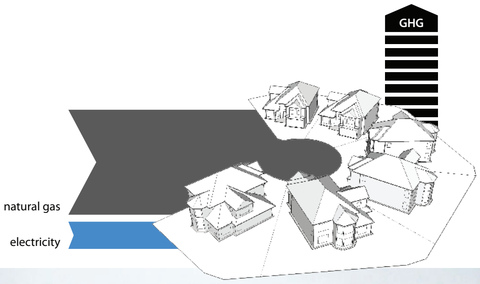
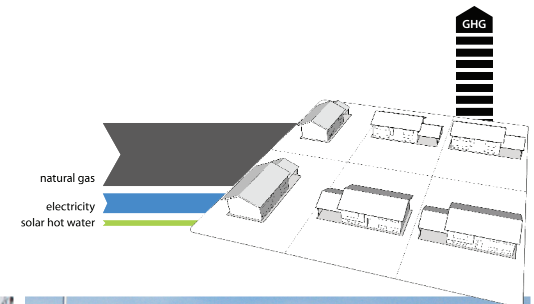
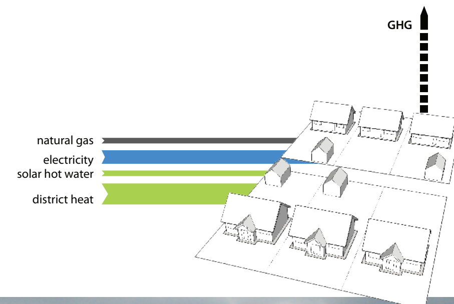
THE RETROFIT CHALLENGE







Re-thinking Existing Residential Neighbourhoods for Deep Greenhouse Gas Reductions

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UBC CALP

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EXECUTIVE SUMMARY

British Columbia has established targets of 33% reductions in total Provincial greenhouse gas (GHG) emissions by 2020 and 80% reductions by 2050 (Province of British Columbia 2007). Among the major sectors contributing to climate change, buildings – and the residential sector in particular – play a substantial role. Buildings across BC contribute 12% of total Provincial GHG emissions and account for nearly a quarter of all household emissions. A majority of building related emissions (57%) is attributable to residences (Province of British Columbia 2008) and is primarily due to the combustion of fossil fuels for the provision of space heating and hot water. Even with currently proposed policies and actions, reducing total GHG emissions from buildings will not be easy. While new construction has clear advantages for incorporating low-energy and GHG design and technologies, the scale of GHG reductions required cannot be achieved through new construction alone.

This research project examines a range of different options to retrofit existing residential neighbourhoods for building-related GHG reductions out to 2050. The study looks at the GHG reductions achievable under existing policy directions and grant programs, intensive building-level retrofits, and shared opportunities for reductions, including neighbourhood-scale renewable energy systems. The purpose of the study is to test what current policy might achieve in comparison to an 80% GHG reduction target for residential buildings, and to consider how this target might be achieved through individual and shared actions. The study did not include GHG emissions related to transportation.

1990's cul-de-sac subdivision

1970's subdivision

Older, adjacent to downtown

The examination of shared actions tested the hypothesis that achieving GHG emission reduction targets will require not only actions for individual buildings, but also consideration of neighbourhood, city and regional scale planning. New energy and GHG strategies such as small-scale energy supply technologies (e.g. district energy), waste-heat sharing, and the shaping of urban form to maximize solar access and other energy opportunities, require that neighbourhoods be thought of as systems, rather than as groups of individual buildings. In addition, the study sought to explore regional differences, and the trade-offs between demand reductions, energy efficiency, and low-carbon energy supply.

A combined scenario and case study methodology was used to examine different approaches for neighbourhood scale GHG reductions across BC. Three neighbourhoods from different climatic regions - Delta, Kimberley and Prince George - were selected as representative of typical street design, building type and building age. The Delta case study neighbourhood, with 199 single-family homes on 10.6 hectares, represents recent subdivision development, including large, complex houses, and a disconnected, cul-de-sac street system. Kimberley's neighbourhood, with 71 single-family homes on 7.2 hectares, represents 1960s and 1970s suburban/rural development, including rectangular building forms and an irregular but interconnected street system. Prince George, with 335 mixed single-family and apartment units on 11.2 hectares, represents an older neighbourhood adjacent to a downtown area, with a grid street system including back lanes.

Three scenarios, Current Policy Direction, Intensive Building Retrofits, and Neighbourhood Focused Approach, were developed to represent how each case study neighbourhood could evolve by 2050, using a variety of retrofit strategies. Redevelopment rates were assumed to be low for Delta and Kimberley, with 10% building replacement and no increase in the number of units; in contrast, redevelopment was assumed to add 54% more units for the Prince George case study, given the neighbourhood's older age and proximity to the downtown core.

Neighbourhood models were produced using an energy strategy assessment, building energy modeling, and neighbourhood-scale spatial analysis. Retrofits were assumed to have 100% uptake across the case study neighbourhoods. Twelve neighbourhood model runs (1 baseline and 3 scenarios for each of the 3 different case studies) were used to measure the total energy use and GHG implications across the scenarios.

	Scenario 1 **Current Policy Direction**	**Scenario 2** **Intensive Buildings**	**Scenario 3** **Neighbourhood Approach**
DELTA			
Demand reductions	Minor	Extreme	Moderate
Efficiency/System Changes[a]	Efficiency upgrades	Air to air heat pumps	Air to air heat pumps
Main Energy Supply	Natural gas	Electricity	Electricity
KIMBERLEY			
Demand Reductions	Moderate	Extreme	Moderate
Efficiency/System Changes[a]	Efficiency upgrades	Wood stoves	Shared District Heat
Main Energy Source	Natural gas	Biomass	Biomass
PRINCE GEORGE			
Demand Reductions	Moderate	Extreme	Moderate
Efficiency/System Changes[a]	Efficiency upgrades	Individual Geothermal	Shared District Heat
Main Energy Source	Natural gas	Electricity	Biomass

KEY CHANGES FOR DEMAND, EFFICIENCY AND HEATING SYSTEMS, AND HEATING ENERGY SUPPLY. In addition, all the case studies move to solar hot water where possible, with some implementation in Scenario 1, and increased implementation across Scenarios 2 and 3.

RESULTS

The Current Policy Direction Scenario focuses on current practices for energy retrofits, as promoted by federal, provincial and other organizations for home-owners, and "green buildings" for new construction. The core strategy of this scenario is demand reductions through building envelope upgrades and heating system efficiencies, with minimal energy system or source changes. Some solar hot water is implemented. Overall, the scenario achieves GHG reductions of 33-50% for the case study neighbourhoods. The Kimberley case study shows the greatest reductions because the vintage of the houses means that greater gains are available from efficiency retrofits than for the newer homes in Delta. The older Prince George residences can achieve considerable energy savings with upgrades; however, these are partially offset by the 54% increase in residential units.

The goal of the Intensive Building Retrofits Scenario is to find strategies that move residences off fossil fuels altogether, with a specific GHG reduction target of +80% reductions from the baseline. The scenario therefore employs aggressive building scale retrofits, including substantial building renovations not typically contemplated in current practice, such as moving or re-sizing windows, re-cladding houses with extra insulation, and adding ground level insulated sub-floors. Heating and hot water systems are changed to heat pumps, wood stoves, and solar thermal (where possible) with on-demand backup. New construction is designed to meet very high energy and GHG performance standards (e.g. Passivhaus). The strategies thus represent substantially more aggressive buildings changes, costs, and lifestyle impacts, and achieve higher GHG reductions: overall, the scenario achieves GHG reductions of 55-93% for the case study neighbourhoods. The low result for Prince George is due to the increase in electrical use for the geothermal heat pumps, and the overall energy demand increases due to the 54% increase in dwelling units. Responsibility for successful implementation lies with home-owners and builders.

The goal of the Neighbourhood Focused Approach Scenario is to temper the extreme space heating demand reductions required by the second scenario by finding alternate ways of reducing GHG emissions. This scenario therefore explores strategies at the neighbourhood scale, including biomass-based district energy systems for heat and hot water, and multi-parcel approaches such as shared solar thermal, and redevelopment of the worst-performing buildings. As in the second scenario, a target of 80% GHG reductions for the neighbourhoods was adopted. Overall, this scenario achieves GHG reductions of 80-94% for the case study neighbourhoods, even with the 54% increase in units in the Prince George scenario. Due to the shared systems, responsibility for successful implementation lies with local government as well as home-owners and builders.

Compared to Scenario 2, the move to a shared low-carbon energy supply (biomass-based district energy) for heat and backup hot water enables the smaller total energy reductions but greater or equivalent GHG reductions in Kimberley and Prince George. In addition, it is only in Scenario 3 that growth in residential units can be accompanied by deep GHG reductions, shown by Prince George. However, the Delta results also show that for some neighbourhoods, a shared approach may not be as effective as an intensive, individual house retrofit approach.

	Scenario 1 Current Policy Direction	Scenario 2 Intensive Buildings	Scenario 3 Neighbourhood Approach
DELTA			
Total Energy	-30%	-78%	-75%
Total GHGs	**-33%**	**-89%**	**-80%**
KIMBERLEY			
Total Energy	-45%	-82%	-60%
Total GHGs	**-50%**	**-93%**	**-94%**
PRINCE GEORGE			
Total Energy	-36%	-70%	-54%
Total GHGs	**-34%**	**-55%**	**-92%**

SIMPLIFIED SCENARIO RESULTS TABLE. Percent change from the baseline in energy use and GHGs, for the neighbourhoods as a whole, not individual residences.

CONCLUSION

The results illustrate that deep reductions in building-related GHGs in existing residential neighbourhoods are achievable with currently available technologies. Scenario 1 achieves results that meet the 2020 BC Government targets of a 33% reduction, but will not achieve the 80% reductions required to meet 2050 targets. Scenarios 2 and 3 demonstrate that 80% reductions are achievable, and that there are different pathways to significant GHG reductions. All of the scenarios assume a rate of retrofitting, 100%, that is almost inconceivable. Critical questions regarding which technological pathway to choose, who is responsible, how to pay, and how to implement remain.

Five no-regrets moves that apply across all scenarios are evident. They will require uptake of improved technology, and collaboration between policy-makers, builders/developers, the building trades, the real estate industry, and home-owners to implement. They are:

1. Building envelope upgrades are required for most if not all current residences;

2. Solar thermal (hot water) will need to become a standard feature for retrofits and new-buildings;

3. Significant reductions in current electrical use will be required;

4. Redevelopment to rowhouses and multi-family, using compact geometry and smaller unit sizes, rather than single-family dwellings, can help to achieve net-zero neighbourhoods;

5. It is easier to "build green" from the beginning than to retrofit later: all new construction should be built to net-zero or Passivhaus standards.

In addition, the study shows that low-carbon, locally available energy supplies, such as biomass, will be important for many communities to achieve deep GHG reductions, as demand reductions and energy efficiency are critical but not necessarily sufficient.

Beyond the initial "no regrets" steps, the three case studies demonstrate that a single retrofit/redevelopment solution will not be applicable to every neighbourhood across BC. Each neighbourhood will require a specific assessment of its particular potentials and constraints with respect to reducing GHGs. The analysis needs to consider the characteristics of individual homes (including age, orientation and construction details), the overall spatial configuration of the neighbourhood, and the age and condition of existing neighbourhood infrastructure, the availability of local renewable energy sources, and the local climate.

Other criteria that will help communities to make decisions about which pathway to follow include quality of life trade-off, levels of responsibility, and economic considerations. The Intensive Building Retrofits scenario places most of the responsibity on individual home-owners, and requires considerable quality of life and behavioural changes, while the Neighbourhood Approach places a shared responsibility across home-owners and local governments, with fewer quality of life changes. Costing, which was beyond the scope of the research study, will also point to the best way to move forward, enabling a richer comparison across scenarios.

Institutional and costing factors, rather than technology development, are the likely barriers to overcome in realizing deep greenhouse gas reductions within existing residential neighbourhoods. Builders, developers, realtors, local governments, home-owners and others are critical players in forwarding the strategies for meeting the challenges posed by climate change mitigation within existing BC communities. On-going work is needed to determine how best to achieve the building and neighbourhood changes required for deep GHG reductions as it is clear that implementing the strategies presented in this report will require substantial buy-in from individuals, the real estate industry, and local and higher levels of government. How best to achieve this buy-in remains an open question; at a minimum, it will require informed, engaged, and motivated community members - residents, developers, realtors - working closely with local government.

1. INTRODUCTION

The importance of significant greenhouse gas emission (GHG) reductions internationally and across all sectors is now widely recognized. Based on scientific evidence documented by the Intergovernmental Panel on Climate Change, GHG reduction targets established by national and local governments worldwide are calling for GHG reductions of at least 80% by 2050 to avoid drastic and potentially damaging impacts from climate change (Bernstein et al. 2007).

British Columbia has joined the many institutions taking action on climate change, establishing targets of 33% reductions in total Provincial GHG emissions by 2020 and 80% reductions by 2050 (Province of British Columbia 2007a). Meeting these targets is critical, as the local impacts of climate change are already apparent, including warming rates twice the global average in some regions of the Province, a loss of up to half BC's mountain snowpack over the past century, increased annual precipitation and longer summer droughts (Province of British Columbia 2008).

Among the major sectors contributing to climate change, buildings – and residential homes in particular – play a substantial role. Buildings across BC contribute 12% of total Provincial GHG emissions and account for nearly a quarter of all household emissions. A majority of building related emissions (57%) is attributable to residences (Province of British Columbia 2008) and is primarily due to the combustion of fossil fuels for the provision of space heating and hot water. Currently, the BC Climate Action Plan (2008) outlines a variety of strategies in place or under development to mitigate GHG emissions in the building sector.

Even with the proposed policies and actions, reducing total GHG emissions from buildings will not be easy. This research project examines a range of different options to retrofit existing residential neighbourhoods for GHG reductions out to 2050. The study looks at the GHG reductions achievable under existing policy directions and grant programs, intensive building-level retrofits, and shared opportunities for reductions, including neighbourhood-scale renewable energy systems. The purpose of the study is to test what current policy might achieve in comparison to an 80% GHG reduction target for residential buildings, and to consider how this target might be achieved through individual and shared actions[1].

Four key challenges frame this report and are addressed in the following sections.

1 While the overall provincial target is 80% GHG reductions across all sectors, allocations by sector could vary, i.e. some sectors could achieve higher reductions while others might achieve lower reductions. For the purposes of this study, 80% was chosen as the reduction target for residential buildings.

1.1 Why retrofit?

The 2006 census reports that, in British Columbia, there are over 800,000 detached single family houses already constructed. Meanwhile, new construction across Canada accounts for only 2% of total housing stock annually (www.statcan.gc.ca). While new construction has clear advantages for incorporating low-energy and GHG design and technologies, the scale of GHG reductions now required cannot be achieved through new construction alone. Extensive and comprehensive building retrofit initiatives are also required.

Despite the need for massive retrofits, a majority of current policy nationally and within the Province focuses on the issue of new construction. A recent report produced by the municipality of Prince George, B.C. identifies this gap:

> "The provisions or tools [in Bill 27 relating to new construction] may assist in reducing the growth of GHG emissions, but will not be as effective in achieving absolute reductions. Therefore, *their impact in the short to medium term will be substantially less than the strategies addressing current development*. These provisions should be considered as part of an overall strategy, while keeping in mind their relatively minor contribution to GHG and energy reductions" (Adamson 2010, pg 7, emphasis added).

The scale of retrofit required is unprecedented, and represents a new imperative requiring new solutions and implementation measures. The requirement for deep energy renovations and neighbourhood energy systems needs to be better understood, recognizing there are tremendous opportunities for existing buildings and neighbourhoods. This study aims to begin to fill this gap.

1.2 Neighbourhoods as Systems

Achieving GHG emission reduction targets will require not only actions for individual buildings, but consideration of neighbourhood, city and regional scale planning as well. Increasingly, new energy and GHG strategies such as small-scale energy supply technologies (e.g. district energy), waste-heat sharing, and the shaping of urban form for maximized solar access and other energy opportunities, require that neighbourhoods be thought of as systems, rather than as groups of individual buildings.

One of the dominant themes in planning to address future energy and climate change concerns is relocalization (Andrews 2008). This relocalization is based on several premises, including the more local nature of renewable energy sources (ibid), the land-use and urban planning implications of energy conservation efforts (Kellet et al. 2008) and the desire of local communities to move quickly on issues of energy and climate change (e.g. ICLEI 2009).

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). At the other end of the scale, energy modeling has been done extensively for the individual building. Few studies analyse energy systems, demand, GHG performance and retrofit options at the local (neighbourhood to region) scale[2]. A relocalized approach to energy planning suggests a tighter integration between local energy supply and local demand management (Church and Ellis 2007), with a need to think about energy supply and demand at the local scale (i.e. neighbourhood, municipal, and regional) as a system.

Planning for, and managing these local energy systems will require new means of considering energy demands and sources (both present and future) for a number of different sectors. Using spatial analysis of neighbourhoods, as well as building and neighbourhood-scale energy modeling, this study investigates the mitigation opportunities available to neighbourhoods, and how neighbourhood design and policy considerations might change when shared strategies for GHG reductions are employed.

1.3 Regional Differences

British Columbia is a highly diverse province with distinct regional differences in geography, climate and economy, as well as distinct variation in building stock and vintage even within single communities. These differences have a significant impact on the feasibility of various GHG reduction strategies and call for locally-relevant GHG reduction approaches. This study uses three case study neighbourhoods from varying B.C. communities, and building archetypes from different eras, in order to explore local variability in climate change mitigation strategies.

However, similarities in the built form occurring across BC mean that many aspects of this study are applicable to communities outside of the selected case study areas. For example, housing by era (e.g. houses from the 1970s) tends to share similar characteristics such as shape, size and construction techniques, whether they were built in Kimberley, Prince George, or other communities. Additionally, development patterns and neighbourhood structure also tend to share characteristics by era. Across North America, older town centres are often configured with a gridded street system, with lanes and garages in the back, while newer automobile-oriented subdivisions have curvilinear streets with attached garages that face the street. Therefore, the findings related to neighbourhood form from one case study may be applicable across a range of municipalities, provided climatic differences are accounted for.

2 The NRCAN/CANMET Urban Archetypes project is one study that assesses energy use and GHG performance at the neighbourhood scale (Natural Resources Canada 2010). In addition, several recent UBC studies (e.g. Miller and Cavens 2008, Flanders et al 2009) assess GHGs and/or energy at the local scale.

1.4 Factors Contributing to GHG Emissions

Reducing GHG emissions involves a complex set of interacting factors which must be addressed, including energy demand variables, energy efficiency, and the GHG intensity of the energy supply. The use of scenarios in this study allowed for testing of different combinations of these factors. The British Columbia Greenhouse Gas Inventory Report 2007 identifies three primary factors involved in building-related GHG emissions:

1) Energy DEMAND (e.g. hot water and heating requirements, amount of heated floor space, etc.)

2) Energy EFFICIENCY (e.g. amount of natural gas per unit of heat delivered), including the systems used to meet demand

3) Energy SOURCE (i.e. the GHG intensity of fuels used)

The combination of the first and second factors, demand and efficiency, result in building energy use. Energy use combined with the third factor, energy source, results in GHG emissions, dependent on the GHG intensity of each source. Because GHG emissions result from the combination of these factors, reductions in GHGs can be achieved by making improvements in any one or a combination of these factors. For example, residential heating GHG emissions may be reduced by reducing heating energy demand through the increased thermal performance of buildings (Factor 1), by installing more efficient heating systems (Factor 2), or by supplying heat through a low-GHG energy source such as biomass or hydro-electricity (Factor 3). Ideally, improvements will be made for all 3 factors. The current study explores GHG reductions from all three factors, including neighbourhood opportunities for shared energy systems.

The scale of the changes required to achieve substantial GHG reductions in existing British Columbian neighbourhoods is difficult to grasp. This study lays out alternate neighbourhood retrofit pathways so that the breadth and depth of the changes, as well as trade-offs between options, can be better understood. Builders, developers, realtors, local governments, home-owners and others are critical players in forwarding the processes and strategies for meeting the challenges posed by climate change mitigation within existing BC communities.

2. METHODS

This project used a combined scenario and case study methodology to examine different approaches for neighbourhood scale GHG reductions across BC. Three neighbourhoods from different climatic regions were selected as representative of typical street design, building type and building age. Three different scenarios were developed to represent how each case study neighbourhood could evolve by 2050.

An energy/GHG reduction strategy assessment, building energy modeling, and neighbourhood-scale spatial analysis were used in an iterative process to generate neighbourhood energy and emissions numbers. A total of 12 model runs (3 scenarios and 1 baseline for each of the 3 different case studies) were completed to measure the total energy use and GHG implications of the different retrofit scenarios.

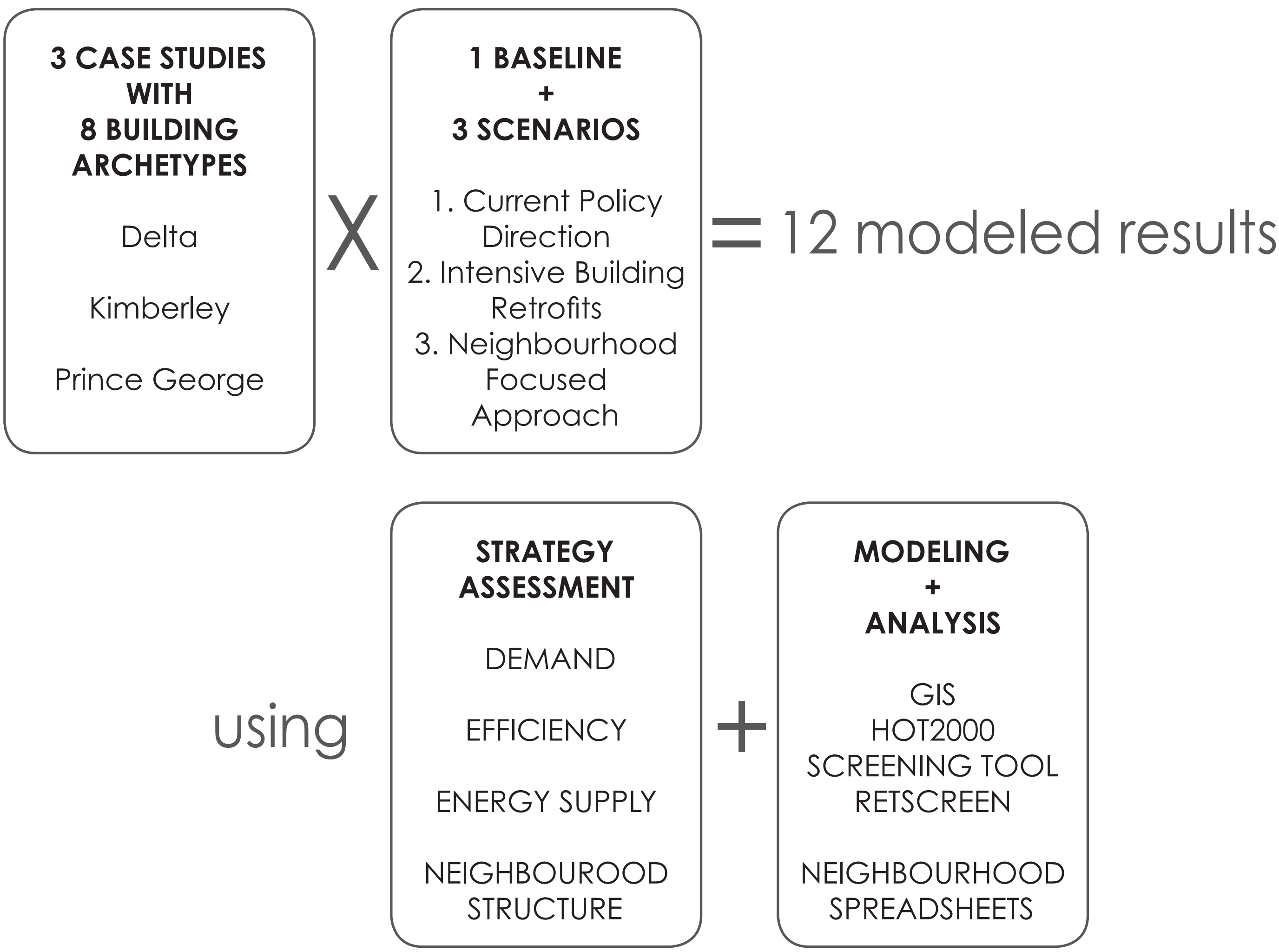


Figure 1: Study methodology diagram

Careful consideration was given to keeping the scenarios and case studies consistent in order to allow them to be compared. At the same time, variations in the case study and scenario assumptions were used to explore different feasible approaches to reaching the same goals, especially given regional, climatic and building age variations. This allowed for exploration of a broader range of approaches to reducing neighbourhood GHGs than choosing a single set of strategies and applying them to each case study.

