprints in the study area. Given the methodological constraints previously discussed, and the large number of buildings to be analyzed, individual building analysis was not practical. Because large-scale models of potential energy generation and costing tend to be aspatial, a new methodology fitted to the needs of this study area had to be devised, drawing on recent experience in Burnaby, BC (Pond, 2008). For the current study, it was decided that a suitability analysis for building roofs based on inter-building shading and the percentage of available (non-obstructed) roof area was a useful way of approximating the area on which solar collectors could be located.

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[13] Based on Tooke, Thoreau Rory, N. Coops and J. Voogt. 2009. "Assessment of Urban Tree Shade Using Fused LiDAR and High Spatial Resolution Imagery." *Urban Remote Sensing Joint Event.*

Shading was examined for each building at the vernal equinox, summer solstice and autumnal equinox, using the Sketchup model (see Figure 11). Each building was assigned a weight based on a visual examination of daily shading between the hours of 9:00 am and 5:00 pm for each of the above dates. Weighting factors were 0 for no significant shading, 1 for moderate shading (less than 50% shading for less than 2 hours), and 4 for significant shading (greater than 50% shading for greater than 2 hours). Figure 12 shows the resulting inter-building shading map. Those buildings with a weighting of 4 were removed from the later calculations of suitable roof area. Shading from trees, buildings and landforms outside the study area was not taken into consideration, and may further reduce the solar thermal capacity of the study area.
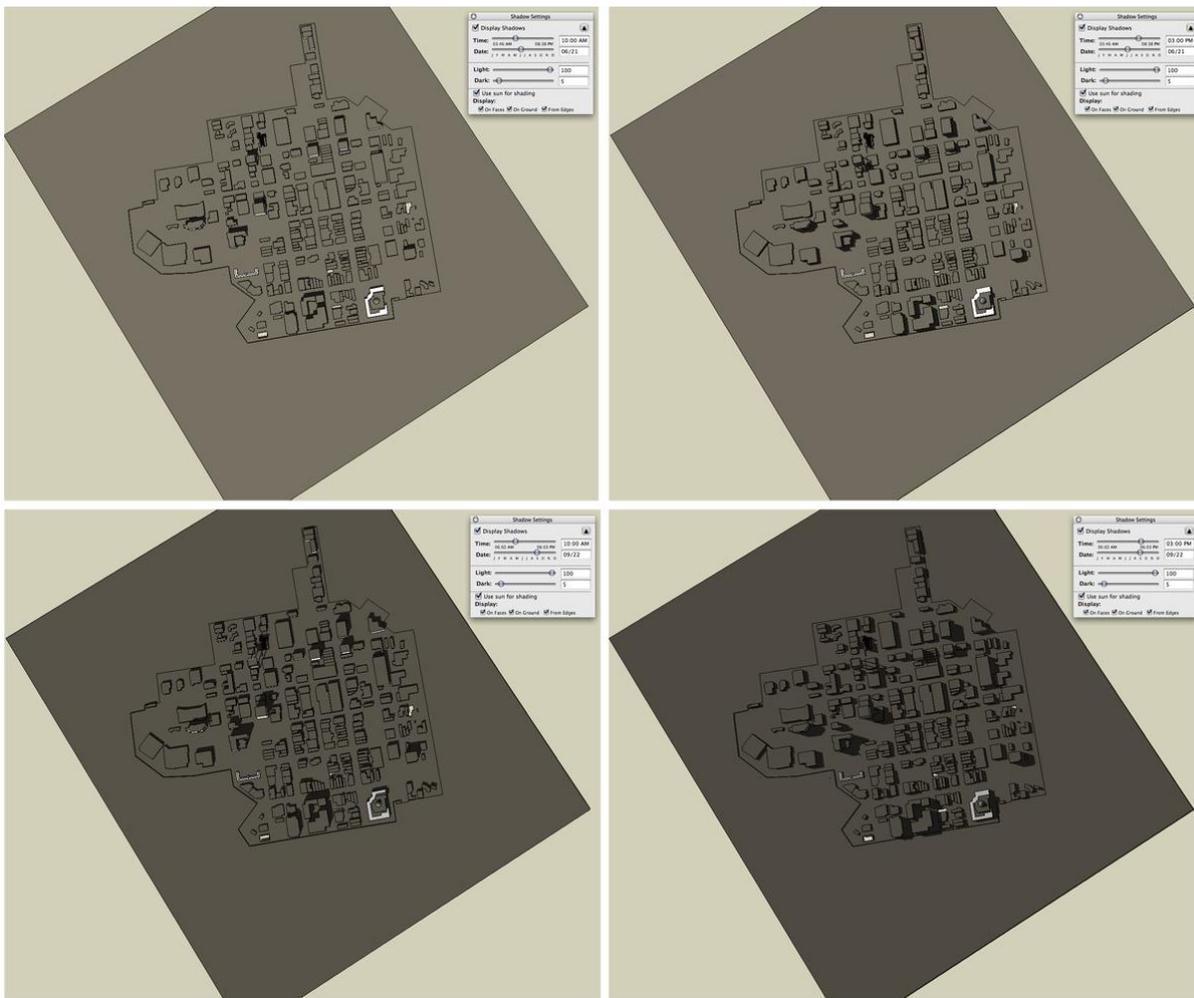
Figure 11: Sketchup shading studies for the summer solstice (top) and autumnal equinox (bottom) for 10 am (left) and 3 pm (right).
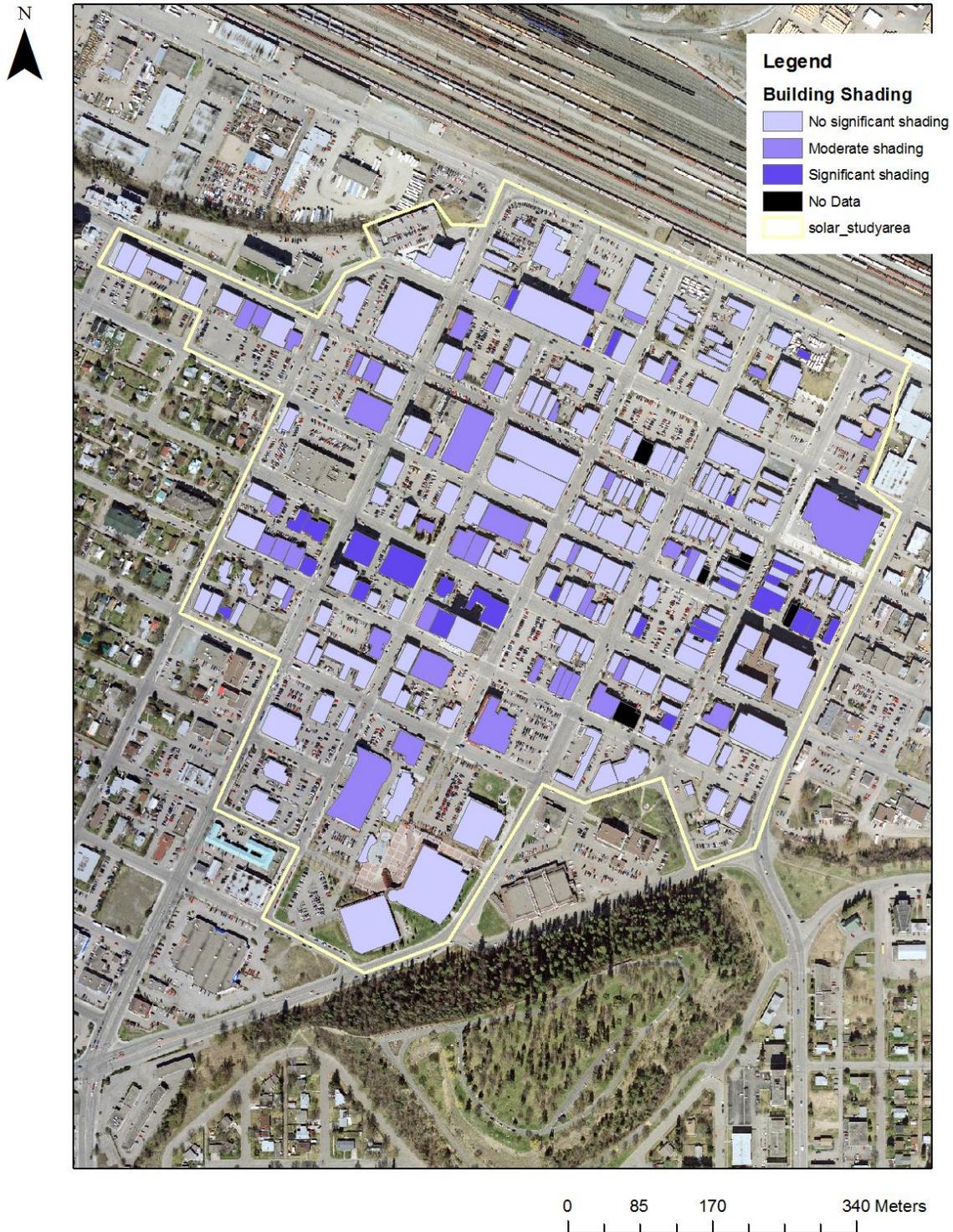
Figure 12: A map showing inter-building shading for buildings in the study area.