2.1 Case studies and building archetypes

Three case study sites were selected for the project representing a range of typical conditions from across British Columbia: the north, the southern interior, and the south coast. The case study neighbourhoods were chosen to represent regional contexts, including climatic conditions, regional growth projections, and development eras. Although the characteristics of and lessons drawn from the case studies can be generalised to represent a broader range of locations, each case study is based on a real site within a BC municipality as a source of baseline data. Data collected from selected sites included neighbourhood layout, parcelization, and type and age of existing homes, and was based on GIS analysis and site visits.

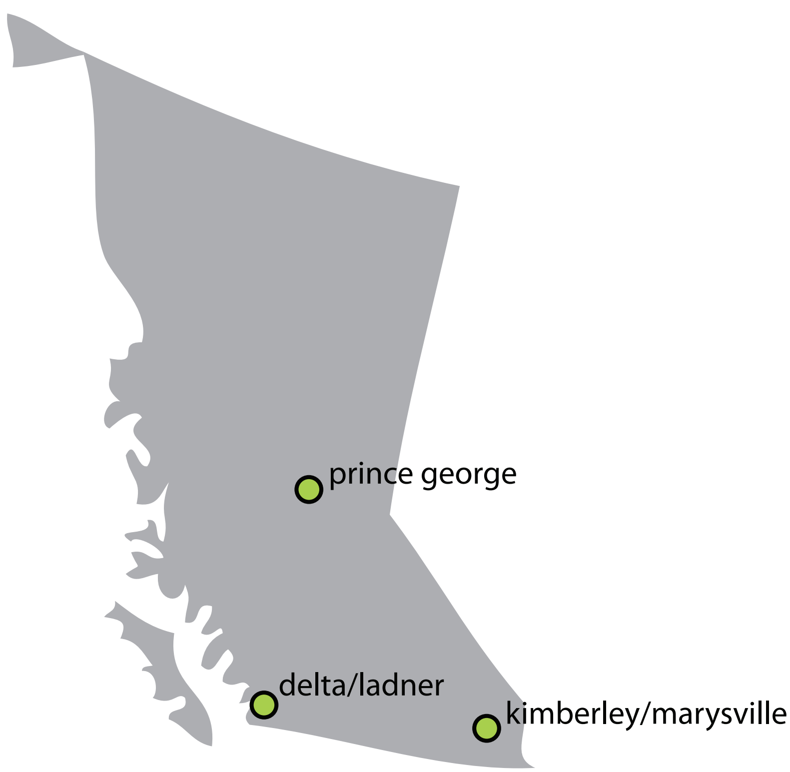


Figure 2: Context map of the three case study locations within British Columbia

To facilitate the modeling of energy and GHG emissions at the neighbourhood scale, residential building archetypes were developed for each case study (Figure 3). These archetypes were used to capture key building characteristics influencing building energy demand and building performance. They represent typical housing in the case study neighbourhoods, and were developed using a combination of several data sources starting with building footprint averages generated in GIS. Photo analysis from site visits provided design parameters, and real estate listings were used to verify assumptions (e.g. floor area, ceiling heights, basement insulation, heating systems, and era of construction). New construction building archetypes were also developed to represent potential redevelopment options for the scenarios.

While the case studies are based on a real location, they were selected to be broadly applicable across the province. All three of the retrofit house archetypes can be found in communities throughout BC. The 1990s buildings represented by the Delta archetype are found, with only slight variations, in recent subdivisions across the Lower Mainland, the Okanagan and elsewhere. Similarly, the split-level homes that form the basis of the Kimberley single family archetype were built extensively across BC in the 1970s. Many BC communities also have older, central cores with housing analogous to the single and multi-family archetypes modeled for the Prince George case study.

An additional key variable for this project was the rate of expected redevelopment (i.e. how many of the existing buildings one would expect to be torn down and replaced over the next 40 years). Growth projections at the neighbourhood scale are difficult to find as projections are typically done at the municipal scale. In Delta and Kimberley, redevelopment over the next 40 years was therefore assumed to replace 10% of the existing housing stock, with no change in overall population: any redevelopment in these case studies would simply replace existing buildings with similar buildings of the same type (single-family). For the Prince George case study, 30% of parcels were assumed to be redeveloped, with a 154% increase in the total number of units. While this rate is higher than that projected for the city as a whole, the rate reflects the case study's inner city location, and the fact that it has already been re-zoned for higher density (City of Prince George 2003).

The projected growth rates were held consistent across all the scenarios for each case study neighbourhood, as were the numbers of units by type (single-family, rowhouse, multi-family). The redevelopment numbers are shown in Table 1. The retrofit rate was assumed to be 100% for the remaining existing units across all case studies and scenarios.

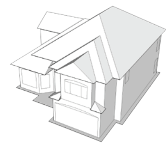
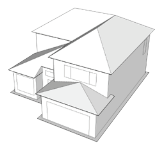
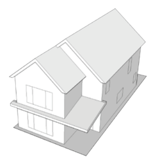
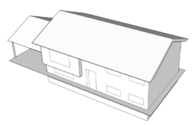
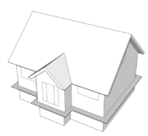
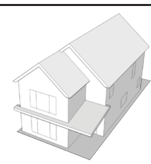
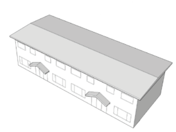
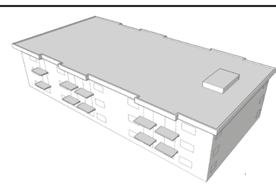
	Building Form	Description	Vintage	Floor Area	Units/Bldg.	# of Corners
Delta						
Existing Single Family		Larger single family detached home, 1.5 stories, complex building geometry and roof structure	1994	3023	1	17
New Single Family, Built Green standard		Single family detached home, 1.5 stories, reduced complexity in building and roof geometry, improved construction standards for energy performance	2010	2584	1	8
New Single Family, Passivhaus standard		Single family detached home, 2 stories, simple building and roof geometry oriented for solar access, high-performance building construction standards	2010	2470	1	6
Kimberley						
Existing Single Family		Single family home, 2 storey split-level, simple building and roof geometry, improved/high-performance construction standards for energy performance in new construction	1978	2236	1	6
New Single Family, Built Green standard			2010	2236	1	6
New Single Family, Passivhaus standard			2010	2236	1	6
Prince George						
Existing Single Family		Smaller single family home, 1.5 stories, simple building and roof geometry	1944	1458	1	8
New Single Family, Built Green standard		Single family detached home, 2 stories, simple building and roof geometry, improved/high-performance construction standards for energy performance	2010	2470	1	6
New Single Family, Passivhaus standard			2010	2470	1	6
Existing Rowhouse		Multi-family attached rowhouses, 2 stories, shared walls, simple building and roof geometry, improved/high performance construction standards for energy performance in new construction	1978	4524	4	4
New Rowhouse, Built Green standard			2010	4524	4	4
New Rowhouse, Passivhaus standard			2010	4524	4	4
Existing Apartment		Multi-family apartments, 3 stories, shared walls and floors, simple building and roof geometry, improved/high-performance construction standards for energy performance in new construction	1978	27486	30	4
New Apartment, Built Green standard			2010	27486	30	4
New Apartment, Passivhaus standard			2010	27486	30	4

Figure 3: Building Archetypes by Community Case Study

Table 1: Redevelopment by Case Study

Delta	Baseline	Scenarios
Housing Type		
Single Family Units	199	199
Existing Single Family/Retrofits	*199*	*179*
New Single Family		*20*

Kimberley		
Housing Type		
Single Family Units	71	71
Existing Single Family/Retrofits	*71*	*64*
New Single Family		*7*

Prince George		
Housing Type		
Single Family Units	153	159
Existing Single Family/Retrofits	*153*	*130*
New Single Family		*29*
Attached Units	4	60
Existing Rowhouse/Retrofits	*4*	*4*
New Rowhouse		*56*
Multi-Family Apartment Units	178	298
Existing Apartment/Retrofits	*178*	*178*
New Apartment		*120*
Total Units	335	517
Retrofits		*312*
New Construction		*205*

2.1.1 Delta

Case Study: Lower Mainland, 1990s Single Family Development
Source location: Delta, B.C.

The Delta neighbourhood is representative of residential subdivision development over the past 20 years, including large, single-family houses with complex building geometry, a curvilinear, disconnected street system with cul-de-sacs, high parcel coverage, and attached, front-access garages. Neighbourhoods similar to the Delta example can be found throughout Metro Vancouver as well as in many other regions of British Columbia such as the Okanagan. Although buildings of this era are constructed to higher energy and building envelope standards than older residential stock, energy use and GHG emissions from these developments are still significant as gains in efficiency have been moderated by the upsizing of floor space and appliances, as well as increased heat losses due to complex house geometry.

10.6 Ha
199 Parcels
535 m^2 av. lot size

0 25 50 100 Meters

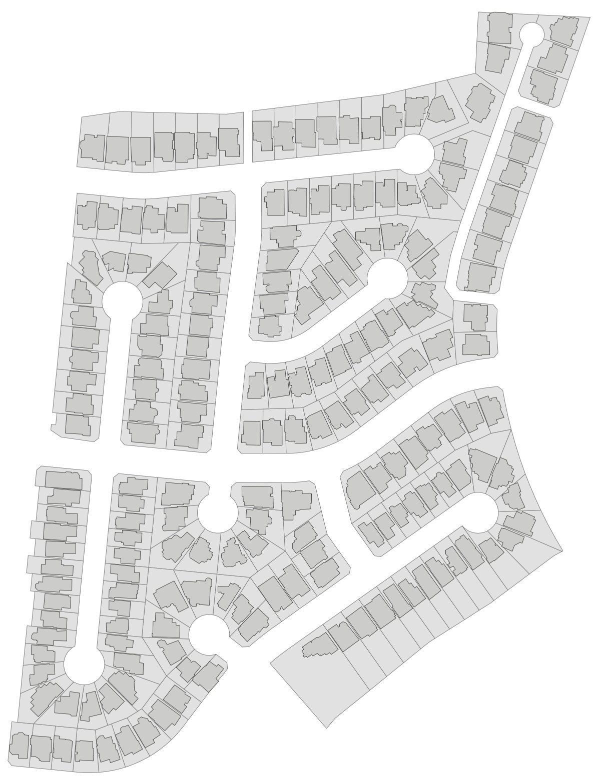


Figure 4: The Delta case study neighbourhood: parcels and current building footprints

In the Delta case study neighbourhood, all of the houses are of the same type and age, such that one archetype was developed to represent the existing building stock. An average building footprint was developed, and no changes or upgrades were assumed in the baseline building envelope or heating systems from time of construction to the present. A site survey with photos was used to select a representative house on which to base the archetype: a 2 storey, slab-on-grade, 3000 square foot structure illustrating the complex geometry (e.g. upwards of 18 corners, complicated roof design) of the 1990s style houses.

Figure 5: Representative photos from the Delta neighbourhood

New construction archetypes for Delta maintain a single family, detached form but are reduced in size and complexity for improved energy performance and reduced GHG emissions, as shown in Figure 3.

Neighbourhoods like the Delta example are not expected to grow or redevelop significantly over the time period considered in this study. Little land is available for infill development, although the subdivision of existing residential units could be considered. This study assumes that 10% of total units within the study site (20 units) will be redeveloped by 2050, with no net gain in total residential units (i.e. no change in density).

The Delta case study further represents neighbourhood GHG performance and retrofit opportunities within the temperate climate of the Lower Mainland, characterised by mild, rainy winters and dry summers. This region has similar or lower solar energy potential than other case study locations considered in this report.

2.1.2 Kimberley

Case Study: Kootenays Region, 1970s Single Family Development
Source location: Kimberley/Marysville, B.C.

The Kimberley case study location represents a suburban/rural residential neighbourhood typical of development occurring throughout the 1960s and 1970s. The case study is characterised by an irregular but interconnected street system and attached, front-access garages or carports. The less complex building forms prevalent in these neighbourhoods (i.e. rectangular buildings and simple roof geometry) provide the potential for building-scale renewable energy installations and passive solar strategies. This case study represents neighbourhoods with aging housing stock where substantial renovation may be desirable or feasible, particularly considering British Columbia's GHG reduction goals. It is also representative of subdivision developments in smaller communities that may be located in close proximity to older commercial and residential areas.

7.2 Ha
71 Parcels
997 m² av. lot size

Meters
0 25 50 100

Figure 6: The Kimberley case study neighbourhood: parcels and current building footprints

In Kimberley, although a few original homes have been replaced, the archetype was based on the 1970s houses initially built in the subdivision. Like the Delta case study, one archetype was used to represent the baseline housing stock, based on average size and type, determined using GIS analysis and site visit photos. The split-level houses are characterised by simple rectangular geometry and roof systems and are approximately 2200 square feet in floor area. No upgrades to the envelope or the heating systems were assumed for the baseline, although in the actual neighbourhood some upgrades (e.g. newer windows) may be in place. The Kimberley baseline analysis thus illustrates a "worst case" example, by universally assuming original system and envelope conditions.

Figure 7: Representative photos from the Kimberley neighbourhood

The new construction archetype for Kimberley was based on the retrofit archetype's form and footprint, with improved construction standards from current code. Given the 10% projected redevelopment rate, only 7 new houses were included in the scenarios.

The Kimberley case study reflects the climatic conditions of south-eastern British Columbia, including dry and moderate to hot summers and cold winters with a majority of precipitation being received as snowfall. The region has some of the best potential for solar energy in Canada (Natural Resources Canada 2010a).

2.1.3 Prince George

Case Study: Northern British Columbia, Pre and Post-war Development including Multi-family Residential
Source location: Prince George, B.C.

The Prince George case study contains a mix of pre-and post-war (i.e. pre-1960s) single family houses, as well as a small number of attached homes and low-rise apartment buildings, typically constructed in the 1970s. The selected neighbourhood borders on the downtown area and has potential for some infill development on undeveloped and under-developed parcels. Neighbourhoods such as the Prince George example can be found in many of BC's interior communities and represent opportunities to utilise incremental infill strategies as an important part of GHG mitigation strategies. The existing residential building stock has large opportunities for enhanced energy and GHG performance due to the age of the buildings, simple building geometry and excellent solar orientation within a gridded street system. Mixed building types, proximity to commercial uses in the downtown area and the potential for moderate increases in density also provide supportive conditions for community-scale energy systems.

11.2 Ha
335 units
354 m² av. lot size

0 25 50 100 150 200 Meters

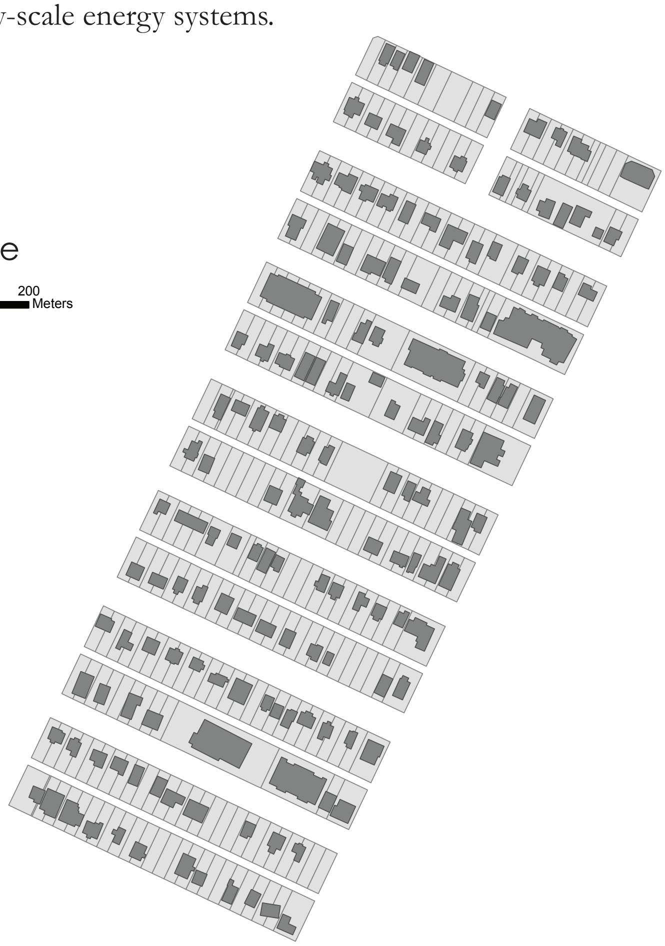


Figure 8: The Prince George case study neighbourhood: parcels and current building footprints

The amount of redevelopment has been greater in Prince George due to the age of the neighbourhood, and building types within the study area are diverse. However, a large number of single family homes constructed in the 1940s are still existing (Prince George Folio Listing 2009) and it is on this building type that the case study's single family archetype was created. A 1970s rowhouse and a 1970s apartment building archetype were also developed to represent the multi-family development present within the site. For the baseline 1940s archetype, some upgrades in the heating system were assumed to have occurred (Parekh 2005); however, envelope upgrades were assumed not to have occured. Thus, the baseline single family archetype represents a "worst case" situation (see Webster 2009 for comparison). As with Kimberley, more complexity in the real neighbourhood than in the archetypal neighbourhood means that the baseline scenario is likely to be overestimating actual neighbourhood energy use and emissions. Some of the significant gains with simple energy upgrades may have already been achieved for some but not all of the houses.



FIGURE 9: Representative photos from the Prince George neighbourhood

In Prince George, new single family homes are represented by a narrow-lot infill archetype, as shown in Figure 3, similar to several redeveloped buildings already present within the case study site. The new archetypes for rowhouses and apartments use the same building form as the baseline multi-family archetypes, with improved construction standards.

The Prince George neighbourhood and similar examples have significant potential for growth and infill development when economic conditions allow. For the Prince George case study, researchers have assumed a growth rate of approximately 150% in the number of units, reflective of the planned capacity of the larger neighbourhood that includes the study site (Milburn 2010). Additional growth beyond projected changes could easily be accommodated through the increased use of attached building forms, such as rowhouses.

This case study represents neighbourhoods within the northern climates of BC, consisting of cold winters with average temperatures well below freezing and moderate summers. While annual solar insolation is reasonable (similar to Delta), it varies substantially across the winter and summer seasons (Natural Resources Canada 2010a).

2.2 Scenarios overview

Three scenarios - Current Policy Direction, Intensive Building Retrofits and Neighbourhood Focused Approach - were developed to reflect varying types and intensities of retrofit strategies. The basic narrative of each scenario was held consistent across the three case studies, while allowing room for local variation in strategies based on case study characteristics such as climate, house form and age, expected growth and locally available energy sources. The scenarios assume that all the buildings in the case study neighbourhoods are upgraded (retrofit or rebuilt) over a time frame out to 2050. Rates of retrofit over time were not calculated, rather, the results report on the final outcomes for each scenario, as applied across the three case studies.

Each scenario uses a different set of retrofit strategies and varying new construction standards for the redevelopment buildings. The purpose of the scenarios is to identify what is likely to be adopted under current policy directions, as well as what is possible with more aggressive individual actions, or with neighbourhood-based approaches. The scenario strategies were developed based on a literature review of available programs for homeowners as well as programs for builders (see Table 2). The final detailed retrofit options were chosen using an iterative process that tested multiple options such as different wall insulation, changed heating systems, etc., and are given in the Results tables (Section 4).

It should be noted that the scenarios are not sequential: the strategies are not necessarily cumulative from Scenario 1 to 2 to 3. Rather, they illustrate three different pathways that could be taken from the baseline. Quantitative results for each scenario include energy use by source and GHG emissions to facilitate comparison and evaluation across scenarios. Qualitative criteria related to the retrofit strategies, such as lifestyle changes, can be found in the Discussion, Section 5.

Table 2. Literature review sources for the different scenarios

Scenario	Retrofit Sources	New Construction Sources
1. Current Policy Direction	Homeowners grants and guides, particularly federal ecoEnergy	BuiltGreen, LEED
2. Intensive Building Retrofits	Modeling studies, case studies, evidence-based research	Passivhaus, evidence-based research
3. Neighbourhood Focused Approach	Combined Scenario 1 and Scenario 2 strategies, case studies, prior research, and modeling	Case studies, prior research, and modeling

2.2.1 Scenario 1: Current Policy Directions

Scenario 1 focuses on current practices for energy retrofits, as promoted by federal, provincial and other organizations for home-owners, and "green buildings" for any new construction. In general, strategies for building retrofits presented to homeowners are often tied to rebate and incentive programs addressing the issues of envelope upgrades (insulation, air sealing), and heating/mechanical system improvements. Thus, the focus is on demand reductions through envelope upgrades and system efficiencies, with minimal energy source changes (with the exception of solar hot water). No specific energy or GHG reductions targets were set for this scenario, rather, the modeling tested what overall reductions were possible given the application of existing retrofit and new-build policies.

Scenario 1 Building Retrofits

For each case study in Scenario 1, retrofit bundles were developed based on the table of recommended, grant-based actions, appropriate for the construction era of the archetype buildings in the case study. Selected measures were generally understood to be cost-effective, particularly envelope upgrades through air sealing and easily accessible insulation upgrades. Heating system efficiencies were upgraded, but heating system types (e.g. furnace/boiler) were not changed. On-demand hot water was used to replace baseline conventional tanks, or solar hot water systems were added alongside conventional tank systems. The NRCAN ecoEnergy grant table was used as the baseline for developing and choosing retrofit options.

Scenario 1 assumed that renovations for energy efficiency would not include extensive interior or exterior alterations ("gut and rehab"). No additional main wall insulation was added, as it was assumed to already be present in all existing archetypes. Windows were upgraded to double glazed as necessary. Given that the maximum federal ecoEnergy grant (prior to it being discontinued) was $5000 for all upgrades, this scenario assumes that homeowners pursue simpler upgrades rather than maximising retrofit options.

Criteria for strategy selection:

- known to be cost-effective
- targets poorly performing components of the baseline building archetypes
- relatively simple and straightforward, i.e. homeowners can manage project work
- not required to achieve particular GHG performance targets
- not requiring behavioural or major lifestyle changes
- associated with available grants for homeowners, or recommended through energy efficiency programs directed towards homeowners

Key strategies for Scenario 1, Current Policy Direction:

- increased attic insulation
- reduced air infiltration

- upgraded furnace/boiler efficiency
- integrated solar hot water where possible, or on-demand hot water
- reduced electrical loads through efficient appliances and CFL lighting

Scenario 1 New Construction

For new buildings, consulted literature included current programs for the building industry, including the Built Green and LEED rating systems. Built Green is a rating system based both on a specific energy performance target (Energuide rating), as well as a checklist point system that covers energy systems, building envelope, building materials, water use/landscaping, and building and business practices; the City of Prince George has adopted policy supportive of Built Green homes (Milburn, pers. comm 2010). New construction strategies chosen for use in this project emphasize heating and hot water systems, as well as envelope and materials choices, particularly those that improve envelope performance.

Criteria for strategy selection and key strategies:

- improved (beyond current code) envelope performance for attic and slab insulation, and reduced thermal bridging
- high efficiency heating/hot water systems
- strategy packages capable of achieving Built Green gold or platinum ratings

2.2.2 Scenario 2: Intensive Building Retrofits

Scenario 2 assumes aggressive building scale retrofits, including substantial changes to buildings not typically contemplated in current practice (e.g. moving or re-sizing windows, re-cladding houses with extra insulation). New construction is designed to meet high energy and GHG performance standards (e.g. net-zero, Passivhaus). The goal of Scenario 2 is to find retrofit bundles that moved residences off fossil fuels altogether, with a specific GHG reduction target of +80% reductions from the baseline.

Thus, Scenario 2 focuses on extensive demand reductions and efficiencies, as well as changing heating systems to super high efficiency (heat pumps) and/or low-GHG intensity (existing hydro-electric resources, biomass). To achieve this, extreme demand reductions are required, including the super-insulation of buildings. Heating system energy demand is sharply reduced by moving to heat pumps (air or ground source) with efficiencies above 100% so that the heating load can be met by electricity, including backup electric baseboards. Local biomass (wood) heating sources are employed in one case study.

A secondary target for the project is to maintain baseline electricity use for each case study, thereby relying on the existing hydro-electric sources currently supplying the majority of electricity in BC, rather than adding additional load to the provincial system. Where this electrical baseload target was exceeded for particular scenarios, additional electrical demand was assumed to have a higher GHG-intensity (i.e. equal to electricity from natural gas-fired plants) for the purposes of the study.

Scenario 2 Building Retrofits

Although basic home energy retrofit recommendations can be found through initiatives such as NRCan's ecoEnergy program, Vancouver OneDay and the BC Sustainability at Home Toolkit[3], information on the deeper retrofits required to radically reduce energy use and GHG in residential homes, i.e. not readily available in "easy guides" for homeowners[4]. Strategies for Scenario 2 were thus based on a literature review of prior modeling studies, case studies, and evidence-based research[5]. Upgrades involving significant changes and major renovation were considered.

In Scenario 2, envelope upgrades were more extensive (and would be correspondingly more expensive, although costing analysis was not undertaken) than in Scenario 1. They involve rebuilding or adding to walls, using triple-glazed, low-e argon windows, and changing window sizes and locations (in once case study, the Prince George archetype). The addition of sub-floors over slabs-on-grade increases insulation values, but results in a loss of headspace within living spaces. Attic insulation upgrades are more intensive than in Scenario 1 as well. Changes to heating systems might also involve renovation, such as the ducting required for heat recovery ventilators.

Criteria for strategy selection:

- aggressive envelope changes
- not dependent on fossil fuels
- not necessarily cost effective, but necessary to achieve GHG reduction targets
- minimal changes to internal floor area (eg. retrofits with additional inside wall insulation were rejected, except in PG kneewall/cathedral ceiling situation); other significant changes to interior living space are acceptable
- may require behavioural change (e.g. stoking/running wood stoves), however, such changes must remain consistent with changes in ownership

Key strategies for Scenario 2, Intensive Building Retrofits:

- high attic insulation

3 http://oee.nrcan.gc.ca/corporate/retrofit-summary.cfm; http://vancouver.ca/oneday/; http://www.thenaturalstep.org/canada/toolkits#bc

4 REGREEN (American Society of Interior Designers 2008) is an exception: its detailed renovation project guidelines and library of strategies include "Deep Energy Retrofit" renovations.

5 Modeling studies and built examples demonstrate that deep reductions in energy use and concurrent GHG emissions are possible for a range of older houses: modeled retrofits required for a Vancouver bungalow to become a net-zero house (CMHC 2008); NOWHouse gut and rehab project in Toronto (www.nowhouseproject.com); deep energy retrofit for a Victoria heritage house (Coulson and Ross 2008).

- excellent (energy tight where possible) air sealing with heat recovery ventilators
- additional wall insulation (significant external changes)
- slab insulation (significant interior changes, see selection criteria)
- window upgrades to triple glazing with low-e argon; some windows re-sized and/or moved (significant interior/exterior changes)
- heating systems changed to super high-efficiency (heat pumps), or to local biomass (high efficiency wood stoves), with electric baseboards as a backup
- solar hot water combined with an electric on-demand system
- reduced electrical loads through high efficiency appliances and CFL/LED lighting

As costing was not included in this study, it was not a direct factor in decisions on retrofits and upgrades; however, a few of the most extreme and expensive options were regarded as unrealistic for the study, and were not used. Even so, many of the chosen retrofits in Scenario 2 would likely represent very significant costs to homeowners or others in order to achieve.

Scenario 2 New Construction

New houses in Scenario 2 aimed to achieve Passivhaus[6] standards. Passivhaus standards, developed in Germany and adopted across Europe, use super-insulated building construction to reduce space heating demand to the point where it can be met with heat recovery ventilators (HRV, ducted fan systems that exchange the heat from expelled indoor air with incoming fresh air), appliances, and occupant loads (Feist 2004).

Passivhaus standards are achievable within Canada, and evidence-based case studies exist to show that new houses can be built in difficult climactic conditions to achieve excellent energy performance. For example, the CMHC National EQuilibrium Housing Demonstration project showcases a net zero passive solar home built in Edmonton, Alberta that uses triple-glazed windows (with quadruple-glazed on the north side) and double-thick, super-insulated walls (CMHC 2009).

2.2.3 Scenario 3: Neighbourhood Focused Approach

Scenario 3 incorporates neighbourhood or shared opportunities to enhance GHG reductions by rebalancing the reductions achieved via demand, efficiency and supply-based strategies. The goal of Scenario 3 is to temper the extreme space heating demand reductions required by Scenario 2, Intensive Building Retrofits, by finding

6 Passivhaus standards set stringent space heating and air infiltration numbers, achieved through super-insulation and tight envelopes, and applied to any building type or geometry. Passivhaus differs from passive solar, which maximizes the use of solar gains for space heating, through south façade glazing and internal thermal mass, which confines building form and geometry to specific parameters.

other shared ways of reducing GHG emissions. Energy systems and multi-parcel approaches such as block-scale geothermal systems and shared solar thermal systems were explored. Like Scenario 2, a target of 80% GHG reductions for the neighbourhoods was adopted.

The research questions framing the Neighbourhood Focused Approach came from the finding that few of the individual house studies or grant-based programs assess the level of retrofit required beyond the individual house. From the Intensive Building Retrofits scenario, it is clear that low-energy houses can be built or retrofitted (often at great expense), but it is less clear what opportunities (or constraints) exist when the neighbourhood is treated as a system. Potentially, there are advantages and disadvantages, as well as implications involving how neighbourhood structure might change and how new construction is located within neighbourhoods when the challenge is to maximize opportunities to radically reduce greenhouse gas emissions. The Neighbourhood Focused Approach thus sought to maximize local renewable energy options. Background research included not only building level options, but also neighbourhood and local region alternatives for low GHG-intensity energy opportunities. The approach assumed that strategies requiring changes in municipal policy (re-zoning, etc.) could be achievable.

Scenario 3 Neighbourhood Retrofits

Few studies are available on neighbourhood or small-scale collective options; however, previous work by Flanders et al 2009, Miller and Cavens 2008, Pond 2008, and Miller 2006 provided a basis for neighbourhood energy opportunity analysis. As well, evidence-based case studies were reviewed (e.g. Drakes Landing, Okotoks; small district energy in Quebec (CanMET Energy 2009)) in order to assess what might be technically and spatially possible in each case study.

The shared systems strategies that were assessed for the three case study neighbourhoods are explained in more detail in the Strategy Assessment section. Researched systems included: shared geothermal, shared solar thermal, district energy systems, shared photovoltaic systems and altered redevelopment patterns to maximize GHG reductions.

Scenario 3 Building Retrofits

Given that the goal of Scenario 3 was to test whether neighbourhood systems could enable energy and GHG performance comparable to or better than the Intensive Building Retrofits Scenario without requiring the most extensive building-scale upgrades, retrofitted buildings for the Neighbourhood Focused Approach incorporated a combination of Scenario 1 and 2 upgrades. Extreme wall insulation and slab upgrades from Scenario 2 were dropped while the attic insulation upgrades and triple-glazed windows were maintained. Selected strategies depended in part upon climatic conditions: more extreme upgrades were retained in colder climates (Prince George), and relaxed in maritime climates (Delta). Overall, energy demand reductions were not as extensive as in Scenario 2.

Criteria for strategy selection:

- envelope upgrades between Current Policy Direction and Intensive Building Retrofits
- minimal lifestyle changes (e.g. internal living spaces not significantly altered)
- inclusion of shared and neighbourhood-scale strategies
- inclusion of locally renewable energy sources for baseload heating, where possible

Key strategies for Scenario 3, Neighbourhood Focused Approach:

- increased attic insulation; some slab and wall insulation (Prince George)
- reduced air infiltration from baseline
- solar hot water for all units, coupled with DES or on-demand
- district energy systems using wood as baseload energy supply where biomass is locally available (Prince George and Kimberley)
- altered re-development patterns to optimize GHG reductions (e.g. remove worst performing buildings) (Delta)
- reduced electrical demand equivalent to the Intensive Building Retrofits Scenario
- exploration of local electrical generation opportunities (Delta and Kimberley)

The combination of individual house demand reductions and shared solutions were developed iteratively using individual house energy modeling, case studies, neighbourhood spatial analysis, and neighbourhood energy/GHG spreadsheet modeling, as described in the modeling methods to follow.

Scenario 3 New Construction

Scenario 3 assumed the same new Passivhaus-style buildings as in Scenario 2 for Kimberley and Prince George, where climatic conditions require high performance envelopes in order to keep space heating demand down.

In Delta, two variants for new buildings were modeled for Scenario 3: the Passivhaus single family home used in Scenario 2, and as a comparison, a Passivhaus rowhouse based on the Prince George rowhouse archetype. Very low energy demand in the rowhouse buildings was possible due to a combination of an energy tight envelope, small size, compact rectangular form, shared walls, and southern orientation. The final Scenario 3 neighbourhood numbers for Delta used the single family house, in order to maintain housing type consistency across the scenarios.

2.3 Scenario strategy assessment

Based on the criteria and scenario definitions outlined above, detailed Strategy Assessments were undertaken in order to determine specific options for reducing GHGs across three strategy types: reducing demand, increasing efficiency, and low-GHG energy sources. Additionally, neighbourhood structure was assessed to improve understanding of the neighbourhoods as systems, establish baseline numbers, and assess opportunities for shared strategies for the Neighbourhood Focused Approach of Scenario 3.

2.3.1 Neighbourhood structure

New buildings and green developments are often looked to for solutions in reducing GHG emissions. However, for existing neighbourhoods, rates of new construction through piecemeal redevelopment may not be high enough to substantially reduce emissions overall within the neighbourhood as rapidly as required; alternate or additional strategies will have to be used to meet stringent GHG reduction targets. For this reason, the neighbourhood structure of each case study was examined with the intent of understanding each neighbourhood as a system, including how individual buildings create aggregate impacts on the neighbourhood, and how buildings are provided greater or fewer GHG reduction opportunities depending on neighbourhood structure. Thus, solar access, building and parcel orientation, housing size and form, housing type, and locational energy opportunities were all assessed with a view to maximizing GHG reduction opportunities.

Solar access

Solar access, the ability of sunlight and solar energy to reach a building's surface, was considered in all case studies both for solar thermal applications (e.g. hot water panels on rooftops), as well as for heat gains through windows. Solar access is of particular concern in Prince George with higher density development. Sketch-up and GIS analysis of buildings up to 3 storeys indicate that taller multi-family buildings could impede winter solar access for the ground floors of neighbouring buildings to the north. Thus, one of the redevelopment patterns explored for Scenario 3 in Prince George strategically located new development in a staggered MFD/2-storey rowhouse pattern to preserve solar access, ensuring both rooftop solar thermal and solar gains through glazing in the winter for adjacent residences (shown in Figure 13B).

Solar access is also a concern in Delta due to the tight spacing of the buildings. Building spacing would have the greatest impact on passive heating potentials (passive solar), which were assessed spatially, but were not modeled within the scenarios for this project. In Kimberley, the larger lots allow for excellent solar access for all residences, and would allow for re-orientation of new construction to maximize solar gain. New construction in Scenarios 2 and 3 was thus assumed to be oriented to maximise solar access, particularly for rooftop applications.

Orientation

Building orientation can impact energy use due to solar gains through south, east, and west oriented windows (thereby reducing heating demand), and heat losses through north-facing windows (thereby increasing heating demand). According to study models, neighbourhoods with curvilinear streets and multiple house orientations can have significant (over 10%) differences by orientation in energy performance across the same building archetype. Gridded street systems allow for more consistent building orientation and therefore support maximised solar gains when paired with appropriate building design (i.e. extensive southern glazing). However, care must be taken in building construction practices and/or landscaping to minimize excessive summer solar gains.

Glazing orientation was a key strategy for the Intensive Building Retrofits Scenario for Prince George in order to improve envelope performance. Building orientation was also used for new construction in Kimberley and Delta in order to improve solar energy potential.

Building size and geometry

Building size and geometry have important effects on building energy demand. While the assertion that larger buildings consume more energy seems obvious, the effect of total building area on energy demand is often overlooked in standards that measure energy in terms of demand per unit of area, or in terms of percent reductions. Recently, LEED for Homes has incorporated a "home size adjuster" factor in its scoring calculations to encourage the construction of smaller homes, stating that "a large home consumes more materials and energy than a small home over its lifecycle" and that "…a 100% increase in home size yields an increase in annual energy usage of 15% to 50%, depending on the design, location and occupants" (Canada Green Building Council 2009, pg. 22).

Beyond size, building geometry also plays a role in determining overall energy demand. Relationships between building depth and floor to floor heights have important implications for both space condition and natural lighting potential (Baker 2000). Of particular importance for this study, more complex building geometries (e.g. more corners) increase a building's perimeter with respect to the volume of space enclosed, resulting in increased heat loss for residential buildings. Building geometry also impacts the feasibility of roof-top energy technologies such as solar hot water systems and photovoltaics, where complex roof design breaks roof surfaces into smaller areas less suitable for panel installations.

Existing house size and geometry vary considerably across the case studies, and were a consideration in the development of new construction archetypes for the study, where variations from the original building archetypes could be easily accommodated. In Delta, new single family archetypes are characterised by reduced footprints and simplified building geometry (fewer corners) as compared to the existing houses. The existing Kimberley archetype has relatively simple geometry (4 corners on the ground level and 6 corners on the second floor), and a moderately sized building footprint, and that building form was maintained for new construction in all scenarios. In Prince George, infill houses with narrower profiles and simple geometry are already under development in the case study neighbourhood, and the new archetype was based on these houses. Rowhouses and multi-family development in Prince George assumed the same footprints and geometry as the retrofit archetypes, again due to existing simple geometry and small footprints (as shown in Figure 3).

Housing type

Housing type is an additional characteristic impacting energy demand and GHG emissions. Housing types are generally classified according to whether buildings accommodate one or more households, and whether residential units share walls and/or floors. In addition to generally smaller unit sizes associated with multi-family housing types, shared walls (e.g. rowhouses) and shared floors (e.g. apartments) greatly reduce the amount of surface area per unit exposed to external climatic conditions, reducing heat exchange and associated space heating demand substantially (see, for example, energy consumption data from the 2007 BC Hydro Conservation Potential Review). Housing types considered for this project are single family, rowhouses and low-rise apartments.

Rowhouses, provided they meet the criteria of good form, small footprint, proper orientation, etc., offer a superb alternative to single family, detached housing types in terms of energy performance while maintaining the potential for private yards and ground-oriented unit access. The reduced height of these buildings in comparison to other forms of multi-family housing also may maintain solar access for neighbouring buildings, depending on building locations and orientation.

Housing types and proportions were held constant between scenarios. Prince George was the only case study to add units in the future scenarios, and the additional units were rowhouses and multi-family apartments. Utilising these lower-energy housing types for this case study is a critical strategy for mitigating the additional energy demands and GHG production resulting from increasing populations.

Locational opportunities for neighbourhood energy

Neighbourhood energy systems were considered for all case studies, with consideration of both internal opportunities and external, but local, resources. Opportunities for several shared systems were analysed, such as shared geothermal and district energy systems, using spatial analysis.

Overall, Prince George was found to have the most opportunities, with lanes, empty parcel open spaces, and an adjacent school as potential geothermal vertical or horizontal loop locations. Prince George also has a proposed municipal district energy system (DES), with planned piping through the case study neighbourhood, although the system is currently only planned for commercial/institutional use (FVB Energy 2006).

Kimberley has options for field geothermal in an adjacent schoolyard, the potential for a shared energy system with an adjacent development site (to the west), and proximity to the highway (biomass supply). The Kimberley case study also has the potential for a more diverse baseload due to adjacent commercial and institutional uses. A costing analysis would be required, however, to more closely determine feasibility. Small in-neighbourhood biomass boilers might be possible as well, including a shared-load system with the adjacent care home to the south. Given the excellent solar resources, a combined solar thermal/geothermal or biomass system might also be possible in for this case study, similar to the one in Drake's Landing, Okotoks Alberta.

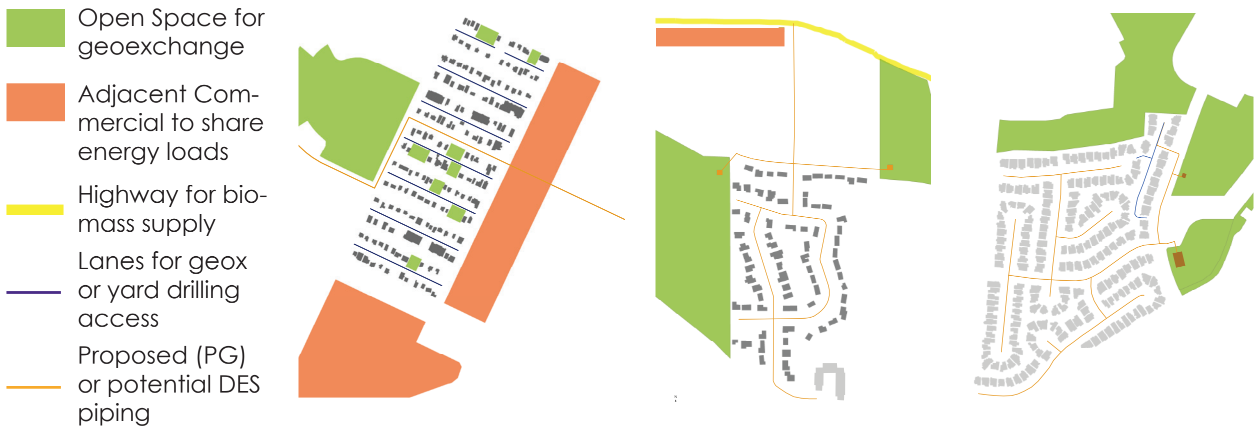


Figure 10: Locational opportunities for neighbourhood energy systems: Prince George, Kimberley, and Delta

Delta has adjacent golf courses that could provide space for shared geothermal systems, or a location for a small biomass plant. One laneway exists in the neighbourhood that could be used for a small shared geothermal system for those few houses. Cul-de-sacs present in this case study were considered as possible locations for additional geothermal installations, but were eliminated due to insufficient space and potential conflict with other utilities (water, sewage, natural gas lines). The Delta case study has the fewest neighbourhood renewable energy options.

Redevelopment patterns

Redevelopment was assumed to be random for the Current Policy Direction and Intensive Building Retrofit Scenarios, and was randomly distributed across the different housing orientations (Figures 11A, 12, and 13A below). In the Neighbourhood Focused Approach of Scenario 3, the possibility of shared action meant that redevelopment patterns could be re-thought. In Delta, where the tight houses and resultant lack of solar access meant that random redevelopment could not maximize orientation and solar access opportunities, two different development patterns were tested. The first removed the worst performing houses by orientation and replaced them with better performing, south-oriented single family residences (Figure 11B). The second replaced sets of houses including some of the worst-performing houses with smaller rowhouses. In Kimberley, the larger lots allowed for new houses to be oriented for best performance regardless of lot orientation (e.g. a new house on an east or west facing lot would be oriented to face south), and random redevelopment was assumed across all 3 scenarios.

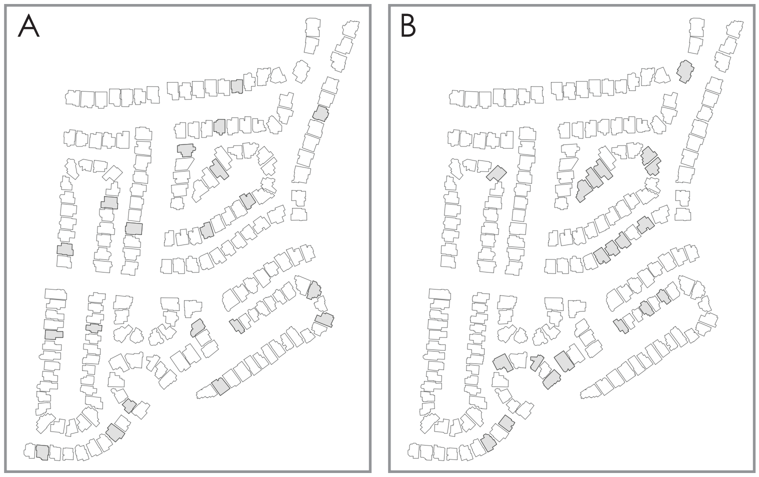


Figure11A, 11B: Redevelopment in the Delta neighbourhood. A) Random redevelopment pattern for Scenarios 1 & 2; B) Redevelopment to replace poorest energy performance by orientation, Scenario 3.

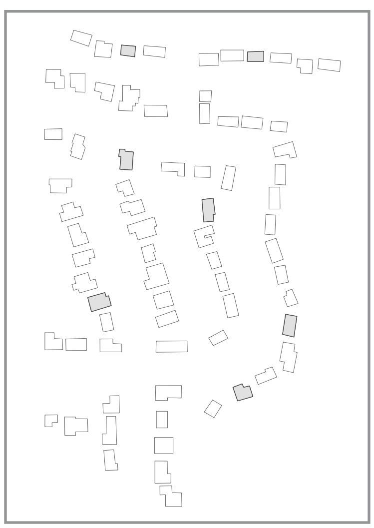


Figure 12: Random redevelopment in Kimberley, Scenarios 1, 2, 3

In Prince George, random redevelopment was assigned in the first two scenarios (Figure 13A), while two variants were explored for the Neighbourhood Focused Approach of Scenario 3. The first assumed random redevelopment with the entire neighbourhood on a district energy system (Figure 13A); the second variant used re-zoning so that the parcels adjacent to the main district energy piping would redevelop to multi-family and rowhouses, and the rest of the neighbourhood would remain on individual heating systems (Figure 13B). The latter scenario illustrates how land use planning based on accessibility to the DES piping could be implemented in future planning policy. The final Prince George numbers assumed random redevelopment, with all buildings on the district energy system.