To estimate the available roof area for solar thermal hot water panel installation, a photo interpretation analysis was conducted for all buildings in the study area. Four weights were assigned to buildings based on how much of their gross roof area was visibly suitable for panel installation. Roofs were assigned a value of 0 if 100% of the roof was available, 1 if 75% of the roof was available, 2 if 50% of the roof was available, 3 if 25% of the roof was available, and 4 if 0% of the roof was available. Sloped roofs (not facing southeast to southwest), HVAC equipment, stacks, sectioned roofs, and unidentified objects were all considered obstacles to panel installation. Potential impacts of panels on HVAC airflow, etc., is difficult to approximate, therefore relatively conservative weights were applied. The resulting map is shown in Figure 13. The available roof area for panel installation was calculated by multiplying the percent of available roof area according to category by the gross roof area for each building and then summing the resultant values. The resulting total available roof area was 62,620m^2. This method enables capacity estimation for a study area without having to do building by building engineering assessments.

Figure 13: Percentage of each building that is available for solar thermal panel installation.

A composite building suitability map for solar thermal panel installation was created by adding the weights for building shading and available roof area (see Figure 14 and Table 8). Those buildings with low shading and a large percentage of available roof space (combined weights of 0 to 3) were considered suitable for solar thermal installations. Buildings with a suitability score greater than or equal to 4 were not considered suitable, and therefore were not included in the calculations of solar thermal capacity.

Table 8: Composite suitability weights created by merging the shading map with the available roof area map.

		WEIGHTS FOR ROOF AREA AVAILABLE (%)				
		0 (100%)	1 (75%)	2 (50%)	3 (25%)	4 (0%)
WEIGHTS FOR INTER-BUILDING SHADING	O (no sig. shading)	0	1	2	3	4
	1 (mod shading)	1	2	3	4	5
	4 (sig shading)	4	5	6	8	8

Figure 14: Cumulative suitability (shading and available roof area) for each of the buildings in the study area.

The final stage in the capacity analysis was to estimate the amount of roof space that could potentially be occupied by solar thermal collectors. An important factor in this estimation was to determine the distance necessary between rows of panels to prevent them shading each other. To estimate shading implications, models of evacuated tube collectors 2.13m in length at an angle of 54 degrees (matching Prince George's latitude) were constructed in Sketchup and oriented south (see Figure 15). Shading studies were then conducted for noon at the vernal equinox, October 31st and the winter solstice to determine the necessary spacing in more constrained times of year with lower sun-angles. The studies were done assuming a flat roof. For the vernal equinox, 3.5m was required between panels to prevent shading. Based on this analysis it was determined that panels could occupy approximately 35% of available roof area with minimal shading in the most viable summer season[14]. Although only 35% of the roof area would be used for panels, the panel area itself is larger due to the angled installation, and equal to 53% of the roof area.
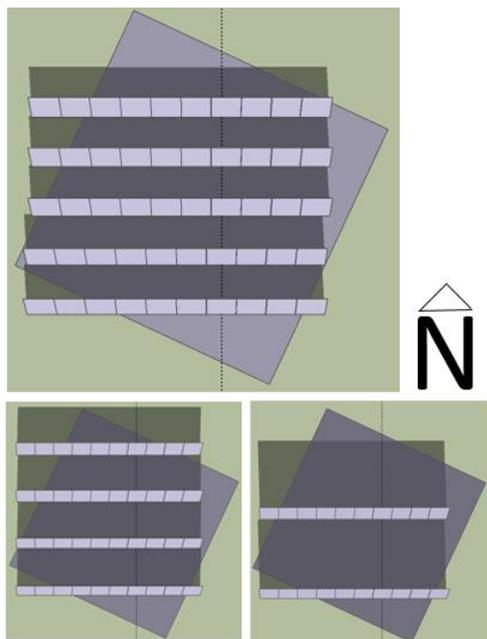
Figure 15. A SketchUp model showing the required inter-panel spacing for evacuated tube solar panels at the vernal equinox (top), October 31st (bottom left) and winter solstice, December 21st (bottom right). The roof shown is 20mx20m, angled at the same degree as the roads and buildings in Prince George's downtown.

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[14] For October 31st, a spacing of 5.4 m was necessary, resulting in only 23% of available roof space being used for panels, and for December 21st, a spacing of 9m means that only 14% of the roof can be used for panels; also shown in Figure 15.