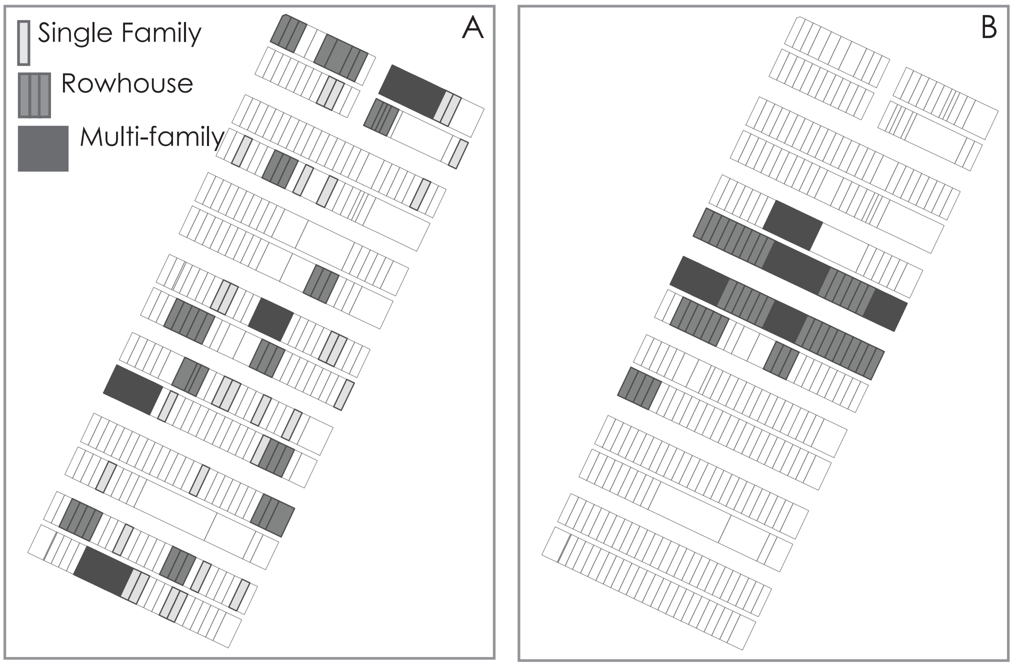


Figure 13A, 13B: Redevelopment in the Prince George neighbourhood. A) Random, Scenarios 1, 2, 3; B) Along the proposed DES route, alternate for Scenario 3.

Spatial arrangements for redevelopment could have a significant impact on the economic feasibility of Scenario 3 in particular as spatial arrangement and location impact the costs of linking new and existing development to a community energy system. Clustering development along the same corridor might significantly reduce costs as compared to piping the entire neighbourhood, given that costing for the Prince George DES assessed a rate of $1282/meter of pipe (calculated from DES Feasibility Report, FVB Energy 2006). As economic analyses were not part of the scope of this study, future work to explore the financial implications of alternate DES redevelopment patterns is needed.

2.3.2 Demand reductions

Demand reductions focused on space heating, and in particular, looked to improved building envelopes as a key strategy for GHG reductions. All of the upgrades across the Scenarios were considered for their construction viability – i.e. whether they could actually be built/installed, based on the researchers' experience in the construction industry and architecture backgrounds.

Retrofit building envelopes

Building envelope details include wall, ceiling/attic, header and slab insulation, thermal bridging in wall construction, air sealing or natural infiltration, and window and door performance. Effective R values (ER)[7] for each of these were determined for the baseline archetypes, and then upgraded by scenario.

Baseline building envelopes were developed using the building wizard in HOT2000, which assigns R values based on the era of construction, and compared to the BC Building Code, historical construction practices, and real estate listings. Wall construction was assumed to be standard 2x4 at 16" on centre, with window cripples, 3 stud corners for Delta and Kimberley, and 4 stud corners for Prince George. All archetype baseline walls were assumed to have insulation, except the Prince George single family basement walls. Attic insulation was determined by era and ceiling type. Air infiltration numbers were taken from HOT2000, which uses an NRCAN database; in Delta the assigned numbers were upgraded marginally. Window type was determined by housing type, era, and location, and compared to site photos.

In Scenario 1, upgrade feasibility was based on baseline conditions and no walls other than the Prince George basement walls were upgraded. Attic insulation was upgraded for gable and cathedral ceilings (except the kneewall/cathedral ceiling in Prince George which was left until Scenario 2 due to the complexities involved in insulating these areas). Although the ecoEnergy grant program required only 20% of a given envelope component (main wall, foundation wall, attic) to be upgraded to qualify for a minimum grant, this study assumed 100% upgrading for components being insulated. Additional slab insulation was not added, as the NRCAN ecoEnergy grant does not include any rebates for slab insulation. Windows were upgraded if they were not double vinyl or equivalent.

Scenario 2 experimented with more intensive demand reductions through envelope upgrades, including extensive re-insulation of the walls. Additional insulation (strapping, rigid-board, and new cladding) was assumed to be installed on the house exteriors; a thermally broken interior insulated wall was also used on the second floor in Prince George. Insulation of the slab required an additional insulated sub-floor – which would result in a loss of overall room height. In Delta, the ceilings would change from 9 feet to approx. 8'5" on the main floor; in Kimberley, the downstairs would be less than 8 feet, as would the basement in Prince George.

As an example of the extent of changes required for the Intensive Building Retrofits of Scenario 2, in the Prince George archetype building retrofits would include:

7 Effective R values consider the building component construction as a whole for its insulation value and were used throughout this study. Effective R values are generally lower than an individual insulation material's R value, due to thermal bridging and construction methods. They were provided by the energy modeling software (HOT2000) that calculates wall and other assemblies' overall insulation performance.

removing poorly performing existing insulation from the walls for replacement by sprayfoam; adding exterior insulation and new exterior wall cladding; adding doubled interior walls/ceiling to insulate the challenging kneewall/cathedral ceilings of the second floor; and, super-insulating the basement slab and foundation walls with an insulated sub-floor and doubled interior walls. Windows were resized and/or removed from the north side and added to the south side.

For the Neighbourhood Focused Approach, for all case studies, envelope improvements were relaxed from the Intensive Building Retrofits of Scenario 2, although they were still improved over the Current Policy Directions of Scenario 1. Additional exterior wall insulation was not used, nor were the slab upgrades using sub-floor framing (except for the Prince George basement). Attic insulation was assumed to be attainable to Scenario 2 standards.

Air sealing was improved for Scenarios 1 and 2 from the baseline to "average" at 4.55, "present" at 3.57 or "energy tight" at 1.5 (as given in HOT2000 and shown in the results tables). In Delta and Kimberley, the air sealing improvements to energy tight in Scenario 2 would likely involve considerable work to achieve but were assumed possible due to the attention paid to other envelope upgrades. For Scenario 3, air sealing was either maintained (Delta) or relaxed (Kimberley and Prince George), depending on the perceived ease of achieving the air sealing in conjunction with other Scenario 3 upgrades for each archetype.

New building envelopes and Passivhaus

Building envelopes for the new archetypes in Scenario 1, Current Policy Directions, used HOT2000 current assigned R values for wall and ceiling insulation, with BuiltGreen additions for additional slab insulation and wall construction practices to limit thermal bridging. In Scenario 2, Intensive Building Changes, where the goal was to achieve Passivhaus standards of 0.5 ACH and 15 kwh/m2 space heating demand, wall and attic insulation values and construction details were upgraded beyond BuiltGreen depending on the case study climate (i.e. as much as necessary to reach the low space heating demand goal). All windows were triple-glazed, low-e argon. Air sealing was set at 1.5 ACH due to modeling constraints. Simple rectangular house construction was used – the infill house for Prince George was the prototype.

In Delta, Passivhaus standards were relatively straightforward to achieve, with excellent slab and ceiling insulation, a tight envelope, and triple-glazed windows. In Prince George, Passivhaus standards proved more difficult to achieve through modeling: diminishing returns on wall/attic/slab insulation meant extreme insulation additions provided only minimally improved performance. It was thus assumed that a Passivhaus targets would be achievable (see, for example, the EQ Edmonton house, CMHC 2009), but it was beyond the scope of this project to determine the exact construction details required.

In contrast to the single family houses, the compact rowhouses considered in the Prince George and Delta case studies proved successful in achieving Passivhaus standards. These were used in Scenario 2 and 3 for Prince George, and only as an exploratory variant in Delta's Scenario 3.

2.3.3 Energy Efficiency

Energy efficiency considered the systems in use for hot water and heating systems, as well as appliances and lights that contribute to household electrical use.

Heating

High efficiency natural gas furnaces and boilers were used in Scenario 1 to replace existing natural gas boilers and furnaces with pilot lights. The efficiency upgrades are given in the Scenario 1 strategies tables (Results section, Tables 8, 9, 10). Baseline efficiencies were based upon the era of construction (Parekh 2005), with one upgrade assumed for the 1940s archetype. The other archetypes assumed original era efficiencies.

For the Intensive Building Retrofits Scenario, alternate and more efficient systems were explored, particularly heat pumps/exchangers, with each case study employing a different heating system.

Air to air heat pumps, used in Delta for Scenarios 2 and 3, act like reverse refrigerators, taking energy out of outdoor air to supply ducted air heating systems, or hydronic heating systems. Their space requirements are minimal, at about or under 10 square feet. They are best suited for mild maritime climates, as they do not perform as well in cold conditions. They could have an impact on the noise levels in neighbourhoods, although newer systems (and more expensive systems) have very low noise levels. Their efficiencies are well over 100%, and can be closer to 300%. Air to air heat pumps use electricity as their energy source; backup heat for peak demand was assumed to be met with electrical baseboards[8].

Geoexchange or ground-source heat pump (GSHP) systems also have efficiencies over 100%. A Coefficient of Performance (CoP) of 3.5, i.e. an efficiency of 350%, was used for the modeling (Miller and Maynes 2008). Space heating demand can therefore be met with far less actual energy than heating demand. Hot water can also be obtained from the system. Geoexchange systems require adequate space without conflict with underground utilities, as can be found in the parcels in PG and Kimberley, but not the parcels in Delta where the building coverage is high. Vertical systems would be needed unless larger open spaces could be used. Systems in front yards might conflict with utilities, and thus backyards are preferable.

8 Even with the super-high efficiencies of heat pumps, it is critical that demand reductions (envelope upgrades) be undertaken prior to assessing heating loads and running systems. Without demand reductions, the increase in household electrical use could be very high due to excessive heat pump use, and heavier demand on backup systems.

Back lanes ensure access to backyards for drilling for individual vertical systems. Geothermal is listed as a possible energy source in the Smart Growth policy document (Smart Growth BC 2009) for Prince George. Ground-source heat pumps use electricity as their energy source; backup heat for peak demand would be met with electrical baseboards.

High efficiency wood stoves were adopted as a strategy in Scenario 2 in Kimberley, due to the presence of a local biomass source, and current practice in the region of heating with wood stoves. Modeling for this study assumed one wood stove on each floor of the split level, although changes to building ventilation/additional fans/etc could allow for one larger stove instead. Backup heat would be supplied by electric baseboards. Wood stoves could also be used in Prince George, although it was deemed that they might be more appropriate in more rural locations rather than the city centre. Air quality concerns in "the bowl" in Prince George could be a public barrier to large-scale use of wood stoves for heating, even with low emission, EPA certified stoves.

HRV, or heat recovery ventilators, were used when the air sealing dropped below 3.5 ACH. There is a trade-off with HRV between the gains in space heating demand/heat supplied, and the additional electrical load. HRV systems require intake and output ducting to each floor of the house, and may use pre-existing ducting from forced air furnaces (e.g. Kimberley Scenario 2), or could require renovations to install ductwork (e.g. Delta Scenario 2).

Hot water

The highest impact strategy for reducing energy consumption and GHG emissions for hot water for the project scenarios was the use of solar hot water (discussed below under Energy Supply). Remaining hot water demand was then met through efficient systems.

In Scenario 1, on-demand natural gas systems were used when solar thermal was not: either solar thermal was installed alongside a conventional natural gas pilot light tank, or the conventional system was replaced by on-demand hot water. For Scenario 2, multiple system changes were used to optimize performance, such that solar hot water was coupled with on-demand systems. To eliminate fossil fuels in this scenario, electricity was employed as the energy source. In Scenario 3, individual on-demand hot water systems were only used in Delta, as both Prince George and Kimberley moved to biomass-based district energy systems to meet the hot water demand not provided by solar thermal. Many additional strategies to reduce hot water demand are behavioural (short showers, clothes washed in cold water, etc); however, these were not considered for the models.

Electricity

As shown in Table 3, electrical loads were reduced across the scenarios. Baseline electrical baseloads were calibrated using NRCan data for BC (Comprehensive Energy Use Database) and the building energy modeling pre-sets. Major appliances were assumed to function as in 1994 (i.e. the appliances in Delta have not been replaced, while Kimberley and Prince George have been updated to 1990 levels).

For the Current Policy Directions Scenario, major appliances were upgraded to current models including some Energy Star, and lighting was improved by 25% through increased use of Compact Fluorescent Lights (CFLs). Further improvement from CFLs was assumed to be limited as Canadian households now use energy-efficient bulbs for over half of their lighting needs (Natural Resources Canada 2010b). Other appliance use (TVs, computers, etc), and additional electrical loads were assumed to remain the same, with a minor reduction in exterior loads. The overall electrical use reduction was thus assumed to be 20% in Scenario 1.

For Intensive Building Retrofits, major appliance performance was improved based on very efficient refrigerator performance (available now, but with limited market penetration and high cost), the use of front-load washers, and very energy-efficient dishwashers. Major appliance loads dropped by over 50% from the baseline. Lighting loads were reduced from the baseload by 50%, due to increased use of CFLs and market penetration of LEDs (Light Emitting Diodes, extremely efficient lighting technology). Other small appliance loads had assumed reductions of 20%. The overall electrical use reduction was thus assumed to be 40% in Scenario 2.

Table 3. Annual electrical loads per household, with assumed efficiencies by scenario

	BASELINE		Scenario 1. CURRENT POLICY DIRECTIONS		Scenarios 2 & 3. INTENSIVE + NEIGH.	
Major Appliances	**Annual Use**	**Type**	**Annual Use**	**Type**	**Annual Use**	**Type**
Refrigerator	627	1994 av.	423	Energy Star	175	SunFrost
Range	747	1994 av.	523	Self-cleaning	523	Self-cleaning
Washer	923	1994 av.	555	Top-loading	203	Front-loading
Dryer	910	1994 av.	905	Standard	905	Standard
Dishwasher	777	1994 av.	324	Energy Star	120	Super-efficient
Total	**3,984**		**2,730**		**1,926**	
Minor Appliances	**1,691**		**1,691**		**1,353**	
Interior Lighting	**1,095**		**821**		**548**	
Exterior Loads	**1,460**		**1,095**		**803**	
Other	**1,095**		**1,095**		**931**	
Total	**9,325kWh/year**		**7,432kWh/year**		**5,561kWh/year**	
Percentage of Baseline	**100%**		**80%**		**60%**	

• Does not include electricity from space and hot water heating systems.
• Major appliance data sources, web-based: NRCan "Energy Consumption of Major Household Appliances 1990-2006" 2009; NRCan "EnergyStar qualifying criteria" (Dishwashers, Refrigerators, Clothes Washers); NRCan "Efficiency Ratings" (Refrigerators); BC Hydro PowerSmart; www.sunfrost.com.

Electrical loads could be further reduced through behavioural changes such as using clotheslines to reduce the heaviest appliance load (dryers); however, as these changes depend upon variable individual behaviour, they were not modeled.

The electrical baseload numbers do not account for additional electrical loads due to changes in space and hot water heating systems, including HRV (heat recovery ventilator) systems and solar hot water pumps. The Intensive Building Retrofits Scenario in particular, where reduced natural air infiltration rates required additional mechanical ventilation, saw significant increases in HRV/fans electrical loads (+300% for some archetypes). These numbers were added in the spreadsheet models and are counted in the final results for electrical use.

Other systems

Several energy efficient heating/hot water systems were researched, but not modeled for archetype scenarios. They could provide significant demand reductions or improved demand efficiencies:

• Combined hot water heating systems using wood stoves and solar thermal as the space heating source, supplying radiant floor, radiator or other space heating as well as hot water heating.

• Integrated mechanical systems (IMS), as developed in collaboration with NRCan (EKOComfort), combine space heating, hot water and ventilation into one mechanical system similar in size to a conventional furnace. They were tested in Scenario 1 modeling for Delta and provided improved performance (approx. 20% of total energy use) over separate high efficiency furnaces and on-demand hot water systems. As they are not yet commonly promoted to homeowners, they were not used in Scenario 1; and, as they continue to depend upon fossil fuels, they were not used in Scenario 2.

• Passive solar, which makes use of super-insulated envelopes, glazing oriented for maximal winter gains or an additional greenhouse attached to the main house, and interior thermal mass, involves very extensive gut and rehabilitation projects, and would be applicable for Intensive Building Retrofits. Passive solar represents an excellent option for the Kimberley case study neighbourhood and archetype; would work in Prince George; and could work in Delta (no climate restrictions) but for the lack of solar access, as previously discussed. Backup heating could be provided by wood stoves, natural gas, or baseboards. As the energy modeling methodology chosen for the project was not designed specifically to model passive solar houses[9] this option was explored but not quantitatively modeled.

• Other green building types such as strawbale (e.g. Gusdorf 2008) and timber frame/thermal mass houses use thick walls that provide both super-insulation and thermal mass. Coupled with smaller footprints, proper orientation and glazing, and housing type (duplex, rowhouse), the performance of these houses should be able to achieve or exceed the new low-energy (Passivhaus) construction modeled for this project.

9 Such software is under development (O'Brien et al. 2008).

2.3.4 Energy sources

Beyond reducing energy demand and increasing efficiency, changing to low- or zero-GHG energy sources is a critical component of significant GHG reductions. Several opportunities to utilise low-GHG energy sources have already been covered in other sections (i.e. air and ground-source heat, passive solar heat, etc.). This section looks at further energy source strategies for heating and hot water, as well as for meeting increased electrical loads.

Heat and hot water

Where possible, solar thermal was used to reduce the demand placed on conventional hot water systems. Renewable energy modeling (RETScreen - see Leng 2000) for individual houses showed that 50% of annual hot water demand could be met in Delta (using flat-glazed panels), 55% in PG (using evacuated tubes), and almost 68% in Kimberley (evacuated tubes).

An aerial photo survey of existing roofs was undertaken in order to assess neighbourhood potential, looking for orientation and adequate roof space for a 6.25 m^2, 2 panel system. In Delta, the curvilinear streets, multiple house orientations, and complex roof systems meant that only 74 houses of 199, or 37%, could use south-oriented solar thermal for Current Policy Directions (Figure 14A). The Intensive Building Retrofits added systems on roofs facing southeast to east and southwest to west (Figure 14B). The Neighbourhood Focused Approach took a shared system approach, installing oversized systems on several houses in order to supply solar hot water to the remaining residences without their own systems.

Figure14A, 14B: Available roofs for solar thermal, Delta. A) Primarily south facing roofs; B) All roofs with space for solar panels.

In Kimberley for Scenario 1, over 50% of residences could accommodate solar thermal, based on roof orientation (Figure 15). For the remaining scenarios, all Kimberley houses used solar thermal. In Prince George, all retrofits and new construction across all the scenarios were assumed to have solar thermal as the building and roof orientation was appropriate (northeast/southwest gridded street network). An assessment of the roof space available on the multi-family buildings determined that even with shading and roof obstruction constraints, there would be adequate installation space to supply solar hot water to all occupants (see the solar thermal methodology in Flanders et al 2009).

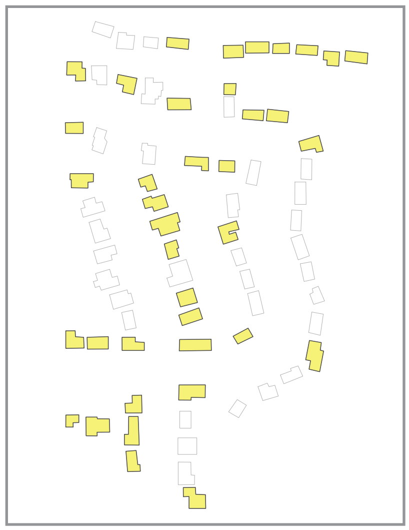


Figure 15: Available roofs for solar thermal, Kimberley, Scenario 1, Current Policy Direction. All remaining roofs accomodated solar thermal for Scenarios 2 and 3.

District Energy Systems (DES) for space heating/hot water systems were also explored for Scenario 3 in each case study, with biomass (wood) as the base energy source and natural gas to meet peak loads. In Kimberley and Prince George, biomass DES was considered a viable option at this level of analysis due to the potential availability of biomass sources locally. In Delta, although the biomass source is farther away, district biomass might be feasible in the future (given that, for example, pellets are currently shipped from Prince George to Europe), particularly for mixed-use areas outside the case study neighbourhood. However, known drawbacks for using DES within the case study area such as increased truck traffic and the high cost within low density/low demand areas, and a road infrastructure that is not due for upgrading by 2050 (i.e. no cost-effective means of installing piping) meant that DES was not chosen for Delta.

In Kimberley, a DES system was considered to offer additional efficiency and lifestyle advantages. DES performs more consistently and at higher efficiencies than individual wood stoves, and home owners, including second home owners, would not have to run and maintain wood stoves on a daily basis. DES was thus modeled for Kimberley in Scenario 3.

Electricity

Electricity is often described as a renewable energy resource in British Columbia. However, even within British Columbia, emissions from electricity vary dramatically depending on the original energy source, as discussed below in the emission factors for electricity. While BC's current average electricity emission factor is very low due to the abundance of hydropower within the province, there is no guarantee of what future emissions from electricity might be, particularly if demand for electricity continues to grow. Meeting large proportions of residential energy demand with electricity (e.g. such as space heating and hot water) to avoid the use of fossil fuels and reduce GHG emissions may not be successful if electrical demand is raised to such an extent that the use of fossil fuels becomes necessary in the generation of electricity.

Therefore, for the purposes of this study, any increases in a case study's electricity consumption was assumed to be met with electricy generated from natural gas. The spreadsheet model assumes that all additional electricity has a GHG emission factor of 0.134 tonnes CO2e/GJ, compared with B.C.' Hydro's currently accepted factor of 0.006 tonnes CO2e/GJ (Province of B.C. 2008b.)

As an alternative to natural gas electricity, photovoltaics (PV) were modeled for both Delta and Kimberley to test whether additional neighbourhood electrical demand due to heat pumps, HRV, electric on-demand hot water, etc., could be met using this renewable energy source. In Delta, the number of PV systems possible would be constrained by the lack of adequate roof space. Only 25 existing houses could add PV systems, as most of the minimally available roof space would be used for solar thermal systems. The Kimberley building archetype, in contrast, can accommodate multiple panels on south-facing roofs. Based on an orthophoto survey of existing homes, the neighbourhood as a whole could add 97 panels on 34 houses, including the new construction houses (assuming 6.25 m2 panels, similar in size to a 2 panel solar thermal system). The potentials for PV are given in the results (Section 3), but were not included in the final neighbourhood energy and GHG numbers.

Additional systems

Additional shared systems that were considered but not modeled or used in the final numbers included cogeneration, where the waste heat from electrical production can supply a District Energy System and other, more complex integrated systems using hot water as the carrier, with multiple heating sources: shared solar thermal, geo-exchange system, and/or biomass boilers. Cogeneration was only considered for Prince George, where the adjacent industrial lands and scale of the proposed DES could make a cogeneration plant feasible. Cogeneration would allow for increased electrical use due to non-DES supplied residential areas going to geothermal or other electrically-based heating systems, or for increased electrical demand due to an increasing population.

2.4 Energy and Greenhouse Gas Modeling

In order to model the energy and greenhouse gas implications of the scenarios and strategy assessments, a number of standard software packages were used. These modeled various characteristics of the different case studies, including single-family energy modeling, multi-family energy modeling, and renewable energy supply modeling. Figure 16 illustrates the relationships between the methods used. The various modeling methods are discussed in the following sections.

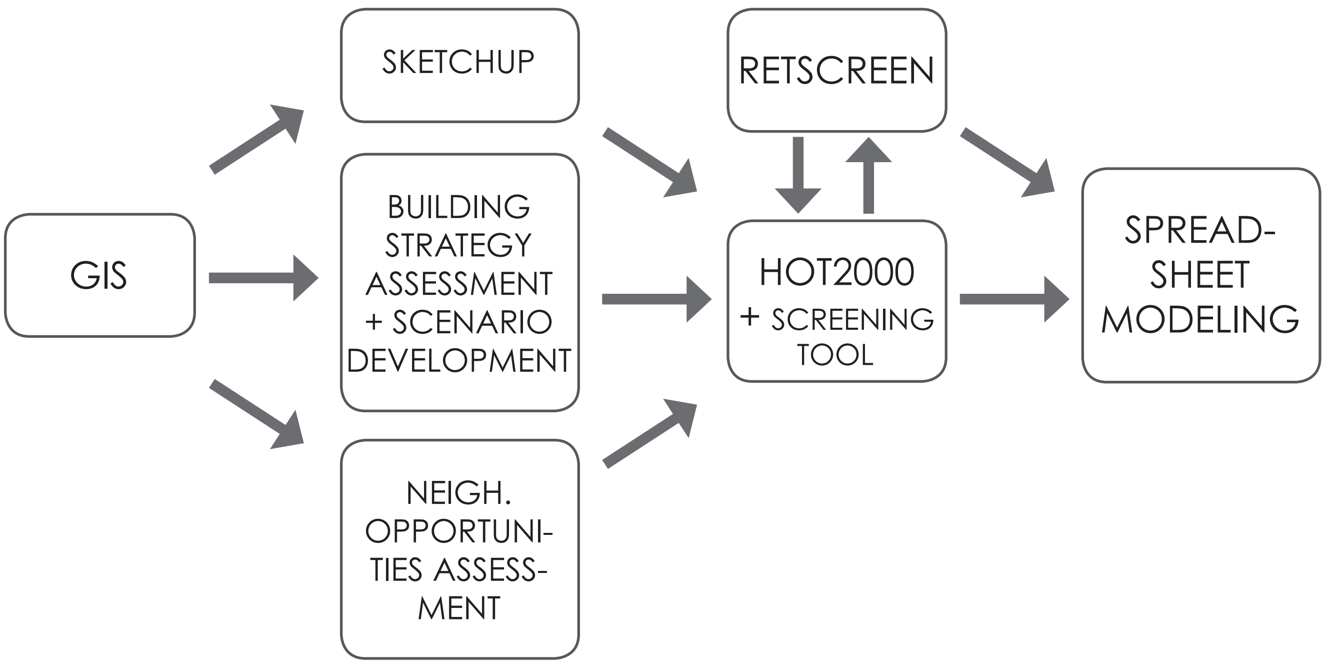


Figure 16: Energy and GHG modeling flowchart

2.4.1 Single-family buildings

Each archetype single-family and rowhouse building was modeled in HOT2000, an energy-simulation software available online from NRCan free of charge, and used by Energy Advisors to perform energy ratings and audits on homes across the country. Results from each baseline were checked against other sources (such as NRCAN's Urban Archetypes project) to ensure that findings were consistent with other observed and modeled data.

Inputs into the HOT2000 models were taken from this project's Sketchup archetypes, including floor areas, wall heights, window sizes, and geometry. Other modeled parameters taken from the strategy assessments or the HOT2000 presets included: wall construction/insulation, roof type/insulation, slab and foundation construction/insulation, air infiltration, heating system/efficiency, hot water system/efficiency, and baseloads (electrical demand, hot water, and numbers of occupants).

Occupancy was assumed to be 2 adults and 1 child[10]. Electrical baseloads were adjusted to reflect BC numbers and reductions across Scenarios (as shown in Table 3). Hot water demand was determined by HOT2000, based on occupancy loads and location.

Energy upgrades were modeled from the baseline for Scenarios 1, 2 and 3, based on the Strategy Assessment above. The modeling used an iterative process that tested construction details for envelope upgrades, efficiencies and systems, to find "house-as-system" best performances (i.e. interactions across the strategies) given the criteria for each scenario. Hot water energy use was modeled by reducing base-load hot water demand by the amount that could be supplied by solar thermal (as modeled by RETscreen). The remaining demand was then modeled in HOT2000 using the appropriate case study and scenario systems; there may be minor discrepancies between actual systems and the modeling due to this method. Electrical loads related to mechanical systems were calculated separately by HOT2000 (HRV and fans) and were added in the modeling spreadsheets (as was the additional electrical from solar hot water: 360 MWh/year for the water pump).

HOT2000 models were run for all house orientations, as required by the different case studies, to present a more complete neighbourhood energy analysis. In Delta, eight orientations were modeled; in Kimberley, four orientations were run for retrofits, and two for new construction; in Prince George, all the buildings were modeled for a southwest orientation. Rowhouses were modeled for energy performance for both the end and the middle units, and these numbers were averaged to calculate per unit energy use.

HOT2000 treats the house as a stand-alone unit, without interactions from siting/context. Therefore, although it is possible that shading from existing apartment buildings could occur on some southwest facing windows in the winter in Prince George, such shading is not accounted for in the HOT2000 modeling. In Delta, shading of south, east and/or west windows on the tightly spaced houses has not been accounted for. HOT2000 could thus be overestimating the internal energy gains from glazing in some contexts.

10 To maintain consistency across the case studies, the BC average for unit occupancy (2.5 people per household) was rounded up for input into HOT2000 for all archetypes to 2 adults and 1 child. In all three cases, this exaggerates the number of people living in a typical unit (2.3 for the Delta tract area, 1.9 for Kimberley overall, and 1.8 for Prince George (Census Canada 2006)). However, given unknown demographic change over the next 40 years, as well as the lower energy demands associated with children in the modeling software, and the coarseness of some of the demographic data (by City), this seemed a reasonable assumption.

2.4.2 Multi-family buildings

In the Prince George scenarios, multi-family apartment buildings are also present. As these buildings are outside the modeling capabilities of the HOT2000 software, an additional tool was required to estimate apartment building energy performance. For this application, the commercial building Screening Tool for New Building Design was selected to provide simplified energy estimates (http://screen.nrcan.gc.ca). The Screening Tool is a web-based tool based on Natural Resources Canada's EE4 energy model, requiring a limited number of standard inputs including building type, floor area, envelope insulation values and areas, HVAC system type and heating and cooling efficiencies. The tool provides an energy demand profile including annual energy consumption by fuel type and end use, energy costs and greenhouse gas emissions, as well as comparison to a reference building, based on thousands of parametric energy simulations pre-modeled for the application.

Apartment building energy profiles were generated based on a representative 3-storey building from Prince George, with most parameters held constant across the scenarios. Window type, envelope insulation values, HVAC and hot water systems and efficiencies and lighting demand were varied to approximate existing building performance as well as retrofit and new construction improvements across the scenarios.

2.4.3 Renewable energy

Potential solar thermal (hot water) and solar photovoltaic electric (PV) supply were modeled using NRCan's renewable energy modeling software RETscreen. For the solar thermal, RETscreen's hot water demand numbers were matched to the numbers in HOT2000 depending on case study location. The RETscreen software allows for a choice of systems by manufacturer and series. Solar thermal systems were chosen based on web research on available systems in BC, using a 2 panel system which is the most common household installation suitable for smaller families. RETScreen outputs a percentage of demand met by the specified system. Note that the hot water supplied is an aggregated annual amount, rather than monthly. The actual monthly solar supply will vary considerably, particularly in Prince George, and secondary hot water systems are necessary for backup.

For the photovoltaic exploration, a system was chosen in RETscreen that approximated the size of the solar thermal system (for ease of spatial potential analysis). Electrical generation numbers were calculated per system for Kimberley and Delta. These were brought into the spreadsheet models to determine total neighbourhood capacity, based on the aerial photo roof survey of the number of units that could be installed.

District energy system modeling was done in the neighbourhood spreadsheets using aggregated neighbourhood demand numbers, and applying the district energy system's efficiencies to calculate energy use.

2.4.4 Spatial analysis

Geographic Information System (GIS) spatial analysis was undertaken to provide building footprints for the archetypes and inputs for the HOT2000 modeling (e.g. number of units by orientation). Lot areas, number of units, and other neighbourhood structure indicators were calculated in GIS, and redevelopment patterns were mapped.

Solar thermal potential was determined using a visual GIS orthophoto roof survey for potential accommodation of one or more 8'x8' (6.25 m^2) 2 panel solar thermal arrays (as shown in Figures 14 and 15) . Spatial surveys of neighbourhood characteristics, including internal and external opportunities for shared systems, passive solar thermal, potential geothermal system locations (horizontal, vertical), were conducted in GIS also.

2.4.5 Neighbourhood modeling

Total neighbourhood energy and GHG performance for each case study and scenario was evaluated using spreadsheet models to aggregate the energy profiles (generated through HOT2000 and the Screening Tool for New Building Design (http://screen.nrcan.gc.ca/) building energy modeling described above) for each scenario archetype and archetype orientation. Each archetype energy profile was input into the neighbourhood spreadsheets as megajoules of energy by end use and fuel type. Changes in building archetypes, number of buildings and building orientations relating to redevelopment occurring in the various scenarios were tracked through the neighbourhood spreadsheets.

The spreadsheet models output aggregate neighbourhood performance as total megajoules of energy by end use and energy source, and estimate GHG emissions using CO2-equivalent emission factors for each fuel type. Sub-variants in the scenarios were explored using the spreadsheet, such as different new construction options for Delta in Scenario 3.

3. RESULTS

3.1 Baselines

For each case study location, current conditions were modeled using the same methods as those used for the scenarios in order to establish a baseline from which to compare results. These results only calculate GHG emissions due to residential buildings, and do not include transportation related emissions.

3.1.1 Delta

In the Delta case study, 199 single family detached homes are arranged within a curvilinear street system. Due to the street layout, the Delta baseline has the highest level of variation in building orientation, resulting in differences in energy consumption for space heating of up to 12%. On average, the archetype single family home for this case study consumes 177 GJ of energy and results in 7.5 tonnes of GHGs, primarily from the use of natural gas for space heating and hot water.

Because the Delta houses are built to more recent construction standards and located in a region with milder winters, the Delta archetype has the lowest per unit energy consumption and GHG emissions of the three existing single family homes modeled for the project, despite being the largest in terms of building area, and having the most complex geometry.

In total, the neighbourhood is estimated to annually consume 35,247 GJ of energy, resulting in 1,485 tonnes of GHGs.

Table 4. Delta baseline annual energy and GHGs.

	Per Unit	Neighbourhood
Number of Units	n/a	199
Total Energy Consumption (GJ)	**177**	**35,247**
Natural Gas Consumption (GJ)	142	28,298
Electricity Consumption (GJ)	35	6,950
Total Greenhouse Gas Emissions (tCO2e)	**7.5**	**1,485**
Emissions from Natural Gas (tCO2e)	7.3	1,443
Emissions from Electricity (tCO2e)	0.2	42

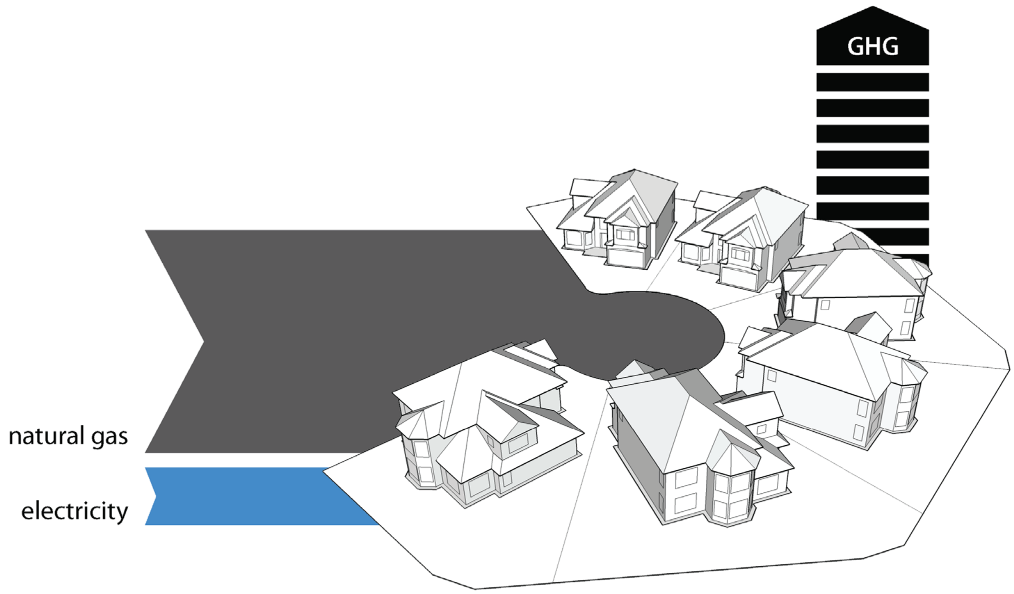


Figure 17. Current Delta average household annual energy use and greenhouse gas emissions.

3.1.2 Kimberley

The Kimberley case study is comprised of 71 single family detached homes. On average, the archetype single family home for this case study consumes 210 GJ of energy and results in 9.1 tonnes of GHG, primarily from the use of natural gas for space heating and hot water.

The Kimberley house archetype has the second highest per unit energy consumption and GHG emissions, despite being significantly smaller in terms of building area than the Delta house archetype. Higher energy consumption is largely the result of colder winters, paired with reduced construction standards due to the age of the buildings. The more regularised street pattern in Kimberley and simpler building forms result in less variation in orientation, with minimal consequent changes in space heating demand.

In total, the neighbourhood is estimated to annually consume 14,882 GJ of energy, resulting in 647 tonnes of GHGs. While total neighbourhood energy and GHG emissions for Kimberley are significantly lower than the other two baselines, this is a result of the smaller number of units included in the study site, rather than better performance.

Table 5. Kimberley baseline annual energy and GHGs.

	Per Unit	Neighbourhood
Number of Units	n/a	71
Total Energy Consumption (GJ)	**210**	**14,882**
Natural Gas Consumption (GJ)	175	12,390
Electricity Consumption (GJ)	35	2,492
Total Greenhouse Gas Emissions (tCO2e)	**9.1**	**647**
Emissions from Natural Gas (tCO2e)	8.9	632
Emissions from Electricity (tCO2e)	0.2	15

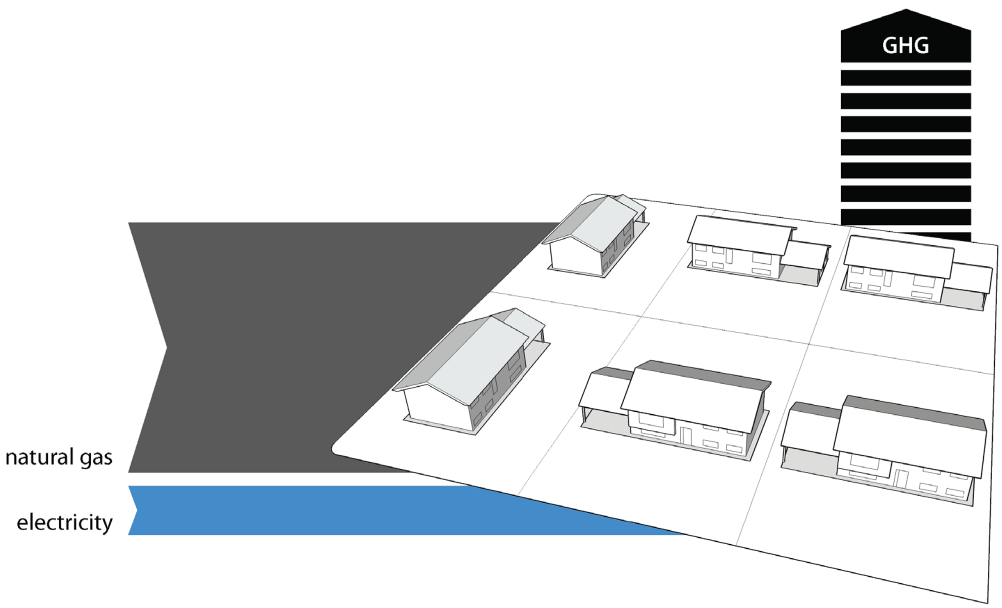


Figure 18. Current Kimberley average household annual energy use and greenhouse gas emissions.

3.1.3 Prince George

In the Prince George case study, a total of 335 residential units consist of a mix of single-family detached houses, multi-family apartments and a small number of attached rowhouse units. The housing mix is represented by three building archetypes, ranging widely in energy and GHG performance due to both the average size of each unit type, as well as the amount of shared walls and floors. Based on these archetypes, the average residential unit for this case study consumes 172 GJ of energy and results in 7.5 tonnes of GHG, primarily from the use of natural gas for space heating and hot water.

While the average per unit energy consumption and GHG emissions is approximately equal to the performance of the Delta baseline, this is due to the superior performance of the apartment and rowhouse units included in the average. As shown in Table 6, the Prince George single family home archetype consumes the most energy and produces the most GHG emissions of the three baseline single family archetypes modeled, due to the age of the buildings and the northern climate within which the case study site is located.

In total, the neighbourhood is estimated to consume 57,707 GJ of energy, resulting in 2,522 tonnes of GHGs annually.

Table 6. Prince George baseline annual energy and GHGs.

				Per Unit	**Neighbourhood**
	SF	ROW	APT	AVG	
Number of Units	153	4	180	n/a	335
Total Energy Consumption (GJ)	**294**	**119**	**68**	**172**	**57,707**
Natural Gas Consumption (GJ)	257	85	48.2	144	48,345
Electricity Consumption (GJ)	37	34	20	28	9,362
Total Greenhouse Gas Emissions (tCO2e)	**13.3**	**4.5**	**2.6**	**7.5**	**2,522**
Emissions from Natural Gas (tCO2e)	13.1	4.3	2.5	7.4	2,466
Emissions from Electricity (tCO2e)	0.2	0.2	0.1	0.2	56

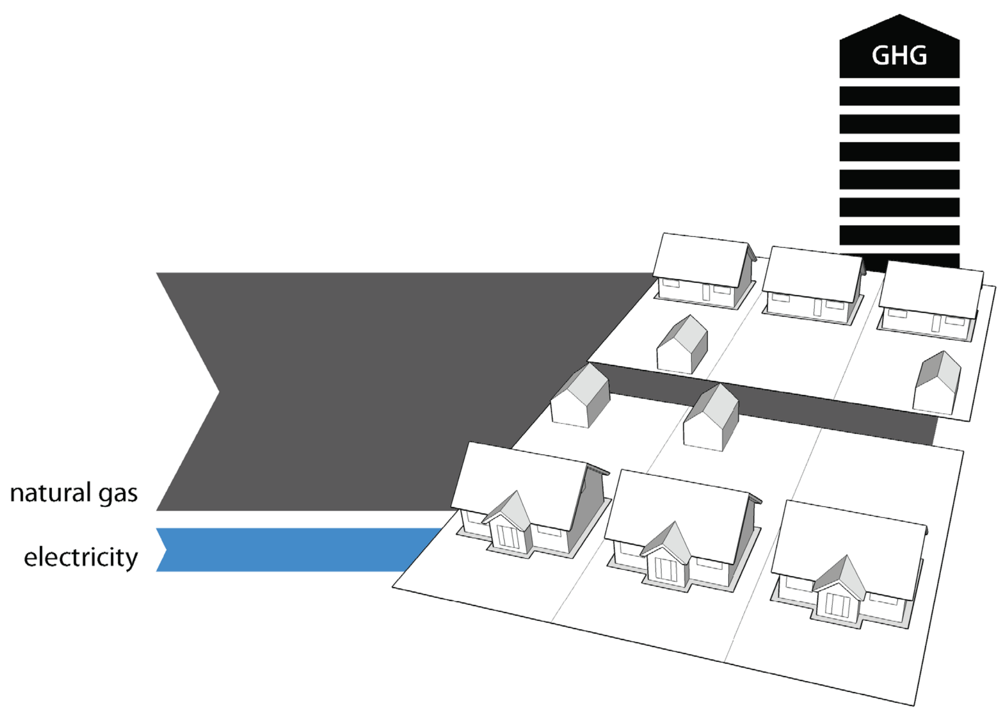


Figure 19. Current Prince George average household annual energy use, and greenhouse gas emissions.

3.2 Scenario 1, Current Policy Direction

The first scenario for each case study explores the possibilities for residential retrofits and new construction based on current practice and building standards, accessible information to homeowners and builders, and current incentive programs for energy and GHG reductions. These strategies represent only a few of the possible combinations that homeowners and builders may utilise in retrofit and construction projects, but do represent typical, available, cost effective and feasible practices for a variety of locations and building types. Strategies utilised in these scenarios are applied at the building scale, placing responsibility on homeowners and builders for successful implementation. **The scenario achieves significant energy and GHG reductions, but does not achieve the 80% neighbourhood GHG reduction targets proposed in this project.**

Table 7. Results for Scenario 1, all case studies

	DELTA			KIMBERLEY			PRINCE GEORGE		
	Baseline	**Scenario 1**	**%Chg**	**Baseline**	**Scenario 1**	**%Chg**	**Baseline**	**Scenario 1**	**%Chg**
Total Conventional Energy (GJ)	**35,247**	**24,640**	**(-30%)**	**14,882**	**8,089**	**(-46%)**	**57,707**	**36,815**	**(-36%)**
Natural Gas Consumption (GJ)	28,298	18,976	(-33%)	12,390	6,071	(-51%)	48,345	24,903	(-48%)
Electricity Consumption (GJ)	6,950	5,664	(-18%)	2,492	2,018	(-19%)	9,362	11,912	(+27%)
Total GHG Emissions (tCO2e)	**1,485**	**1,002**	**(-33%)**	**647**	**322**	**(-50%)**	**2,522**	**1,668**	**(-34%)**
Natural Gas Emissions (tCO2e)	1,443	968	(-33%)	632	310	(-51%)	2,466	1270	(-48%)
Electricity Emissions (tCO2e)	42	34	(-18%)	15	12	(-19%)	56	398	(+611%)
Hydro (0.006 tCO2e/GJ)	*42*	*34*		*15*	*12*		*56*	*56*	
Natural Gas (0.134 tCO2e/GJ)		*n/a*			*n/a*			*342*	

3.2.1 Delta

Scenario 1 in Delta includes a small amount of new construction (20 units), built according to Built Green recommendations and developed randomly across the case study site. All remaining units are assumed to be retrofit. Retrofits for this scenario include improving air tightness and adding attic insulation to improve envelope performance as well as improving energy efficiency through upgraded heating and hot water systems. For appropriately oriented roof structures, solar hot water panels are included in the hot water system, meeting approximately 50% of hot water needs for those units.