3.2.3 RESULTS

Using the described methodology and approximation for available roof and solar thermal panel area, it was possible to estimate the installed capacity for solar thermal panels as 29,953m^2. A summary table of the different area calculations can be seen in Table 9.

Table 9: A summary table of the different area values used and calculated in this study.

Study Area (m2)	Total Roof Area (m^2)	Unshaded Roof Area (m^2)	Unobstructed Roof Area (m^2)	Suitable Roof Area (m^2)	Solar Collector Area (m^2)
530591	159746	148373	62620	56516	29953

Monthly solar insolation at the solar collectors was then estimated for March through September by multiplying the mean daily insolation value for panels tilted to latitude for each month by the estimated solar collector area and the number of days in the month. These values can be seen in Table 10. Potential system energy contribution for the solar panels at the panel, before system losses, was then calculated using the formula (Thermo Technologies, 2009; Build it Solar, 2009):

System Contribution = thermal insolation at the panel x system efficiency

A conservative estimate for evacuated tubes of 40% was used to approximate system efficiency. The resulting potential system energy values for March through September can be seen in Table 14. The amount of energy generated for these months (414,556 kWh or 1492 GJ) would be roughly equivalent to providing hot water for approximately 41 single family dwellings in the Prince George area for one year, using an estimate of 10,000 kWh of energy to provide domestic hot water to a single family dwelling (Pond, 2008).

Table 10: Calculated values for solar insolation at the collector and the potential system contribution of the solar thermal collectors for the months of March through September.

Month	South facing, tilt=latitude (kWh)	Daily insolation at collector (kWh)	Daily system potential (kWh)	Monthly system potential (kWh)
March	4.5	134790.75	53916.3	1671405.3
April	5.1	152762.85	61105.14	1833154.2
May	4.9	146772.15	58708.86	1819974.66
June	5.2	155758.2	62303.28	1869098.4
July	5.3	158753.55	63501.42	1968544.02
August	5.2	155758.2	62303.28	1931401.68
September	4.4	131795.4	52718.16	1581544.8
March - September				414556.4

The results of this preliminary solar thermal case study, summarized in Table 11, include an estimate of solar thermal hot water capacity for the study area, as well as a preliminary suitability map for the buildings in the study area. This was a novel and exploratory approach to addressing solar hot water capacity at the neighbourhood/community scale and, as such, there are a number of caveats and issues that require review, and further study. These considerations will be discussed in the next section.

Table 11: summary of solar thermal heat energy method and result

ENERGY SYSTEM	SPATIAL ANALYSIS USED + CONVERSIONS USED	ENERGY SUPPLIED		
		SPACE HEAT	HOT WATER	ELECTRICITY
Solar thermal, evacuated tubes	Shading by other buildings Roof obstructions Rack spacing 40% efficiency of incoming radiation	N/A	1492 GJ (March to September)	N/A

3.2.3 DISCUSSION AND CAVEATS

Conducting this type of analysis presents a number of challenges. Perhaps primary amongst those challenges is the issue of scale, and the desire to spatialize. As mentioned previously, most energy modeling occurs either at the building scale, in the form of highly detailed engineering models, or at much larger scales as aspatial econometric models. Conducting spatial modeling at community scales

presents many problems in terms of determining where to abstract or generalize, and how to aggregate. In the current study, one of the main difficulties was the lack of demand numbers and an understanding of the functions of the individual buildings (from which load estimates may have been derived). Solar hot water heating is typically analyzed based on loads (CANMET, 2004), and determining capacity without those loads required thinking about the problem in a different way.

In addition, spatializing solar hot water capacity at this scale presents the possibility that consumers of the information will infer a level of detail that is not intended. For example, the composite suitability map should not be taken as an accurate representation of the final potential of each building. Factors such as roof construction, interaction with existing equipment, structural considerations, snow loading, building hot water demand, etc. need to be taken into account. The results of this study should be taken as a composite view of potential capacity for the study area, with available supply being developed with more detailed analysis.

Previous energy mapping that has included some estimation of solar potential has tended to be more general (Solar Atlas of Canada, accessed 2009), indicating areas that may be suitable for solar energy generation based on parameters of urban form such as density (see e.g. Canadian Urban Institute, 2008). Some new techniques are being developed that offer promise for more accurately assessing solar generation capacity (see e.g. Christian, 2009; Pavlovski, 2009). These methods require LIDAR data to better estimate solar energy potential. Work at UBC (Tooke et al, 2009) with LIDAR presents the possibility of improving the accuracy of this methodology, and automating some of the analysis. Incorporation of these technologies may make solar thermal, photovoltaic and passive solar analyses more feasible for interested communities.

The methodology used here was an exploratory first pass that requires review and refinement, but should prove useful as grounds for discussion and further development for addressing energy spatially in a rapid assessment at the community scale. It should also provide an estimate of solar thermal capacity for the study area.

In order for City staff and building owners in Prince George to better assess the potential of their buildings for solar thermal installations, a number of other analyses would be required. RETScreen

provides an excellent tool for sizing potential systems based on loads, as well as estimating costs and payback periods. This project's initial capacity mapping should provide a point of entry, indicating specific buildings that could be assessed in more detail. Solar thermal needs to be further assessed for feasibility through integration of the supply methodology developed here, and building hot water demand.

3.2.4 CONCLUSIONS

The results of this solar thermal capacity analysis suggest that solar thermal hot water could be used to augment hot water supply, primarily during the months of March through September. As table 7 demonstrates, incoming radiation during the rest of the year (October-February) is dramatically reduced. This effect would be exacerbated by inter-panel shading, as panel spacing for this study was calculated for the months of March through September. The resulting total annual energy generated by solar hot water panels would, therefore, be higher than that shown in this analysis, but not by a large margin. Use of solar thermal hot water in Prince George, then, would need to be incorporated with other systems, such as natural gas or biofuels-based heating, or geo-exchange, but could reduce the demand for those fuel sources during the months of increased radiation. An accurate assessment of the impacts of solar thermal hot water would require demand numbers for the buildings represented in the study area, to allow pairing of demand and supply distributions. It is possible to estimate that the 414,556 kWh of estimated capacity would serve 41 single family dwellings for one year, but a better matching of demand for the on-site commercial buildings to this capacity would give a better picture of overall feasibility. Monitoring of similar systems in adjacent communities like Quesnel, BC (Solar BC, 2009) would also provide data about the feasibility of solar thermal hot water in Prince George. Unfortunately data on energy savings in that project are not yet available.

Finally, the method described here was for flat roofs with the capacity to install multiple racks per roof with optimal southern orientation. Changes would be required to adapt the methodology to single family dwellings with peaked roofs and various orientations to south. Such a residential analysis would provide further data about the capacity and feasibility for solar thermal hot water in Prince George, which could reasonably be expected to supply a portion of residential hot water demand outside the downtown core.