Modeled results for this scenario show a 30% reduction in total energy consumption, with greater reductions achieved for natural gas uses. **Total neighbourhood GHG emissions are reduced 33%.** The majority of these reductions are due to more efficient heating systems.

Table 8. Delta Scenario 1 strategies

	Baseline	Retrofit	New Construction
STRATEGY			
Demand			
Main Wall Insulation	ER 11	ER 11	ER 20
Main Attic Insulation	ER 25	ER 34	ER 36
Floor Insulation	ER 8	ER 8	ER 12
Windows	Double pane, vinyl	Double pane, vinyl	Double pane, vinyl, low-e, argon
Infiltration	4.55 ACH	3.57 ACH	2.5 ACH with HRV
Efficiency			
Heating System	Nat. gas boiler with pilot	Nat. gas high eff. boiler	Nat. gas high eff. furnace
Heating Efficiency	70%	90%	95%
Hot Water System	Nat. gas tank with pilot	Nat. gas on-demand (no solar) Nat. gas tank with pilot (w/solar)	Nat. gas on-demand (no solar) Nat. gas on-demand (w/ solar)
Hot Water Efficiency	55%	83%	83%
Lighting	3 kWh/day	2.25 kWh/day	2.25 kWh/day
Appliances	15.5 kWh/day	12.1 kWh/day	12.1 kWh/day
Energy Source			
Space Heating	Natural gas	Natural gas	Natural gas
Solar Hot Water	n/a	2 panels (not applied to all units)	2 panels
Photovoltaics	n/a	n/a	n/a
Wood stoves	n/a	n/a	n/a

3.2.2 Kimberley

Scenario 1 in Kimberley includes a small amount of new construction (7 units), built according to Built Green recommendations and developed randomly across the case study site. All remaining units are assumed to be retrofit. Retrofits for this scenario include improving air tightness, upgrading windows and adding roof insulation to improve envelope performance as well as improving energy efficiency through upgraded heating and hot water systems. For appropriately oriented roof structures, solar hot water panels are included in the hot water system, meeting approximately 68% of hot water needs for those units.

Modeled results for this scenario show a 46% reduction in total energy consumption, with greater reductions achieved for natural gas uses. Greater reductions are achieved in this scenario, as compared to Delta, due to the older building stock and consequent greater opportunity for improved performance, particularly the window upgrades. **Total neighbourhood GHG emissions are reduced 50%.**

Table 9. Kimberley Scenario 1 strategies

	Baseline	Retrofit	New Construction
STRATEGY			
Demand			
Main Wall Insulation	ER 12	ER 12	ER 20
Main Attic Insulation	ER 25	ER 35	ER 43
Floor Insulation	ER 0	ER 0	ER 12
Windows	Double pane, aluminum	Double pane, vinyl, low-e, argon	Double pane, vinyl, low-e, argon
Infiltration	5.41 ACH	3.57 ACH	2.5 ACH with HRV
Efficiency			
Heating System	Nat. gas furnace with pilot	Nat. gas high eff. furnace	Nat. gas high eff. furnace
Heating Efficiency	65%	92%	95%
Hot Water System	Nat. gas tank with pilot	Nat. gas on-demand (no solar) Nat. gas tank with pilot (w/solar)	Nat. gas on-demand (no solar) Nat. gas tank with pilot (w/solar)
Hot Water Efficiency	55%	83%	83%
Lighting	3 kWh/day	2.25 kWh/day	2.25 kWh/day
Appliances	15.5 kWh/day	12.1 kWh/day	12.1 kWh/day
Energy Source			
Space Heating	Natural gas	Natural gas	Natural gas
Solar Hot Water	n/a	2 panels (not applied to all units)	2 panels
Photovoltaics	n/a	n/a	n/a
Wood stoves	Open fireplace	Closed fireplace	n/a

3.2.3 Prince George

Scenario 1 in Prince George substantially increases the number of units within the case study site (205 new units) predominantly through multi-family (rowhouse and 3-storey apartments), with development occurring randomly across the site. Construction standards for new buildings are based on Built Green recommendations. All remaining units are assumed to be retrofit. Retrofits for this scenario include improving air tightness and adding attic and floor insulation to improve envelope performance, as well as improving energy efficiency through upgraded heating and hot water systems. Due to the southwest orientation of all parcels, solar hot water panels are included in the hot water systems for all buildings, including multi-family, and meet approximately 55% of hot water needs.

Modeled results for this scenario show a 36% reduction in total energy consumption, with all reductions achieved for natural gas uses. Due to the increase in population assumed for this case study, electrical loads increase by 27% despite gains in efficiency from lighting and appliances. **Total neighbourhood GHG emissions are reduced 34%, while the number of units increases by 54%**.

Table 10. Prince George Scenario 1 strategies (Single Family Structures)

	Baseline	Retrofit	New Construction
STRATEGY			
Demand			
Main Wall Insulation	ER 9	ER 9	ER 21
Main Attic Insulation	ER 17	ER 34	ER 43
Floor Insulation	ER 0	ER 2	ER12
Windows	Single pane, wood, w/storm	Single pane, wood, w/storm	Double pane, vinyl, low-e, argon
Infiltration	9.95 ACH	4.55 ACH	2.5 ACH with HRV
Efficiency			
Heating System	Nat. gas furnace with pilot	Nat. gas high eff. furnace	Nat. gas high eff. furnace
Heating Efficiency	84%	90%	95%
Hot Water System	Nat. gas tank with pilot	Nat. gas tank with pilot (w/solar)	Nat. gas on-demand (w/ solar)
Hot Water Efficiency	55%	83%	83%
Lighting	3 kWh/day	2.25 kWh/day	2.25 kWh/day
Appliances	15.1 kWh/day	12.1 kWh/day	12.1 kWh/day
Energy Source			
Space Heating	Natural gas	Natural gas	Natural gas
Solar Hot Water	n/a	2 panels	2 panels
Photovoltaics	n/a	n/a	n/a
Wood stoves	Open fireplace	Closed fireplace	n/a

3.3 Scenario 2, Intensive Building Retrofits

The second scenario for each case study explores the possibilities for residential retrofits and new construction based on available strategies for deep energy and GHG reductions. The strategies explored in this scenario represent substantially more aggressive building changes, costs and lifestyle impacts, and **achieve higher neighbourhood GHG reductions, exceeding 80% in two of the three case study neighbourhoods.** Strategies utilised in this scenario are applied at the building scale, placing responsibility on homeowners and builders for successful implementation.

Table 11. Results for Scenario 2, all case studies

	DELTA			KIMBERLEY			PRINCE GEORGE		
	Baseline	**Scenario 2**	**%Chg**	**Baseline**	**Scenario 2**	**%Chg**	**Baseline**	**Scenario 2**	**%Chg**
Total Conventional Energy (GJ)	**35,247**	**7,805**	**(-78%)**	**14,882**	**2,726**	**(-82%)**	**57,707**	**17,428**	**(-70%)**
Natural Gas Consumption (GJ)	28,298	0	(-100%)	12,390	0	(-100%)	48,345	0	(-100%)
Electricity Consumption (GJ)	6,950	7,805	(+12%)	2,492	2,726	(+9%)	9,362	17,428	(+86%)
Total GHG Emissions (tCO2e)	**1,485**	**156**	**(-89%)**	**647**	**46**	**(-93%)**	**2,522**	**1,137**	**(-55%)**
Natural Gas Emissions (tCO2e)	1,443	0	(-100%)	632	0	(-100%)	2,466	0	(-100%)
Electricity Emissions (tCO2e)	42	156	(+271%)	15	46	(+207%)	56	1137	(+1930%)
Hydro (0.006 tCO2e/GJ)	*42*	*42*		*15*	*15*		*56*	*56*	
Natural Gas (0.134 tCO2e/GJ)		*115*			*31*			*1,081*	

3.3.1 Delta

Scenario 2 in Delta includes a small amount of redevelopment (20 units), occurring randomly across the study site. All remaining units are assumed to be retrofit. New construction is built to Passivhaus standards, with high performance building envelopes including higher insulation and air sealing standards than current practice. Retrofit buildings likewise maximise building envelope performance through increased insulation, including the addition of wall insulation outside the existing wall cavity, and an inuslated sub-floor at ground level. Both new and retrofitted buildings are equipped with air-source heat pumps for improved space heating efficiency. Solar hot water panels are included in the hot water system for most units, meeting approximately 50% of hot water needs for those units.

Modeled results for this scenario show a 78% reduction in total energy consumption, with all reductions achieved for natural gas uses. Total electrical consumption increases by 12% for this scenario due to the use of heat pumps run by electricity. **Total neighbourhood GHG emissions are reduced 89% from the baseline.**

Table 12. Delta Scenario 2 strategies

	Baseline	Retrofit	New Construction
STRATEGY			
Demand			
Main Wall Insulation	ER 11	ER 18	ER 35
Main Attic Insulation	ER 25	ER 37	ER 43
Floor Insulation	ER 8	ER 20	ER 13
Windows	Double pane, vinyl	Triple pane, vinyl, low-e, argon	Triple pane, vinyl, low-e, argon
Infiltration	4.55 ACH	1.5 ACH with HRV	1.5 ACH with HRV
Efficiency			
Heating System	Nat. gas boiler with pilot	Air to air heat pump	Air to air heat pump
Heating Efficiency	70%	293% (HSPF 10), 32,000 BTU	293% (HSPF 10), 32,000 BTU
Hot Water System	Nat. gas tank with pilot	Air to air heat pump (no solar) Air to air heat pump (w/ solar)	Air to air heat pump (w/ solar)
Hot Water Efficiency	55%	190%	190%
Lighting	3 kWh/day	1.5 kWh/day	1.5 kWh/day
Appliances	15.5 kWh/day	9 kWh/day	9 kWh/day
Energy Source			
Space Heating	Natural gas	Air source heat, electricity	Air source heat, electricity
Solar Hot Water	n/a	2 panels (not applied to all units)	2 panels
Photovoltaics	n/a	n/a	n/a
Wood stoves	n/a	n/a	n/a

3.3.2 Kimberley

Scenario 2 in Kimberley includes a small amount of new construction (7 units), built according to Passivhaus standards and developed randomly across the case study site. All remaining units are assumed to be retrofit. Retrofit buildings maximise building envelope performance through increased insulation, including the addition of wall insulation outside of the existing wall cavity as well as upgraded windows and improved air sealing. Both new and retrofitted buildings are equipped with high efficiency wood stoves and backup electric baseboard heating for improved space heating efficiency and renewable energy sources. Solar hot water panels are included in the hot water system for all units, meeting approximately 68% of hot water needs.

Modeled results for this scenario show an 82% reduction in total energy consumption, with all reductions achieved for natural gas uses. Total electrical consumption increases by 9% for this scenario due to the use of an electric backup heating system, heat recovery ventilators, and electric on-demand hot water. **Total neighbourhood GHG emissions are reduced 93% from the baseline.**

Table 13. Kimberley Scenario 2 strategies

	Baseline	Retrofit	New Construction
STRATEGY			
Demand			
Main Wall Insulation	ER 12	ER 18	ER 55
Main Attic Insulation	ER 25	ER 35	ER 60
Floor Insulation	ER 0	ER 16	ER 20
Windows	Double pane, aluminum	Triple pane, vinyl, low-e, argon	Triple pane, vinyl, low-e, argon
Infiltration	5.41 ACH	1.5 ACH with HRV	1.5 ACH with HRV
Efficiency			
Heating System	Nat. gas furnace with pilot	High eff. wood stove, el. baseboard	High eff. wood stove, el. baseboard
Heating Efficiency	65%	Stoves 60%, baseboards 100%	Stoves 60%, baseboards 100%
Hot Water System	Nat. gas tank with pilot	Electric on-demand (w/ solar)	Electric on-demand (w/ solar)
Hot Water Efficiency	55%	94%	94%
Lighting	3 kWh/day	1.5 kWh/day	1.5 kWh/day
Appliances	15.5 kWh/day	9 kWh/day	9 kWh/day
Energy Source			
Space Heating	Natural gas	Wood, electricity	Wood, electricity
Solar Hot Water	n/a	2 panels	2 panels
Photovoltaics	n/a	n/a	n/a
Wood stoves	Open fireplace	2 stoves	2 stoves

3.3.3 Prince George

As with Scenario 1, Scenario 2 in Prince George substantially increases the number of units within the case study site from the baseline (205 new units), predominantly through multi-family (rowhouse and 3-storey apartments); development occurs randomly across the site. Construction standards for new buildings are based on Passivhaus standards, which are challenging to achieve in BC's northern climate.

All remaining units are assumed to be retrofit. Retrofitted buildings maximize building envelope performance through increased insulation, including the addition of wall insulation inside and outside of the existing wall cavity as well as upgraded windows and improved air sealing. To achieve high performance in Prince George's climate, windows are reduced in size and reduced in number for the northern façades of the buildings. Window area is increased on southern facades to maximise passive solar gains. Both new and retrofitted buildings are equipped with ground source heat pumps (geo-exchange) for improved space heating efficiency. Solar hot water panels are included in the hot water system for all buildings, including multi-family, and meet approximately 55% of hot water needs.

Modeled results for this scenario show a 70% reduction in total energy consumption, with all reductions achieved for natural gas uses. Due to the increase in population assumed for this case study, paired with a transition to heat pumps, electrical loads increase by 86% despite gains in efficiency from lighting and appliances. Therefore, this scenario was not able to meet the 80% GHG reduction target established for the project; **total neighbourhood GHG emissions are reduced only 55% from the baseline, while the number of units increased by 54%.**

Table 14. Prince George Scenario 2 strategies

	Baseline	Retrofit	New Construction
STRATEGY			
Demand			
Main Wall Insulation	ER 9	ER 24	ER 55
Main Attic Insulation	ER 17	ER 37	ER 60
Floor Insulation	ER 0	ER 16	ER 22
Windows	Single pane, wood, w/storm	Triple pane, vinyl, low-e, argon, reduced size, changed orientation	Triple pane, vinyl, low-e, argon, reduced size
Infiltration	9.95 ACH	3.57 ACH	1.5 ACH with HRV
Efficiency			
Heating System	Nat. gas furnace with pilot	Ground source heat pump	Ground source heat pump
Heating Efficiency	84%	350% (COP 3.5), 36,000 BTU	350% (COP 3.5), 36,000 BTU
Hot Water System	Nat. gas tank with pilot	Ground source heat pump (w/solar)	Ground source heat pump (w/solar)
Hot Water Efficiency	55%	190%	190%
Lighting	3 kWh/day	1.5 kWh/day	1.5 kWh/day
Appliances	15.1 kWh/day	9 kWh/day	9 kWh/day
Energy Source			
Space Heating	Natural gas	Ground source heat, electricity	Ground source heat, electricity
Solar Hot Water	n/a	2 panels	2 panels
Photovoltaics	n/a	n/a	n/a
Wood stoves	Open fireplace	n/a	n/a

3.4 Scenario 3, Neighbourhood Focused Approach

The third scenario for each case study explores the possibilities for residential retrofits and new construction based on available strategies for deep energy and GHG reductions, including the potential to implement new strategies and systems across parcels and at the neighbourhood scale. The strategies explored in this scenario offer the possibility of mitigating some of the responsibility of individual property owners by exploring shared solutions, while still achieving the 80% neighbourhood GHG reduction target established for the project. Strategies utilised in this scenario are applied at the both the building and neighbourhood scales, placing greater responsibility on local governments for successful implementation.

Table 15. Results for Scenario 3, all case studies

	DELTA			KIMBERLEY			PRINCE GEORGE		
	Baseline	**Scenario 3**	**%Chg**	**Baseline**	**Scenario 3**	**%Chg**	**Baseline**	**Scenario 3**	**%Chg**
Total Conventional Energy (GJ)	**35,247**	**8,862**	**(-75%)**	**14,882**	**2,093**	**(-60%)**	**57,707**	**12,013**	**(-54%)**
Natural Gas Consumption (GJ)	28,298	0	(-100%)	12,390	566	(-95%)	48,345	2,581	(-95%)
Electricity Consumption (GJ)	6,950	8,862	(+28%)	2,492	1,528	(-39%)	9,362	9,432	(+1%)
Total GHG Emissions (tCO2e)	**1,485**	**298**	**(-80%)**	**647**	**38**	**(-94%)**	**2,522**	**197**	**(-92%)**
Natural Gas Emissions (tCO2e)	1,443	0	(-100%)	632	29	(-95%)	2,466	132	(-95%)
Electricity Emissions (tCO2e)	42	298	(+610%)	15	9	(-39%)	56	66	(+18%)
Hydro (0.006 tCO2e/GJ)	*42*	*42*		*15*	*9*		*56*	*56*	
Natural Gas (0.134 tCO2e/GJ)		*256*			*n/a*			*9*	

3.4.1 Delta

As in previous scenarios, Scenario 3 in Delta includes a small amount of redevelopment (20 units); however, for this scenario, redevelopment is targeted to replace the lowest-performing houses by orientation, as shown in Figure 11B. New construction is built to Passivhaus standards, with high performance building envelopes that use higher insulation and air sealing standards than current practice.

All remaining units are assumed to be retrofit. Retrofitted buildings realise improved building envelope performance through increased roof insulation and high-performance windows, but do not undertake the major building changes required by Scenario 2 to increase wall insulation. Both new and retrofitted buildings are equipped with air-source heat pumps for improved space heating efficiency. Solar hot water panels are included in the hot water system for all units, meeting approximately 50% of the neighbourhood's hot water needs. Solar hot water is shared between two or more buildings for those units that do not have solar hot water potential due to roof orientation and area.

Modeled results for this scenario show a 75% reduction in total energy consumption, with all reductions achieved for natural gas uses. Total electrical consumption increases by 28% for this scenario due to the use of heat pumps run by electricity. The increase is greater than in Scenario 2 because the envelope upgrades are not as extreme.

Total neighbourhood GHG emissions are reduced 80%. Reductions for this scenario are slightly less than Scenario 2, due to the reduced intensity of building envelope retrofits.

Table 16. Delta Scenario 3 strategies

	Baseline	Retrofit	New Construction
STRATEGY			
Demand			
Main Wall Insulation	ER 11	ER 11	ER 35
Main Attic Insulation	ER 25	ER 37	ER 43
Floor Insulation	ER 8	ER 8	ER 13
Windows	Double pane, vinyl	Triple pane, vinyl, low-e argon	Triple pane, vinyl, low-e, argon
Infiltration	4.55 ACH	1.5 ACH with HRV	1.5 ACH with HRV
Efficiency			
Heating System	Nat. gas boiler with pilot	Air to air heat pump	Air to air heat pump
Heating Efficiency	70%	293% (HSPF 10), 32,000 BTU	293% (HSPF 10), 32,000 BTU
Hot Water System	Nat. gas tank with pilot	Air to air heat pump (w/ solar)	Air to air heat pump (w/ solar)
Hot Water Efficiency	55%	190%	190%
Lighting	3 kWh/day	1.5 kWh/day	1.5 kWh/day
Appliances	15.5 kWh/day	9 kWh/day	9 kWh/day
Energy Source			
Space Heating	Natural gas	Air source heat, electricity	Air source heat, electricity
Solar Hot Water	n/a	average 2 panels (sharing between	2 panels
Photovoltaics	n/a	Exploratory, 0.14 panels/house	Exploratory, 2 panels/house
Wood stoves	n/a	n/a	n/a

Additional modeling to explore photovoltaic electrical generation in the Delta case study showed that, with both existing and new houses adding PV units where possible, the total electricity generated would amount to only approximately 2% of the total electrical load for this scenario. A variant rowhouse scenario could meet 5% of the total electrical load with PV, when the rowhouse roof structures were oriented and designed to allow for additional PV units.

3.4.2 Kimberley

Scenario 3 in Kimberley includes a small amount of new construction (7 units), built according to Passivhaus standards and distributed randomly across the neighbourhood. All remaining units are assumed to be retrofit. Retrofitted buildings realise improved building envelope performance through increased attic and floor insulation and high-performance windows, but do not undertake the major structural changes required by Scenario 2 to increase wall insulation.

Both new and retrofitted buildings are connected to a local biomass district energy system (DES) with supplementary natural gas for peak loads. Solar hot water panels are included in the hot water system for all units, meeting approximately 70% of hot water needs. The remaining hot water demand is met through the DES.

Modeled results for this scenario show a 60% reduction in total energy consumption, with greater reductions achieved for natural gas uses. The provision of heat and hot water through a district energy system do not add electrical demand as occurred due to heating and hot water systems in Scenario 2, enabling total electricity consumption to be reduced by 39% through efficiencies in appliances and lighting (i.e. the gains in efficiencies are not lost due to increased demand from other uses).

Therefore, total neighbourhood GHG emissions are reduced 94%. The use of the district energy system in this scenario allows for comparable GHG reductions to Scenario 2, with less intensive building retrofits and fewer demands placed on occupants, and without increasing total electrical loads for the case study site.

Additional modeling to explore photovoltaic electrical generation showed that, with both existing and new houses adding PV units where possible, the total electricity generated could amount to 22%, or 340 GJ, of the total electrical load for this scenario. If this were applied to the Scenario 3 electrical use, the neighbourhood's electrical reduction from the baseline would be over 50%.

Table 17. Kimberley Scenario 3 strategies

	Baseline	Retrofit	New Construction
STRATEGY			
Demand			
Main Wall Insulation	ER 12	ER12	ER 55
Main Attic Insulation	ER 25	ER 35	ER 60
Floor Insulation	ER 0	ER 2	ER 20
Windows	Double pane, aluminum	Triple pane, vinyl, low-e, argon	Triple pane, vinyl, low-e, argon
Infiltration	5.41 ACH	3.57 ACH	1.5 ACH with HRV
Efficiency			
Heating System	Nat. gas furnace with pilot	District heat	District heat
Heating Efficiency	65%	85%	85%
Hot Water System	Nat. gas tank with pilot	District heat (w/solar)	District heat (w/solar)
Hot Water Efficiency	55%	85%	85%
Lighting	3 kWh/day	1.5 kWh/day	1.5 kWh/day
Appliances	15.5 kWh/day	9 kWh/day	9 kWh/day
Energy Source			
Space Heating	Natural gas	Biomass, natural gas	Biomass, natural gas
Solar Hot Water	n/a	2 panels	2 panels
Photovoltaics	n/a	Exploratory, 0.95 panels/house	Exploratory, 5 panels/house
Wood stoves	Open fireplace	n/a	n/a

3.4.3 Prince George

Scenario 3 in Prince George substantially increases the number of units within the case study site from the baseline (205 new units), as with Scenarios 1 and 2. Units added are predominantly multi-family, with development occurring randomly across the site. Construction standards for new buildings are based on Passivhaus standards, which are challenging to achieve in BC's northern climate.

All remaining units are assumed to be retrofit. Retrofitted buildings realise improved building envelope performance through increased attic, wall and floor insulation. High-performance windows and improved air sealing are also included. Unlike Scenario 2, this scenario does not include the resizing and relocation of windows for added space heating demand reductions. Both new and retrofitted buildings are connected to a biomass district energy system proposed in close proximity to the case study site. Peak loads for this system are assumed to be met with natural gas. Solar hot water panels are included in the hot water system for all units, meeting approximately 55% of hot water needs.