Based on this early data, solar thermal energy appears to be worthy of further consideration as a

potentially viable source of on-site renewable energy in downtown Prince George, at least during the warmer 8 months of the year. Potential system synergies with geoexchange, passive solar, and other sources such as biomass would have to be explored in more depth. Urban design considerations, including competing roof-top uses (such as roof access for leisure, green roofs and water harvesting), aesthetic impacts, and how to add density while ensuring adequate solar access also require continued exploration and consideration. Finally, other solar technologies including passive solar and solar air may also be feasible in Prince George, and are worth further study.

4. SOCIAL AND PERCEPTUAL BARRIERS TO IMPLEMENTATION

Despite a growing understanding of the negative impacts of human-induced climate change, and the associated need to curb carbon dioxide emissions and adapt to a rapidly changing climate, a variety of barriers combine to make implementation of mitigation actions a challenge. These include technical challenges, structural, policy, and institutional barriers, and perceptual and social barriers. In the past, perhaps the biggest barrier to action was the lack of substitute technologies and infrastructure for alternative energy supplies. However, new technologies for mitigating carbon emissions and adapting to climate change impacts are constantly being developed, and it has been argued that currently available technologies can achieve the emissions targets required to mitigate catastrophic climate change (Pond, 2007; Pacala and Socolow, 2004; and Socolow et al 2004). It is therefore the structural, institutional, policy, perceptual and social barriers that remain the most challenging to overcome.

Semenza et. al. (2008) argues that because large-scale mitigation of high-carbon lifestyles requires international cooperation and support from industry and commerce, perhaps the greatest opportunity for meaningful action lies with individuals voluntarily changing their habits to more sustainable, low-carbon lifestyle choices. Many studies have been completed on this individual level of behaviour change. However, there are growing arguments (eg. Sheppard, Pond and Campbell, 2008) that the collective scale of behaviour change and action at the block, downtown neighbourhood, or community scales, may be a neglected but vital mechanism to enable and reinforce individual action and shifting of social norms. Thus, this section will briefly touch on the structural, institutional and policy barriers, but focus primarily on the perceptual and social barriers to action in the context of social acceptance and collective behaviour change. It will conclude with brief, high-level recommendations for addressing these barriers.

4.1 STRUCTURAL, INSTITUTIONAL AND POLICY BARRIERS

Structural barriers to climate change mitigation are those that exist as a result of the physical structure of a community. Semenza et. al. (2008) gives the example of residents in Portland having a higher rate of alternative transportation use because they have the option to take efficient transit; residents in Houston do not have this infrastructure available in their automobile dominated city.

Similarly, those living in rural areas tend to have few alternatives to automobile transportation because population densities are not high enough to make frequent transit economically viable. Thus, urban design and transportation infrastructure can either enable lower carbon emissions, or remain structural barriers (Whitmarsh, 2008). Strategies for addressing structural barriers through urban design must therefore be thoroughly evaluated on their relative costs and benefits, as is currently addressed by the Smart Growth on the Ground planning process in Prince George.

Institutional barriers are another collective-level barrier that can hamper effective action on renewable energy solutions. Unlike physically-constrained structural barriers, institutional barriers have to do with the structure of our social organizations, and particularly governments. Governmental institutions at all levels (local, regional, provincial, federal) deeply influence the context of climate change responses and actions through the policies they enact, and because their operations have evolved slowly over time. Such slow evolution limits the options of actors within the system (as scarce capital has been invested in, and learning accumulated) about a chosen course of action, a situation termed "path-dependency." The longer this course of action is followed, the more difficult it is to change course and respond to new information and changing contexts (Burch et. al, 2007). As climate change is a rapidly evolving field of study with more being learned about impacts, adaptation and mitigation every day (some of which requires rapid changes in direction), the highly structured organizational framework of institutional systems can be a barrier to timely action.

Policies created before climate change was understood to be an issue requiring widespread mitigation may unintentionally impede the implementation of renewable energy initiatives. For example, form and character aesthetic guidelines may prohibit roof structures such as solar thermal arrays, height restrictions may preclude small-scale wind turbines, and noise restrictions might prohibit air-source heat pumps (Community Energy Association, 2008a). In many cases where policies are not clear, local officials (such as engineers or building officials) may have the discretion to approve or reject applications for renewable energy systems, and these individuals may not have the training, knowledge, or precedents to feel comfortable approving new technologies. Elected officials may not feel able to change policies if they believe the constituency for change among the voting public is not there, or even if they are not sure what the public thinks (see perceptual barriers selection below).

4.1.1 POLICY BARRIERS TO RENEWABLE ENERGY IN PRINCE GEORGE

In 2007, the City of Prince George commissioned their Energy and Greenhouse Gas Management Plan (Sheltair, 2007) as part of the Partners for Climate Protection program (Federation of Canadian Municipalities, 2009). This document presents both corporate and community plans for greenhouse gas reductions by 2012. Key initiatives of interest in the corporate plan include the development of a community energy system for downtown municipal buildings, energy reductions initiatives for civic buildings, and high energy efficiency standards for all new municipal buildings. The community plan includes initiatives to encourage energy efficiency in residential buildings, encourage energy conservation in the commercial, institutional, and light industrial sectors, support industry to reduce energy consumption and GHG emissions, incorporate energy considerations into planning documents, implement Phase 2 of the community energy system, and encourage alternate energy supply systems (Sheltair, 2007).

A preliminary review of municipal bylaws in Prince George was undertaken. The scope of this project did not allow for a more thorough review of other policies and plans, but a full review is recommended to provide a more complete understanding of policy barriers. This preliminary review found the only potential barrier to renewable energy projects to be Guideline 8.5.9 in the zoning bylaw's residential development permit area guidelines, which requires rooftop mechanical equipment to be screened from views (City of Prince George, 2008). This could have an impact on solar thermal installations where overlooked by a neighbour or visible from the street. Perhaps the most notable finding from our preliminary review of bylaws was the lack of any mention of renewable energy, energy efficiency, or climate change. While the Energy and Greenhouse Gas Management Plan lays out a road map for energy efficiency gains and renewable energy projects, municipal bylaws do little to directly support these initiatives. Due to the ambiguity of current bylaws with respect to renewable energy, a proponent of a renewable energy project or energy efficiency program could find the existing bylaw and permitting system confusing to navigate. Efforts to streamline the system and make requirements more explicit could go a long way to encouraging more of these projects in the future. Thus, great potential exists to undertake enabling policy change, not only in bylaws but also in other plans and policies, particularly given the changing policy landscape in BC with the introduction of GHG reduction targets and

policy requirements such as those outlined in the recent Bill 27. These potential changes are outlined in section 4.3.

4.2 PERCEPTUAL & SOCIAL BARRIERS

4.2.1 PERCEPTUAL BARRIERS

A variety of barriers exist with regard to social and behaviour change in climate change planning. These include the difficulty in communicating the urgency of climate change (Moser and Dilling, 2004); a perceived lack of money and time to make the necessary changes; a fatalistic belief that climate change is simply too large a problem to handle, and a lack of public support for mitigative government-led actions and concern over how one's behaviour would be perceived by others (Semenza et. al, 2008).

Moser and Dilling (2004) found it was difficult to convey the urgency of climate action because climate change is a long-term, slow onset cumulative issue that is difficult to detect in the short term, and whose impacts are experienced far from their source (and therefore more easily ignored by humans who have evolved to respond to immediately perceived danger). They argue it is a complex issue communicated largely by scientists who communicate in a manner confusing to the average person, made more confusing by media who attempt to present a balanced story and instead mislead the public. People are left with overwhelming and frightening images of impacts, with little knowledge of what actions they may take to empower them to act. In order to avoid such negative feelings, people may not want to discuss climate change at all (Norgaard, 2006). However, recent research with BC communities in the Interior (eg. Harshaw et al., 2008) and Lower Mainland (Sheppard et al., 2008) suggests high levels of concern, desire for policy change or action by government, and in some cases, personal motivation to change behaviour.

4.2.2 SOCIAL BARRIERS

In many cases, climate change mitigation strategies (such as renewable energy projects) are hampered in their implementation by lack of awareness, public opinion and a lack of social acceptance. Although a strategy may be understood by the public to reduce GHG emissions, proposals often will not be socially acceptable for reasons ranging from aesthetics and localized impacts, to other perceived

environmental impacts, concerns with the planning process, or concern regarding large multinational companies profiting at the expense of the local community.

Concerns about aesthetic and other local impacts are seen in the lack of public acceptance for wind turbine installations in Britain, where some 40% of wind turbine projects are unsuccessful because of local opposition (Elliot, 2003). Opposition frequently arises over the perceived visual impact of turbine structures on iconic or significant natural landscapes, or the perception that noise will be a disturbance. However, it is often the preconceived ideas around a particular technology or project which lead to opposition, rather than the actual impacts themselves. As Elliot (ibid) reports, in pre and post surveys of communities with recent wind installations, residents surveyed after the installation reported being minimally affected by both the aesthetics and noise impacts. In British Columbia, windfarms off Victoria have been rejected on aesthetic grounds, and IPPs such as the Pitt Lake run-of-river project have been shelved due to public opposition. The failure of a biomass heat system for the Southeast False Creek development in Vancouver occurred due to public concern over truck traffic, air pollution, waste, and aesthetic and neighbourhood character issues (Glave, 2007; Rossi, 2007). There is also concern in some quarters that biomass removal at the site of production may reduce ecosystem health or soil productivity, resulting in undesirable visual impacts, or that biomass cultivation may complete with food production.

Similarly, in Prince George, air quality is a major public concern. As a result, a financially and logistically feasible, biomass-powered community energy system (CES) proposal was rejected and revised (Hoekstra, 2008). This occurred despite studies which indicated that the project was capable of CO2 reductions of 8000 tonnes per year, and would improve local air quality by reducing several sources of local air pollution (Federation of Canadian Municipalities, 2001). Thus, mitigation strategies require on the ground local support in order to be successful.

At times, public opposition may result due to perceived or real shortcomings in the planning process itself. Generally speaking, people desire to be involved in a process or proposal early, to avoid feeling left out of the process or feeling that there is a lack of transparency. When not involved in the early stages, residents will often oppose a project, even if they support or do not strongly object to the

project on a substantive basis. As Doyle writes, "…If people don't participate in and "own" the solution to the problems or agree to the decision, implementation will be half-hearted at best, probably misunderstood, and more likely than not, fail" (1996, vii). Thus, mitigation strategies in sensitive cases may also require a very carefully planned process of outreach, collaboration, and social learning in order to be successful.

4.3 OVERCOMING BARRIERS

A multi-pronged approach is necessary to address the broad range of interrelated barriers to climate change mitigation initiatives. Structural change (such as a change in urban form) requires both social acceptance (of higher-density lifestyles, for example), and the regulatory policies to support such change (including new zoning, planning documents, transportation plans etc.). Similarly, governments (institutions) are elected by the public, and require public support to feel confident enacting changes in policy. Conversely, the public requires structural options and enabling policies in order to change their behaviour. Wwithout simultaneous movement on both fronts, this can lead to a "chicken and egg" problem where progress is stalled. As such, omitting a single category of barrier in any approach may jeopardize success, because barriers are inextricably linked. The following are initial recommendations drawn from the literature and research experience in collaborative planning on how each kind of barrier could be addressed.[15]

4.3.1 OVERCOMING STRUCTURAL BARRIERS

- Smart Growth planning principles, particularly those promoting compact development and multi-modal transportation options, should be applied in ongoing planning and design development processes.

- Local manufacturing, servicing, and implementation services for renewable energy sources should be developed, with early demonstration projects to expose unfamiliar technological solutions (eg. Dawson Creek Energy College house prototypes)

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[15] It is outside the scope of this paper to make recommendations on institutional barriers. For more information on institutional barriers, see Burch et. al., 2007)

4.3.2 OVERCOMING POLICY BARRIERS

- Local governments should prepare or commission a report identifying policy barriers to renewable energy initiatives (such as the Pembina Institute's report produced for the Corporation of Delta in 2008 [Bailie & MacNab, 2008]), as the first step in a strategy to address and eliminate these barriers.

- Local governments should amend the noise and height bylaws to exempt renewable energy machinery or equipment, as the District of West Vancouver has done in excluding solar from a bylaw requiring screening of rooftop equipment (District of West Vancouver, 2008). Consideration of alternative approaches to protecting neighbourhood character and views should be considered as part of the package.

- Local governments should enact enabling legislation to encourage broader implementation of renewable energy solutions, using a variety of policy tools, including:

    o Development Permit Areas (DPA's) for energy efficiency and low-carbon development as enabled by new Bill 27 legislation
    o Revitalization tax schemes for renewable energy projects
    o Development Cost Charge (DCC) exemptions
    o Rezoning checklists and expedited approvals for renewable energy projects
    o Density bonusing
    o Service Area Bylaws
    o Local Improvement Charges (source for above: Community Energy Association, 2008a)

- Local governments should establish minimum requirements and incentives for on-site renewable energy production (e.g.) the highly successful Merton Rule widely adopted in the UK requiring new developments to incorporate renewable energy production equipment to provide at least 10% of predicted energy requirements.

- Local governments should establish renewable energy production land use designations in appropriate areas (e.g. biomass production zones, with appropriate land management and design requirements).

- Local governments should situate climate change, energy efficiency, and renewable energy as central components into key planning documents such as the Official Community Plan and Zoning Bylaw, as required by new Bill 27 legislation.