Modeled results for this scenario show a 54% reduction in total energy consumption, with all reductions achieved for natural gas uses. Despite the increase in population assumed for this case study, electrical loads are held at baseline levels (increase of 1%) due to electrical load reductions from lighting and appliances and the use of district energy for the provision of heat and hot water.

Total neighbourhood GHG emissions are reduced 92% while the number of units increases by 54%. The use of the district energy system in this scenario allows for substantially greater GHG reductions than Scenario 2, with less intensive building retrofits and without increasing total electrical loads for the case study site.

Table 18. Prince George Scenario 3 strategies

	Baseline	Retrofit	New Construction
STRATEGY			
Demand			
Main Wall Insulation	ER 9	ER 16	ER 55
Main Attic Insulation	ER 17	ER 37	ER 60
Floor Insulation	ER 0	ER 13	ER 22
Windows	Single pane, wood, w/storm	Triple pane, vinyl, low-e, argon	Triple pane, vinyl, low-e, argon
Infiltration	9.95 ACH	3.57 ACH	1.5 ACH with HRV
Efficiency			
Heating System	Nat. gas furnace with pilot	District heat	District heat
Heating Efficiency	84%	85%	85%
Hot Water System	Nat. gas tank with pilot	District heat (w/solar)	District heat (w/solar)
Hot Water Efficiency	55%	85%	85%
Lighting	3 kWh/day	1.5 kWh/day	1.5 kWh/day
Appliances	15.1 kWh/day	9 kWh/day	9 kWh/day
Energy Source			
Space Heating	Natural gas	Biomass, natural gas	Biomass, natural gas
Solar Hot Water	n/a	2 panels	2 panels
Photovoltaics	n/a	n/a	n/a
Wood stoves	Open fireplace	n/a	n/a

3.5 Comparative Results

The study treats neighbourhoods as systems of buildings: strategies undertaken at the building scale across all the buildings in the neighbourhood are aggregated into neighbourhood results in order to find the collective impact. Thus, comparative results can be shown in several ways. Table 19 provides the neighbourhood results for each scenario and case study, with total neighbourhood energy and GHG reductions as a percentage reduction from the baseline. Table 20 lists the key strategies, covering demand reductions, efficiencies, and energy supply for space heating, hot water, and electricity. Figure 20 illustrates the energy use by supply type, and shows resultant GHGs, averaged across all the units in the neighbourhood (in Prince George, the average includes both single-family and multi-family dwellings). Figures 21-23 provide a detailed breakdown of total energy demand and supply types for each building archetype. These figures also show average residential unit GHG reductions by scenario.

Table 19. Scenario Results Table: percent change from the baseline for each neighbourhood.

	Scenario 1 Current Policy Direction	Scenario 2 Intensive Buildings	Scenario 3 Neighbourhood Approach
DELTA			
Total Conventional Energy	**-30%**	**-78%**	**-75%**
Natural Gas	-33%	-100%	-100%
Electricity	-18%	+12%	+28%
Total GHGs	**-33%**	**-89%**	**-80%**
from Natural Gas	-33%	-100%	-100%
from Electricity	-18%	+271%	+610%
KIMBERLEY			
Total Energy	**-46%**	**-82%**	**-60%**
Natural Gas	-51%	-100%	-95%
Electricity	-19%	+9%	-39%
Total GHGs	**-50%**	**-93%**	**-94%**
from Natural Gas	-51%	-100%	-95%
from Electricity	-19%	+207%	-39%
PRINCE GEORGE			
Total Energy	**-36%**	**-70%**	**-54%**
Natural Gas	-48%	-100%	-95%
Electricity	+27%	+86%	+1%
Total GHGs	**-34%**	**-55%**	**-92%**
from Natural Gas	-48%	-100%	-95%
from Electricity	+611%	+1930%	+18%

GHG emissions from electricity are calculated using the BC grid hydro emissions factor for electrical demand up to 100% of the baseline; neighbourhood electrical demand over 100% of the neighbourhood baseline is calculated using a natural gas emissions factor, which is higher.

Table 20. Key strategies compared across Case Studies and Scenarios

	Scenario 1 Current Policy Direction	Scenario 2 Intensive Buildings	Scenario 3 Neighbourhood Approach
DELTA			
Demand Reductions			
through envelope upgrades	Minor	Extreme	Moderate[1]
Space Heating			
System Changes	Boiler upgrade	Air to air heat pumps	Air to air heat pumps
Efficiency	90-95%	293%	293%
Energy Sources	Natural gas	Electricity	Electricity
Hot Water			
System Changes	On-demand, or Solar + Tank	On-demand + Solar[4]	Solar (shared)[5] + On-demand
Efficiency[2]	83%	190%	190%
Energy Sources	Natural gas + Solar	Solar + Electricity	Solar + Electricity
Electrical Demand Reductions[3]	20%	40%	40%
KIMBERLEY			
Demand Reductions			
through envelope upgrades	Moderate	Extreme	Moderate
Space Heating			
System Changes	Furnace upgrade	Wood stoves + baseboards	Shared District Heat
Efficiency	92-95%	60-100%	85%
Energy Sources	Natural gas	Biomass + Electricity	Biomass + Natural gas
Hot Water			
System Changes	Solar + Tank, or On-demand	Solar + On-demand	Solar + District Heat
Efficiency[2]	83%	94%	85%
Energy Sources	Solar + Natural Gas	Solar + Electricity	Solar + Biomass + Nat Gas
Electrical Demand Reductions[3]	20%	40%	40%
PRINCE GEORGE			
Demand Reductions			
through envelope upgrades	Moderate	Extreme	Moderate
Space Heating			
System Changes	Furnace upgrade	Individual Geothermal	Shared District Heat
Efficiency	90-95%	350%	85%
Energy Sources	Natural gas	Electricity	Biomass + Natural gas
Hot Water			
System Changes	Solar + tank, or On-demand	Solar + On-demand	Solar + District Heat
Efficiency[2]	83%	190%	85%
Energy Sources	Solar + Natural Gas	Solar + Electricity	Solar + Biomass + Nat Gas
Electrical Demand Reductions[3]	20%	40%	40%

1 In Delta's Scenario 3, demand reductions were also achieved by replacing the worst-performing buildings (by orientation).
2 Efficiencies are given for the non-solar systems.
3 Given as the percentage of baseline household electrical demand reduced, achieved through efficient appliances, lighting, and other, as shown in Table 3. The reductions do not include the potential increases in electrical demand due to new space and hot water heating systems, such as geo-exchange, air-to-air heat pumps, and solar and on-demand hot water.
4 In Delta's Scenario 2, not all residences had solar; 27 residences had only on-demand hot water.
5 In Delta's Scenario 3, all residences were connected to solar thermal systems, some of which were shared by multiple buildings.

Table 19 shows that Delta and Kimberley's reductions in energy use map almost directly to reductions in natural gas demand in Scenario 1. Slightly greater GHG reductions than overall energy reductions are due to the greater impact on GHGs from natural gas reductions than electricity reductions, due to BC's low-carbon hydro-electricity. In Scenario 1, the Kimberley case study shows the greatest overall neighbourhood reductions because the vintage of the houses means that greater gains are available from efficiency retrofits than for the newer homes in Delta (Figures 21 and 22). These neighbourhoods are assumed to re-develop 10% of their residential units, and retrofit the remaining, but do not add additional residential units.

The older Prince George residences also achieve significant energy savings with envelope upgrades, as shown by the individual house changes in Figure 23. The energy savings are offset, however, by the 54% residential growth. For electricity, the demand reductions from the retrofit buildings are not adequate to fully offset the new unit electrical demand, and overall electrical demand increases, as do overall GHGs from electricity (Table 19). Thus, unlike for Delta and Kimberley, overall neighbourhood GHG's do not map directly to the reductions in natural gas energy demand, and overall neighbourhood reductions are not as high as individual reductions in older, retrofit homes.

Scenario 1 for Prince George thus illustrates that very significant reductions in current residential energy use must be made in order to accommodate increased demands due to growth, if GHG reductions are to be achieved at all. However, the combined effect of reductions in GHGs from retrofits to existing buildings, coupled with only a minor increase in GHGs from well-built new housing, show that residential growth and overall GHG reductions are possible.

In Scenario 2, Intensive Building Retrofits, intensive demand reductions are coupled with either super-efficient (+250%) heating systems using electricity (Delta, Prince George), or with biomass-based heating systems backed up with electricity (Kimberley), in order to achieve deep reductions in natural gas energy use. For Delta and Kimberley, this translates into very significant GHG reductions, even with the minor increases in electrical demand associated with the new space and hot water heating systems. It is critical to note that switching to electric heat pumps without intensive electrical demand reductions would lead to greatly increased electrical consumption, resulting in fewer or negative GHG reductions overall.

The challenge of increasing electrical demand is shown by Prince George's results in Scenario 2, where changing to geo-exchange, which uses electricity to run the system, as well as electrical on-demand hot water for individual homes, adds to electrical consumption. When coupled with residential growth, overall electrical demand rises (+86%, Table 19) and significant neighbourhood GHG reductions become much more difficult to achieve, even with intensive demand reductions for space heating and electrical use for lights and appliances. While natural gas use is eliminated in this scenario, the increased electrical use from additional units and geo-exchange translates into fewer overall GHG emissions reductions than overall energy use reductions: -55% compared to -70% (Table 19). This occurs even though individual residences may have very significant energy reductions, and average GHGs per unit drop significantly, as shown in Figure 23.

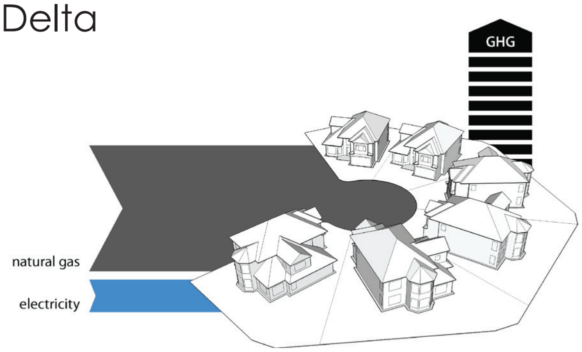
Kimberley and Prince George show that with a Neighbourhood Focused Approach (Scenario 3), the move to a shared low-carbon energy supply through biomass-based district energy for heat and backup hot water allows for smaller total energy reductions but greater GHG reductions. A low-carbon energy supply, coupled with demand reductions, allows for growth in residential units accompanied by deep (+80%) GHG reductions, shown by Prince George.

In Delta's Scenario 3, fewer renewable energy opportunities were found to be possible, and instead, redevelopment of the worst-performing residences enables the GHG reductions target of 80% to be met with more moderate demand reductions and the use of electricity as the energy supply. However, while the GHG reductions meet the 80% target, they are not as high as the results for Scenario 2. Thus, the Delta results show that for some neighbourhoods, the lack of spatial opportunities for shared systems mean the shared approach may not be as effective at achieving overall GHG reductions as an intensive, individual house retrofit approach.

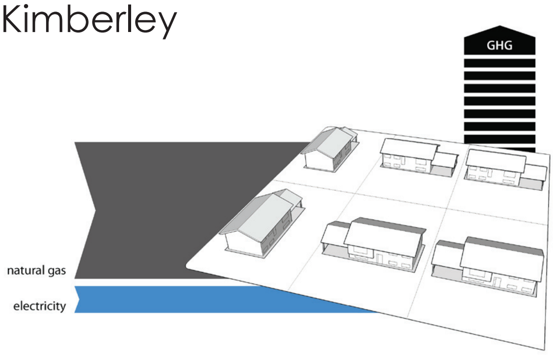
As shown in Figure 20, all the scenarios across all three case studies use solar hot water as a way to reduce the demand on other energy sources for hot water heating. For some neighbourhoods, the solar supply can meet well over 50% of annual demand.

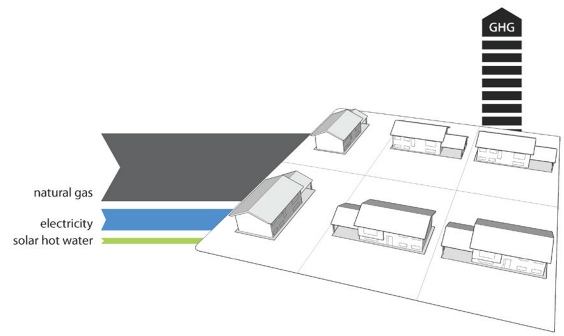
BASELINE | Scenario 1 Current Policy Direction

Delta

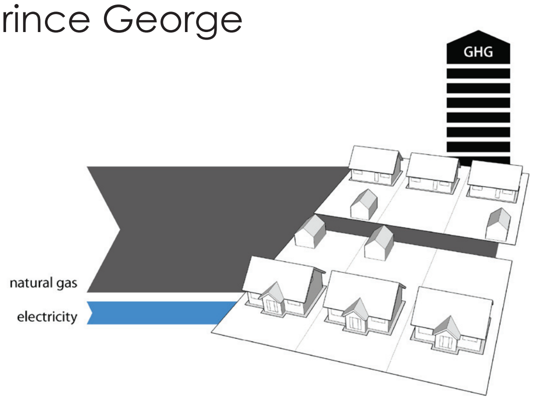


Kimberley





Prince George



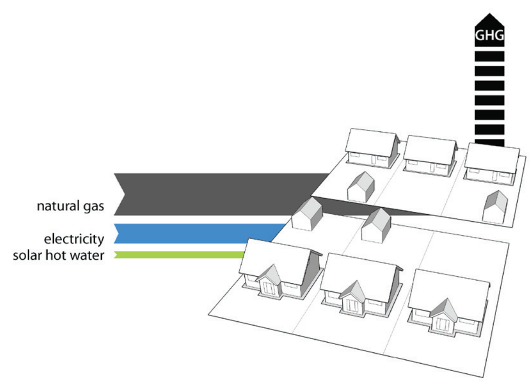
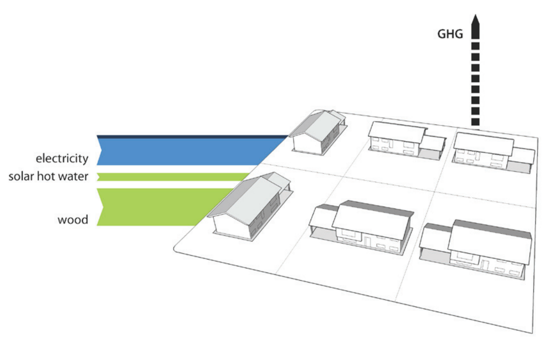
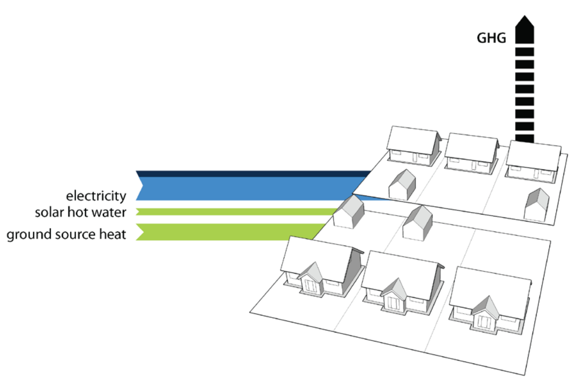


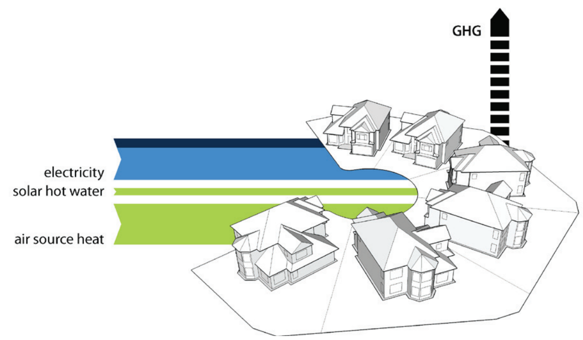
Figure 20. Average energy use and greenhouse gas emissions per household; baselines and results for each case study across the 3 scenarios.

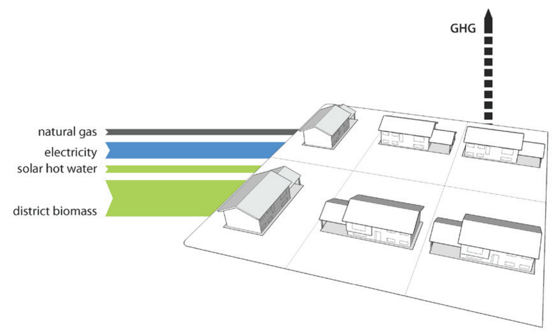
Scenario 2
Intensive Building Retrofits

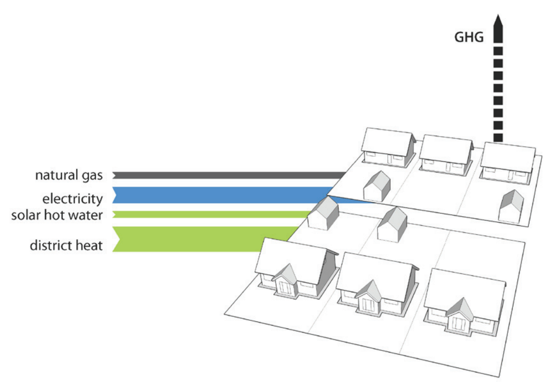




Scenario 3
Neighbourhood Approach







Electrical load beyond 100% of the baseline is shown in dark blue, and is assumed to be met by natural gas-fired electricity.

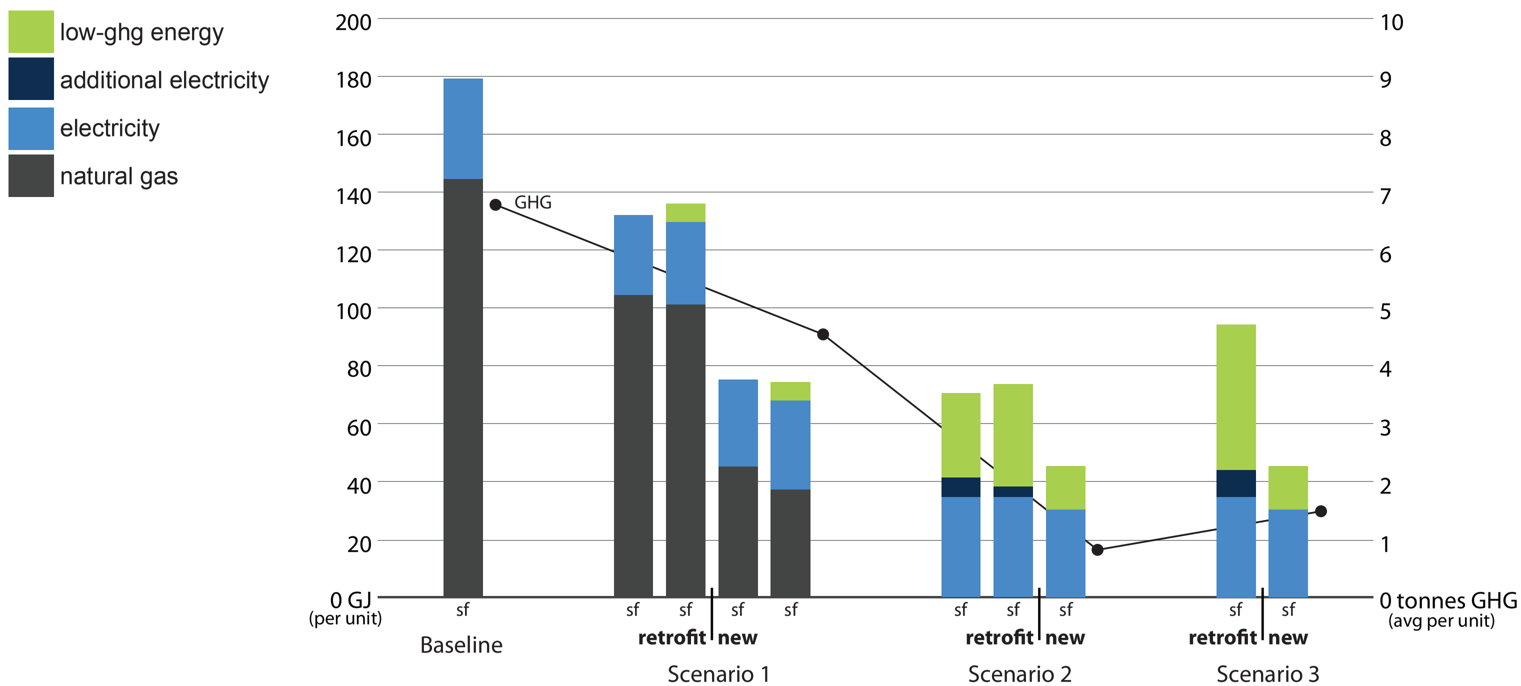


Figure 21. DELTA CASE STUDY. Comparison of energy consumption by energy source for each building archetype in the baseline and 3 scenarios. GHGs represent average GHGs per household for all building archetypes. Low-GHG energy refers to solar (for hot water) and biomass (wood stoves and/or District Energy).

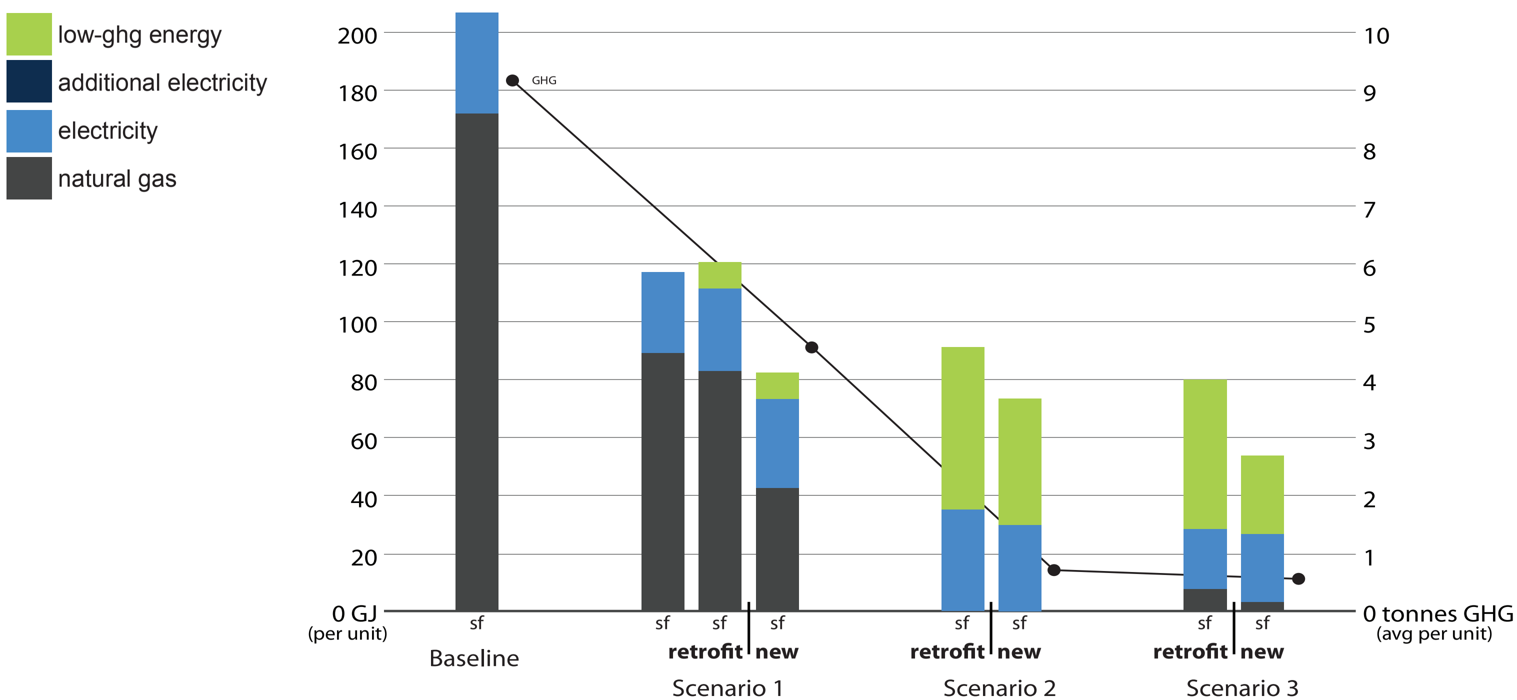


Figure 22. KIMBERLEY CASE STUDY. Comparison of energy consumption by energy source for each building archetype in the baseline and 3 scenarios. GHGs represent average GHGs per household for all building archetypes. Low-GHG energy refers to solar (for hot water) and biomass (wood stoves and/or District Energy).