- Local governments should implement training programs for municipal staff in new and emerging technologies to streamline implementation.

4.3.3 OVERCOMING PERCEPTUAL & SOCIAL BARRIERS

- Citizens should be engaged early and often in planning processes for renewable energy projects, far exceeding the requirements for public consultation set out in the BC Local Government Act. There are many formats this could take, but the process should involve all stakeholders who may be in any way impacted by the development. Carefully planned, transparent processes that engage the public and allow them to consider alternatives and be involved in decision-making, such as the SGOG process with design charrettes, or the Local Climate Change Visioning process with use of visualisation (Sheppard, 2008), have proven successful. These methods can increase public interest in conventional planning processes through compelling imagery and other techniques, particularly if they can fully reveal the major trade-offs between choices that the community can take (e.g. between local short-term impacts and long term GHG reduction benefits)..

- Because it has been identified that knowledge of climate change by itself will not guarantee action, the key drivers of community mobilization should be identified by local governments (in Prince George perhaps the issue of air quality would be central), and develop a community-based social marketing program (McKenzie-Mohr, 1999), which leverages these drivers to build capacity, empower people and actively create change. Grass roots movements of stakeholders or local groups should be encouraged (e.g. Cool Northshore in southwestern BC or the Transition Town movement in the UK (Hopkins, 2008)).

- The "co-benefits" that result from taking mitigative action should be outlined and stressed in communications (e.g. benefits to the local fibre-based economy from a biomass project; benefits to local health from reduced car use; benefits to tourism from recognised leadership in green technology and lifestyles).

- Incentive schemes should be developed and expanded. These could include revitalization tax incentives for renewable energy projects (Community Energy Association, 2008a). Local energy projects should be seen to provide economic or energy benefits to the affected populations (Elliott, 2003).

- Compensation schemes for those significantly and justly impacted by mitigative actions should be considered.

- As a last resort, local governments could pass legislation which mandates that renewable energy initiatives be undertaken.

5. CONCLUSION

A number of renewable energy resources exist in Prince George. For the purposes of this report, the potential local energy capacity from biomass and solar thermal has been examined and a new framework for mapping renewable energy capacity piloted. In a fibre-based economy such as Prince George, opportunity exists to move to a sustainable fibre-based energy system, an option not as readily available to the more developed urban areas of the province. As such, good opportunities exist for Prince George to change its energy usage and reduce its associated GHG emissions. A community energy mapping methodology for solar thermal has been developed to assess potential capacity from a spatial perspective. Further study is needed to provide a preliminary assessment of other renewable energy capacity from sources such as other solar technologies, geo-exchange, landfill gas, and waste incineration, and to provide more detailed analysis of biomass and solar thermal supply.

More broadly, the framework and methodology piloted here is under continuing development and evaluation, in order to help communities assess their local renewable energy options. Further studies should pair demand analysis with the capacity studies to gain an understanding of the degree of energy self-sufficiency that is possible for communities, and provide a platform from which communities can act to reduce their greenhouse gas emissions and sustain themselves into the future.

Finally, the City of Prince George may wish to consider a holistic climate action and energy strategy that addresses the findings and recommendations from this and other recent reports, looking well beyond the current 2012 action plan and building on the progress made in the SGOG downtown studies. Such a program should integrate more fully the consideration of climate change impact scenarios and adaptation options, in order to foster attainable visions of a low-carbon, resilient future pathways for the City which also enhance quality of life. Consistent with suggestions in this report on barriers to action on climate change, the strategy should include a strong participatory component. It should also harness available compelling visual leaning tools (see examples illustrated in this report) and available local/regional science to inform the public, stakeholders, staff and Council on decision-making for renewable energy and other climate change responses, in the context of the City's cultural, economic, and environmental priorities.

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APPENDIX A: BIOMASS SOURCES AND APPLICATIONS

1) RESIDUES left from forest harvesting operations are currently left in piles following cutting activity and frequently burned. This represents an inexpensive, underutilized resource source of biomass for energy that would require no modification of current industrial operations. 10.5 million BDT of harvest residue is estimated to be generated annually across all of BC, over 20 times the amount of waste generated from BC mills. 80% of this is left at roadside, the remaining 20% at stump (Bradley and Thiffault, 2009).

2) SOFTWOODS such as pine and spruce. Pine has the highest heat energy value of around 8000 BTU/lbs, or 18.5 GJ/tonne. Spruce is slightly lower, around 7500 BTU/lbs, or 17.5 GJ/tonne, with low ash content, making it a cleaner-burning fuel.

3) HARDWOODS such as aspen (predominant), poplar and birch. Aspen and poplar have a heat energy value similar to Spruce, but also a higher ash content and water content relative to energy-rich lignins. Hardwoods require a significantly longer drying time than softwood, which would be a modification to current industrial operations by stacking to dry for a full summer season. This is a very under-exploited resource since most forest harvesting doesn't currently include hardwoods, and it is a fast-growing, abundant local resource. Birch, although less abundant, carries a lower ash content, making it a more ideal fuel for heating.

4) ROUND WOOD: all species. Before chipping, most harvested and cut wood takes this form, which requires the least processing costs. Although it is possible to use this as a fuel for industrial-scale, automated feeder furnaces (such as automated large trays or baskets that load fuel into furnace), it tends to require more manual labour / monitoring and is therefore somewhat more difficult to use in such applications. It is therefore more suitable for domestic high-efficiency stove space heating.

5) WOOD CHIPS: all species. By breaking down round wood, chips are easier to feed into auto-feed biomass burning systems, making them a more ideal fuel form to use for industrial-scale energy.

6) WOOD PELLETS: for pine and spruce only. The increased processing energy required to transform wood chips into pellets is only economical for shipping. It can be transported at up to 10 times greater densities, and therefore supplied at a cheaper cost/tonne. Aspen is not suitable for pelletization.

APPENDIX B: ENERGY BY TREE SPECIES

When used for energy, the high biomass quantities that can be produced per unit land area and time (Mg·ha−1·year−1) convert also to high energy yield rates (GWh·ha−1·year−1; 1 watt hour = 3.6 kJ) achievable in boreal SRF compared with conventional forestry, because the calorific value of the biomass from poplars, willows, and boreal forest trees such as spruce usually varies only little (i.e., by <5%, Hakkila 1989).
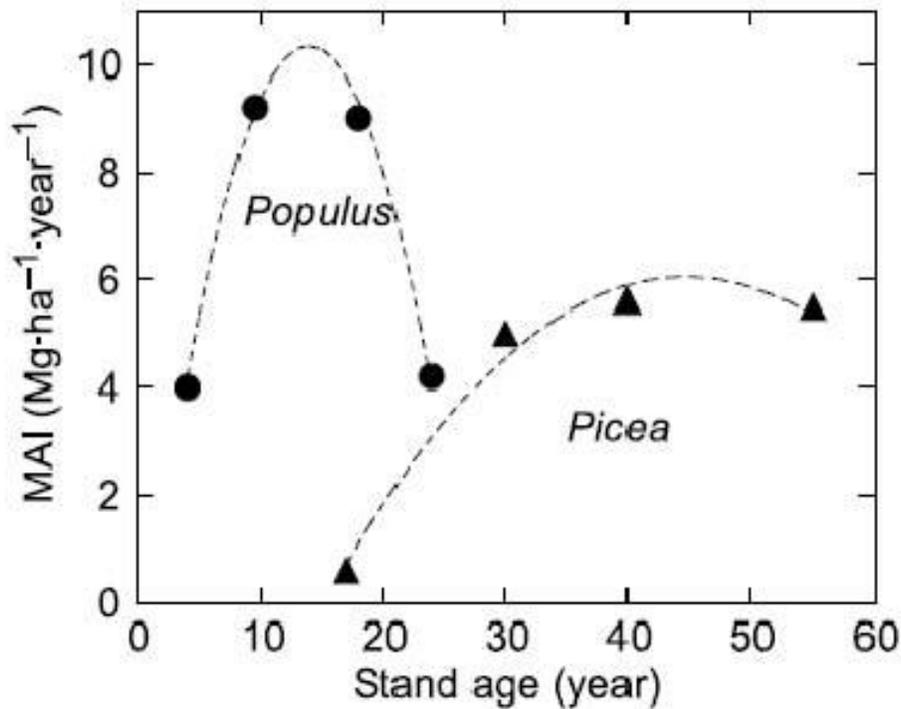

Figure: The mean annual increment (MAI) in aboveground biomass of spruce and poplar stands as related to stand age. The figures are based on data from Johansson (1999, 2002) and Karacic et al., (2003). Image source: Weih, 2004

APPENDIX C: TECHNOLOGIES FOR ENERGY GENERATION FROM BIOMASS

Numerous technologies exist for converting and extracting energy from biomass feedstocks in the form of dry, chipped wood. The drying process can take up to 20% of the energy content of the wood if accomplished with wood chips or residual energy such as char and waste heat. Drying fuels could also consist of natural gas, or simply air-drying in the summer months. Chipping / re-sizing can use up to 10% of the energy in biomass which is often accomplished by grid-electricity. Dry biomass can have a heat content equal to brown coal (lignite), but contains significantly less sulphur. The following technologies are viable in Prince George:

BIOGAS. A biological digester accelerates the anaerobic processes that occur inside a landfill, producing methane and carbon dioxide, and some odour. The methane can be used in internal combustion engines (as to generate electricity or as transportation fuel once the CO2 is scrubbed out), or for heating (combustion to replace natural gas). One tonne of organic biomass such as hog manure will produce over 1000 kWh of electrical energy and a similar amount of heat. Digesting wood is problematic due to high lignin content, though processes exist to digest this material also.

COMBUSTION. By burning biomass aerobically to vaporize water, steam is used as a heat source or to drive a turbine for electricity generation. A cogeneration system minimizes energy inefficiencies by capitalizing on heat produced during the electricity generation process, which would otherwise be wasted. System efficiencies of up to 85% are achievable, compared to 25% efficiency for electrical generation alone. An **Entropic Cycle** combustion system is a smaller-scale system that uses a proprietary fluid in a closed-loop system, requiring no steam boiler, qualified or regulated operators, nor cooling towers, ponds or water.

GASIFICATION-COMBUSTION. This converts biomass into ash and volatile gases by combustion at high temperatures with controlled restriction of oxygen. It uses some of the feedstock energy to produce high temperatures necessary for the process, and produces a calorific value as low as 10-20% of that of natural gas, or as high as 50% if pure oxygen is used. It also requires dry feedstock (represented by bone dry tonnes, or BDT).

GASIFICATION-SYNGAS. This is similar to the above gasification process, however this process produces a syngas closer to the quality of natural gas. However, it is technologically more complicated due to the need for cooling to remove water vapour and filtering tar and other impurities. Both types of gasification reduce air quality problems associated with conventional biomass combustion. The **Nexterra Gasifier** is an example of a cogeneration gasifier. This technology can be used in forest industry mills, after converting boilers, kilns and dryers to gasify wood residues in a manner which produces less particulate emissions.

PYROLOSIS. In anaerobic conditions, finely chipped biomass is heated to very high temperatures causing vaporization. Part of this gas is then condensed to produce bio-oil, which can be 60-80% efficient, leaving char and non-condensable gases as by-products. Similar to comparing wood pellets to wood chips, bio-oil has a higher energy content than raw biomass, which reduces transportation costs per unit energy, highlighting the only major benefit of this process currently. Only dry wood will maximize production efficiency, which can provide 220-450 kWh/tonne in the form of electricity, and may be used in internal combustion engines, turbines, and Stirling engines. Petroleum engines require some modification to run on bio-oil. This fuel may be stored for several years and may also be co-fired in coal or natural gas power plants. Bio-oil tends to have a 20-25% acidic moisture content, and some ash, with less than half the heating value of diesel fuel. It is more suitable as a substitute for conventional fuels in boilers, furnaces, engines and turbines, but doesn't mix well with petroleum fuels.

ETHANOL. Ethanol may be used as a transportation or energy fuel, and is blended with gasoline throughout North America and the European Union, though demand is limited in BC (Verkerk, 2008). The energy conversion efficiency is currently about 22.5%, but is expected to reach 32% by 2020.

APPENDIX D: WOOD STOVES IN PRINCE GEORGE

Prince George Wood Burning Appliance and Residential Heating Survey, 2005.

Recommendation #23: "The City promote the proper use of wood burning appliances in the City and enforce any nuisance caused by wood burning", and

Recommendation #25: "The City and Regional District provide public education opportunities on wood burning appliances, upgrade programs (stove exchange) incentives, and Bylaw implications".

Of 20,598 residences (2005) in Prince George, 87.7% (18064 residences) use Natural Gas as primary heat source, 4.8% (968 residences) use fuel wood, of which 191 residences use it more than 50% of the time. Within the Regional District of Fraser-Fort George, about 25% of surveyed homes used wood as a primary or secondary heat source. A typical home would use 3-4.5 cords of wood annually (US Dept. of Energy, 2009), which would be about 15449 cords of wood annually for 5150 homes (at $150/cord). The number of conventional wood stoves greatly exceeds the number of advanced technology wood stoves or wood pellet stoves, which burn at 60-75% efficiency (compared to ~25% efficiency for a conventional wood stove). A conventional wood stove can be fitted with a basket which allows it to burn pellets.

Pellet fuel stoves are around 78% efficient, compared to 65-75% efficiency for older natural gas fired furnaces. These systems cost between $1700-$3000 and under normal usage, they consume about 100 kilowatt-hours (kWh) or about $6.50 worth of electricity per month. Unless the stove has a back-up power supply, the loss of electric power results in no heat and possibly some smoke in the house. Wood Pellet fuel is approximately the same cost ($0.032/kW) as Natural Gas, and less than half the cost of heating oil ($0.088/kW) (Wood Pellet Association of Canada, 2008). Biofuels aren't taxed under the provincial carbon tax. A stove rated at 60,000 British Thermal Units (Btu) can heat a 2,000 square foot home, while a stove rated at 42,000 Btu can heat a 1,300 square foot space (US Dept Energy, 2009).

APPENDIX E: BIOMASS AND GHG EMISSIONS REDUCTIONS

In BC, switching a building over from natural gas to biomass wood chips or pellets translates to a 74% - 92% reduction in CO_2 emissions for that building (See Table 12), assuming that 100% of the building's emissions are a result of space and hot water heating through natural gas. If all of the 138,500 GJ/yr that could be generated by the simulated sustainable yield of biomass on PGCF Crown and municipal land were to be used to fuel switch from natural gas, 3,794 tonnes of CO_2 emissions would be eliminated from Prince George's annual emissions. Biomass gasification with minimal emissions associated with production, processing and transport, represents the largest potential for CO2 emissions reductions.

Table 12: Comparison of carbon dioxide emissions, carbon dioxide intensity, and emissions reduction potential for various fuel types

Fuel Type	KgCO2/tonne	Net CO2 intensity (kgCO2/GJ)	CO2 emissions reduction by switching to biomass wood pellets (%)[1]
Coal	2025.6[2]	61.48[2,3] - 90[3]	83.3 - 94.8%
Heating oil		75[3]	80 - 93.7%
Natural gas	1303.6[4]	22.9 - 57[3]	73.7 - 91.8%[3,5]
Biomass wood pellets	87.2 - 278.1[3]	4.7 (sawdust as drying fuel) – 15 (natural gas as drying fuel)[3]	
Biomass (gasification)	40[5]	2.2 – 27.7[5]	+53%(increase)- 83%(reduction)

[1]*Reductions are dependent on the fuel used for the drying process during wood pellet production. Using sawdust rather than natural gas as a drying fuel gives up to 80% fewer CO2 emissions during this part of the process. This is assumed for these calculations and is practiced by some local wood pellet producers (Magelli et al., 2009).*
[2]*EPA, 2007*
[3]*Magelli et al., 2009*
[4]*Converted from 0.0546 kgCO2/ft3 Natural Gas, (EPA, 2007)*
[5]*ENVINT, 2008, based on 5000 kWh per 18GJ (or per tonne) of biomass x 0.008 -0 .1 kgCO2/kWh, depending on emissions associated with fertilization, machinery use and transport.*

APPENDIX F: BIOMASS, COSTING, AND PROVINCIAL CARBON TAXES

In general, waste wood residues from the timber/fibre industry (such as hog-fuel) are the cheapest source of biomass, followed by "roadside" waste residues from harvesting (Stennes and McBeath, 2006). About 40% of tree biomass harvested for timber or fibre production becomes residue and waste as an end result (TDB consultants, 2005). Mountain Pine Beetle salvage is the most expensive source of biomass as a bi-product or as an energy source, due to the salvage operation costs (Verkerk, 2008).

A 2005 report by TDB consultants reports that the cost per BDT of Prince George-area harvested biomass would be around $65/BDT, similar to BC-wide estimates by Stennes and McBeath (2006) of delivered costs as low as $55/BDT and up to $83/BDT with development and reforestation costs. Verkerk (2008) cost estimates for Mountain Pine Beetle salvage were slightly higher, at around $96-110/ODT[16] (though by 2020 this is projected to decrease to within the range suggested by Stennes and McBeath), with roadside harvest waste costing $40-79/ODT, and mill waste costing $17-28/ODT. The supply availability of these materials across BC is inversely proportional to their costs per ODT, with sawmill residues being the scarcest, and roadside residues and Mountain Pine Beetle Salvage being 2-5x and 15-30x more abundant (Stennes and McBeath, 2006) respectively.

The Canadian Forest Service (Stennes and McBeath, 2006) has found that a carbon tax in excess of $35/tonne would be required to make the use of beetle salvaged pine cost feasible for electricity generation compared to natural gas combined cycle systems or co-firing with coal. Stennes and McBeath compared a fuel switch from natural gas to biomass for a 100MW plant, based on BC Hydro operation costs, to perform a sensitivity analysis to feedstock costs for energy production and carbon credit values (2006). According to the current cost of natural gas of $9.658/million BTU (Terasen gas, 2009), a carbon tax around $27-40/tonne CO_2 would be sufficient to make biomass the low cost option for heating fuel (interpolated from Stennes and McBeath, see Table 13). The current provincial carbon tax is slated to rise to $30/tonne by 2012. Without a carbon tax, Stennes and McBeath found that a delivered biomass

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16 ODT: Oven Dry Tonnes describes wood that has been dried in a ventilated oven at 102° C to 105° C until there is no additional loss in weight. Analogous to BDT or Bone Dry Tonnes.

fuel cost of around $38/BDT would be required to give biomass a cost advantage over natural gas based on current prices, while $50/BDT would be sufficient given 2005 natural gas prices of $11/million BTU.

Table 13: Sensitivity analysis on feedstock costs for electrical production and carbon credit values ($/tonne CO2) to make direct harvest for biomass power generation feasible (Stennes and McBeath, 2006).

Natural gas prices $/million btu	Feedstock costs in $/BDT				
	0	25	50	75	100
	\$ per tonne CO₂ credit				
5	-12.5	25.5	63.3	101.2	139.1
7	-38.8	-0.9	37.0	74.9	112.8
9	-65.1	-27.7	10.7	48.6	86.5
11	-91.4	-53.5	-15.6	22.3	60.2
13	-117.7	-79.8	-41.9	-4.0	33.9
15	-144.0	-106.2	-68.3	-30.3	7.5

Note: Shaded region indicates biomass low cost option.

A similar analysis was performed on the cost viability for co-firing Mountain Pine Beetle salvaged wood with coal in Alberta. Based on delivered coal costs of $33/tonne and delivered biomass costs of $65/BDT, this strategy becomes feasible with a carbon tax of around $35/tonne CO_2 (finding interpolated from Stennes and McBeath data (2006), Table 14).

Table 14: Sensitivity analysis on carbon credit values ($ tonne-1 CO2) to make direct-harvest beetle-killed pine and cofiring with coal in neighbouring Alberta feasible (Stennes and McBeath, 2006).

Coal costs $/tonne	Feedstock costs in $/BDT			
	25	50	75	100
	\$ per tonne CO₂ credit			
25	10	29	48	68
50	-2	17	36	56
75	-14	5	24	44
100	-26	-7	12	31