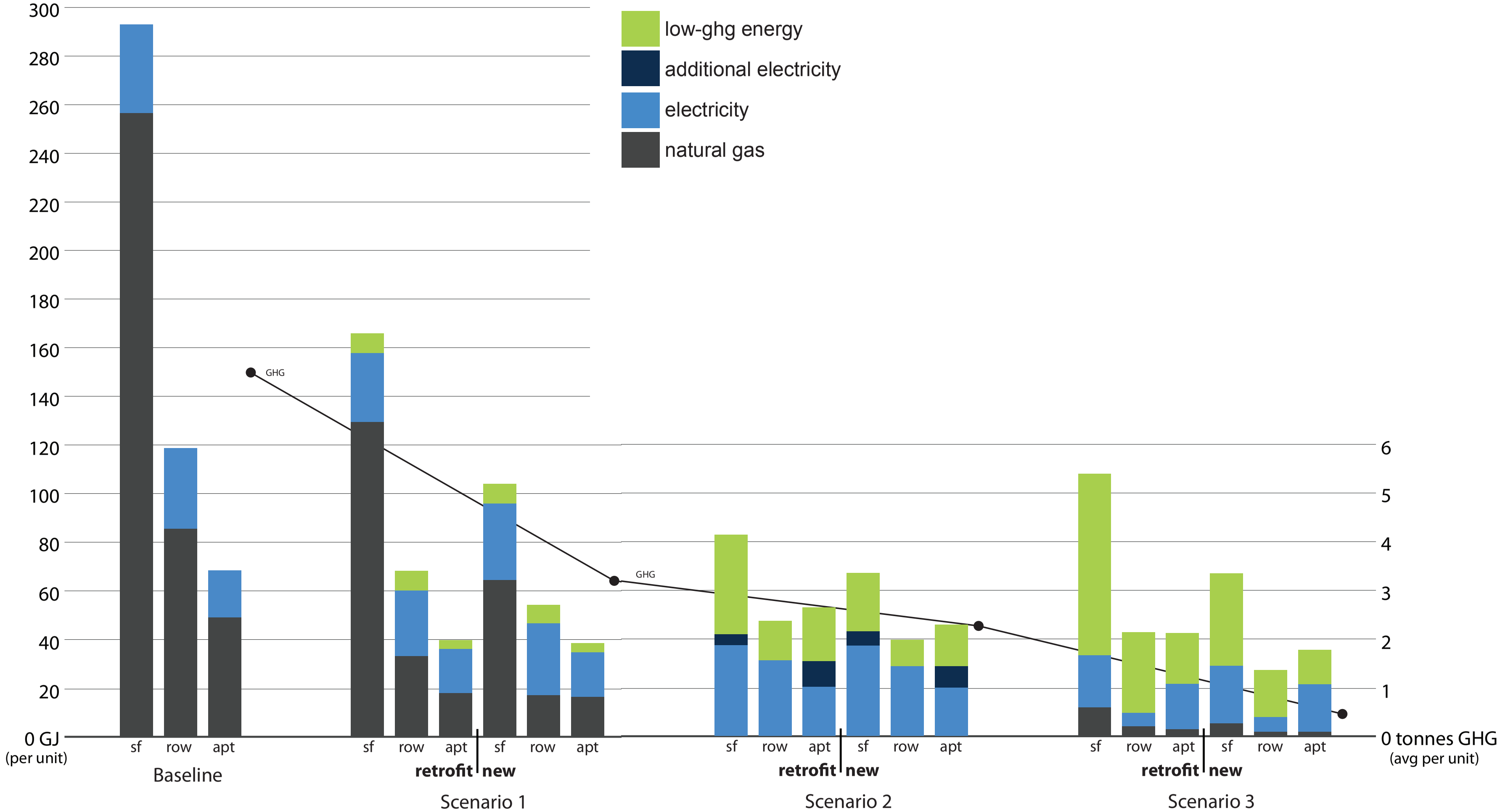


Figure 23. PRINCE GEORGE CASE STUDY. Comparison of energy consumption by energy source for each building archetype in the baseline and 3 scenarios. GHGs represent average GHGs per household for all building archetypes. Low-GHG energy refers to solar (for hot water) and biomass (wood stoves and/or District Energy).

4. DISCUSSION

This report has explored a range of GHG reduction approaches for existing residential neighbourhoods, with a focus on how neighbourhoods can achieve upwards of 80% reductions in residential building GHG emissions in support of provincial and international targets. It is important to note that the provincial targets are coarse and province-wide and may not be applied equally across all sectors. However, given that attaining an 80% reduction target will likely be difficult for all sectors of the provincial economy, it is critical that the residential housing sector understand the available strategies and trade-offs for meeting provincial targets. If significant reductions are not met by the residential sector, other sectors will be required to make up the difference. Assessment of the residential sector must therefore be understood in terms of its opportunities, constraints and other trade-offs in order to be able to be able to negotiate with other sectors for government resources and appropriate changes in policy and regulation.

4.1 Four key challenges

This study was framed by four key challenges: understanding the need for intensive retrofits in existing housing stock; the consideration of neighbourhoods as systems, particularly with regards to residential energy demand and supply; the impacts of regional differences on GHG reductions; and the interactions of GHG building emission factors of demand, energy efficiency and energy supply with regards to deep (+80%) GHG reductions. The case study scenario results both reiterate and re-frame these challenges, providing insight into policy implications.

WHY RETROFIT

The need to retrofit existing buildings and neighbourhoods is supported by two key considerations: first, that slow rates of redevelopment will not meet the urgent and stringent GHG reductions required overall within the residential sector; and second, that growth in residential development, without an overall GHG emissions strategy, will add to, rather than help to solve, the GHG challenge.

Given current rates of redevelopment, targeted new construction, although able to achieve high performance at the individual house level, will not to meet an 80% reduction target for the neighbourhood level. The neighbourhood-scale spreadsheet model for the newer subdivision of Delta shows that achieving an 80% neighbourhood emissions reduction would require replacing up to 75% of existing structures with homes that produce no GHG emissions, and retrofitting the remaining 25% to the level of the Current Policy Direction scenario. Given that replacing 75% of the homes in newer subdivisions is unlikely, even by 2050, moving to low to zero carbon new homes is critical, but not sufficient, to meet GHG targets. Existing housing will have to be retrofit as well: more aggressive actions for reducing the GHG emissions from existing homes, such as those explored in the Intensive Building-Scale Retrofit and the Neighbourhood Focused Approach scenarios, will be required.

Growth in residential units compounds the challenge communities face in meeting GHG reduction targets. While the Delta and Kimberley case studies maintain a constant population to 2050, the Prince George case study increases the number of residential units by 54%. The case study only achieves deep (+80%) GHG reductions in one of the three scenarios: in Scenarios 1 and 2, despite significant reductions in GHGs for individual houses, growth in the total number of units offsets the individually achieved reductions, and the 80% targets are not reached. The neighbourhood GHG reduction targets are more than achievable with a shared low-carbon energy supply for a district energy system (Scenario 3). Prince George thus illustrates that redevelopment that adds units, without consideration of demand reductions, intensive efficiencies and alternate low-carbon energy sources such as biomass, will not support GHG reductions.

The challenge of growth to community-wide GHG reductions may be obscured by the way that GHGs are measured. This study reports total GHG emissions on a neighbourhood by neighbourhood basis (Table 19) as well as averaged across units (Figures 20-23). Previous work (see, for example, Miller and Cavens 2008; Norman et al 2006) has focused on GHG emissions per housing unit, per person, or per square meter, which provides a useful metric for assessing individual building performance, but does not capture the total community emissions on which provincial targets are based. Provincial targets as set in the Green Municipalities Act are absolute targets, and do not vary for demographic changes.

NEIGHBOURHOODS AS SYSTEMS

The study illustrates the importance of aggregating individual residential strategies into larger scales such as neighbourhoods in order to understand the cumulative effects of changes at the building scale. While changing one residence to a super-efficient, electrical heating and hot water system (eg. heat pumps) may not in itself seem significant, aggregated across the neighbourhood, such changes can significantly alter overall energy demand, and resultant GHGs.

The Intensive Building Retrofits scenario, in particular, illustrates how the neighbourhood as a system functions with regards to changes in energy demand and supply. Even with extreme envelope upgrades, all three case studies in the scenario had increased overall electrical demand, while their natural gas demand dropped to zero. Thus, reductions in GHGs were significant, but offset by the increases in electrical GHGs of 200+% in Delta and Kimberley, and almost 2000% in Prince George. In Prince George, this led to only achieving a 55% GHG reduction, despite the 70% reduction in overall energy demand. While not obvious at the individual home-owner scale, the problem of a widespread switch to electricity as a heating energy supply becomes clear when aggregated to larger scales: overall demand will likely be impossible to meet with the current low-carbon electrical grid.

The research also found that thinking of GHG reductions in terms of neighbourhoods as systems played two key roles in developing GHG reduction strategies, particularly in assessing the opportunities and constraints for individual and shared solutions. First, neighbourhood structure has implications for strategy assessment, including building level strategies. For example, solar access can depend upon siting (orientation, parcel coverage, proximity of adjacent buildings) as well as roof structure. Having more or fewer houses with solar thermal potential can impact overall neighbourhood performance. Fewer solar opportunities is one of the reasons that the Delta neighbourhood achieved fewer reductions in Scenario 1 than the other case studies. Such neighbourhood assessments are often missing from retrofit modeling and programs.

Second, neighbourhood structure and context have implications for opportunities and constraints with regards to possible heating and hot water strategies, and shared systems. Different neighbourhoods provide different potential, and some neighbourhoods have more opportunities than others. The Kimberley and Prince George case studies, given the age of their building stock, simple building construction, and parcel-road layout, have more options than the Delta case study with its more recent, more complex house structures, road layout, and location.

Not all neighbourhoods have characteristics that make them suitable for a community energy system. For the Delta neighbourhood, even if a local fuel source were readily available, the subdivision's recent construction means that municipal infrastructure (roads, water and sewer lines) will not need replacement for at least several decades, and investment for road replacement to bury new piping would be very expensive. In addition, the cul-de-sac street pattern precludes an efficient piping network. In contrast, the Prince George case study has unpaved back lanes that would allow for easier installation of district energy piping without disrupting existing infrastructure. As well, the age of the municipal infrastructure is such that installation of district energy piping could alternately be done as part of regular scheduled road upgrades over the next 40 years.

However, Delta's Neighbourhood Focused Scenario (Scenario 3) did find other shared solutions when treating the neighbourhood as a system: policy to replace poorly performing buildings, rather than random redevelopment, can have positive outcomes. This planned rather than random redevelopment was one of the strategies that allowed for less intensive house retrofits in Scenario 3 than in Scenario 2 for this case study.

REGIONAL DIFFERENCES

Climate has a big impact on how easy it is to reduce energy demand. All things being equal, it is easier to achieve significant energy improvements in the Lower Mainland, as evidenced by the Delta case study, than it is in Prince George. This was particularly shown by the ease of modeling Passivhaus standards for new buildings in Delta as compared to Prince George. It is also the case for retrofits, where substantial changes to the building envelope are needed to provide enough room for the insulation required in cold climate conditions, as shown by the extensive envelope upgrades required by both Scenarios 2 and 3 to meet targets in Prince George. Diminishing returns for increasingly complex envelope upgrades were also clear in the modeling, particularly for the Prince George case study.

However, the study also found that while climate plays a significant role on energy demand, other factors related to the variety of neighbourhood types found throughout BC communities also play a role in GHG reduction. The range in GHG reductions achieved in the Current Policy Direction scenarios reflects the diversity of opportunities and constraints imposed on retrofit strategies by different ages of buildings and subdivisions. Envelope upgrades are most applicable for older houses that are constructed to standards below recent code requirements, but are often less practical for newer performing houses. Both Kimberley and Prince George's single-family houses had greater modeled reductions than for Delta due to poor performance of their baseline buildings. Moderate envelope upgrades as well as improved heating efficiencies have significant impacts on GHG emissions. This suggests that current retrofit programs could be more effective if they targeted resources at buildings that currently have poor energy performance.

Thus, the ability to reduce demand by renovation and retrofitting is determined by a number of factors, including climate, neighbourhood structure, building age and complexity/geometry (discussed under demand reductions). Some sites, such as the Kimberley and Prince George case studies, have more retrofit options than others such as Delta, despite the climatic advantages that Delta has over the other two case studies. Neighbourhoods with similar characteristics to the Kimberley and Prince George case studies are plentiful in the Lower Mainland and on Vancouver Island; these neighbourhoods would be ideal to target for greenhouse gas reductions.

The complexity of regional factors suggest that mitigation strategies, particularly those related to renewable energy supply, will need to be locally assessed and implemented. However, the finding that differences by case study are influenced by, but not entirely dependent upon, local climate, suggests that the strategies explored in the various case studies are not exclusive to their particular case study site, and could be applied to similar neighbourhoods across the province, with some localized differences. Further research to establish a set of neighbourhood archetypes related to neighbourhood structure and potential energy supply could aid in the more rapid analysis and implementation of local GHG mitigation.

GHG REDUCTION FACTORS: DEMAND, ENERGY EFFICIENCY, ENERGY SUPPLY

The study explored different combinations of reduced energy demand, increased efficiencies of heating systems, and switching to low-carbon energy supplies in order to achieve GHG reductions. As shown in Table 20, Scenario 1 focused on demand reductions and improved efficiencies, while Scenario 2 moved to extreme demand reductions coupled with high efficiencies (Delta and Prince George) or low-carbon supply (Kimberley). Scenario 3 employed fewer demand reductions at the individual house level, and a greater reliance on a low-carbon supply. Specific findings related to the three GHG factors are discussed below.

DEMAND REDUCTIONS: The Intensive Building-Scale Retrofit scenarios indicate how much effort is required to significantly reduce GHGs by emphasizing demand reduction using building envelope upgrades. Rather than the more conservative approaches advocated by current programs and shown in the Current Policy Direction, considerable changes to the building envelope are required to meet more significant energy demand reductions. These include reductions in the living space (e.g. creating a new insulated raised floor on the ground floor, which reduces the ceiling height from 9' to 8'6", in the Delta case study, and reduces ceiling heights in the ground floor of Kimberley and the basement of Prince George), and moving and/or reducing the size of windows. The energy reductions achieved with the basic upgrades of current policy (improved attic insulation, insulation in the basement, reduced air infiltration), will be relatively inexpensive in comparison to the extraordinary measures proposed by the Intensive Building Retrofit scenario, which are likely to be very costly. Neither set of envelope upgrades will, by themselves, deliver the necessary GHG reductions.

Another significant factor in retrofitting for reduced energy demand is the complexity of the house design itself. Contemporary homes often have highly complex geometry, with many exterior corners and multiple gables in the roof making retrofitting complex and costly. Simpler homes, such as the split level homes built in the 1970s (and modeled in the Kimberley case study) are more suitable for retrofitting, having more rectangular forms and less complicated roof construction. Additionally, the appropriate orientation of homes, particularly roof orientation, makes adding solar systems much easier. Thus, Kimberley and Prince George also achieved more significant reductions due to the more comprehensive use of solar thermal in Scenario 1, a difference primarily related to neighbourhood structure (fewer/more building orientations), and building structure (less complex/ more complex roof systems). If provincial and municipal policies are not willing to mandate zero GHG new homes at present, perhaps they could mandate that homes be built with an eye to making it easier to retrofit, by controlling complexity and orientation.

Multi-family units and rowhouses inherently incorporate demand reductions by their form. While new construction modeling for all the scenarios replaced existing units with the same kind of building (e.g. single family home for single family home), additional modeling work was done to test the implications of replacing single family homes with attached rowhouses. In each case, new construction was built to Passivhaus standards. Achieving the Passivhaus energy standard was much easier with attached home types than with single-family homes in the modeling, due to the shared walls which significantly reduce the heat loss in each unit, reducing their space heating demand.

EFFICIENCIES: Improving the efficiency of individual homes' heating systems through a system upgrade is likely the easiest way, from a home-owner's perspective, to initially reduce energy use and GHG emissions. However, as shown by Scenario 1 which reflects current federal and provincial incentive programs, replacing current heating systems with their high efficiency counterpart is not enough to achieve reductions commensurate with provincial GHG targets, even when combined with current policy direction envelope upgrades. Switching to 100% efficient systems using electricity (i.e. baseboard heaters) will also not reach stringent GHG targets, given the GHG implications of adding increased electrical demand, potentially requiring a move from the current renewable low-carbon grid to higher carbon electricity. Moving to super-efficient (+250%) systems such as heat pumps did allow for significant reductions in GHGs, as shown by Delta's Scenario 2 and 3. However, this was accompanied by reducing electrical demand for other uses by 40% per residence.

SUPPLY: One of the study's key findings is that, without also moving to a lower-carbon energy supply, deep GHG reductions (+80%) are difficult to achieve in retrofit neighbourhoods. Kimberley's results in Scenario 2 illustrate the positive effects of moving to the low-carbon supply of biomass. In addition, the move to shared biomass supplied District Heat Systems, used for Scenario 3 in Kimberley and Prince George, demonstrates that fewer reductions in energy demand may be possible while still achieving significant GHG emissions reductions. As well, increases in residential units are possible while still meeting the 80% GHG reduction target.

The illustrations in Figures 20-23 show that the de-carbonized energy supply is likely to get more complex, with building and regional differences, and partially more localized, in the future. The number of heating and hot water systems required by home-owners could increase, particularly in a scenario based on intensive changes within individual buildings only, such as Scenario 2, given the use of solar hot water and backup, and low-carbon heating and backup. Moving to District Energy requires fewer systems at the individual building scale.

BC's electricity seems to offer an alternative to biomass as a low-carbon supply. However, moving to electricity as a main energy source, as discussed above under efficiencies, not only requires intensive demand reductions and super-efficient systems, it could also increase emissions from electricity if demand outstrips BC's low-carbon supply. Such a possibility is illustrated by the increased electrical use for Delta in Scenarios 2 and 3, Kimberley in Scenario 2, and Prince George in Scenarios 2 and 3; GHG emissions from electricity increase significantly with natural-gas generation sources. As well, using electricity for space heating and hot water could tie up valuable electricity best used in other ways, such as for transportation.

With regards to renewable energy supply, additional modeling and analysis of photovoltaics (PV) to supply electricity provided interesting findings (not included in the scenario/case study results). Kimberley, with superior solar resources and buildings oriented and structured to enable many panels, would be able to supply a significant amount of its electricity, almost 25% in Scenario 3, while Delta's case study PV supply would be limited to the point of being negligible. Given the high current costs of PV systems, however, costing would be required to understand the viability of this option for neighbourhoods where it is technically feasible.

Unlike demand reduction approaches, which are related to individual buildings, the trade-offs between changing types of heating system for super (+250%) efficiency, and using renewable fuel sources in a retrofit situation are related to neighbourhood characteristics, as shown by Scenarios 2 and 3. Choosing the most appropriate approach involves an evaluation of climatic conditions (e.g. to determine the viability of air-source heat pumps), availability of alternative fuels (such as access to biomass fuel supply), available space for horizontal or vertical geo-exchange, and the age/likelihood of replacing existing municipal infrastructure.

The results show that a combination of demand reductions with high efficiency systems, and a low carbon energy supply, will be necessary. Which configuration across these three GHG reduction factors is used will depend upon other trade-offs, such as quality of life, costing, technology, how to pay, who is responsible, and how to implement. It is to these questions of policy that we turn next.

4.2 Policy Implications

This report shows that deep reductions in GHGs related to residential buildings are achievable with currently available knowledge and technologies. Further, it is clear from the research that the strategies necessary to achieve these reductions will likely vary substantially from community to community depending on local climate, housing stock, availability of local resources and other factors. With this understanding, the underlying question remains how such locally targeted, intensive GHG reduction measures will be implemented, particularly within the pressing timeframes indicated both by science and provincial policy.

Current policy and programs supported by the federal and provincial governments are focused on retrofitting and rebuilding strategies similar to those represented in the Current Policy Direction scenario. Even with aggressive assumptions about the number of owners who choose to retrofit their homes, these strategies do not go far enough to meet the long term (2050) provincial targets, given that the Current Policy Direction scenario only achieves a GHG reduction of 33-50%. In addition, these numbers assume a rate of retrofitting (100%) that is almost inconceivable within the study's timeframe, even with aggressive government programs. The breadth of the retrofits required (100% uptake) is unprecedented, and raises serious questions about implementation as well as financing.

Five "no-regrets" strategies are apparent across all three scenarios and case studies. The first three strategies address the substantial energy demand reductions required, while the last two address new construction specifically. These actions will require uptake of improved technology, and collaboration between policy-makers, builders/developers, the building trades, the real estate industry, and home-owners to implement.

1. Building envelope upgrades are required across all three scenarios, at and beyond current policy levels. The biggest immediate impact can be found by targeting the worst-performing buildings; however, all buildings will need to reduce their space heating demand. Energy demand reduction strategies will require widespread, likely 100%, uptake to achieve GHG reductions on the order of 80%; current levels of retrofits and high-performance new construction are inadequate. How to achieve the depth and breadth of retrofit required is a challenge.

2. Solar thermal (hot water) reduces the demand on conventional hot water systems by 50+%, and by 2050, most residences will likely need to move to solar thermal. Requiring new construction to be at a minimum "solar ready" and better yet, to incorporate solar thermal as a standard feature, as well as a requirement for major renovation permits to include solar thermal considerations are clearly called for, as is consideration and protection of solar access. Financing and other implementation barriers need to be addressed.

3. Significant reductions in electrical demand will be required, not only to enable a possible move to highly-efficient space and hot water heating systems powered by electricity, but also to accommodate increased demand due to population growth, and potential new demands such as electric vehicles. Moving to electrically-based heating and hot water systems within existing neighbourhoods, without significant heating demand reductions first, would increase electrical demand well beyond the current baseline, potentially leading to significant increases in GHGs (depending on the new generation source), and reducing the availability of electricity for other needs. Alternates to switching to electricity for space and hot water heating, such as moving to biomass, should be considered first.

4. It is easier to "build green" from the beginning than to retrofit later. All new construction should be built to net-zero or passivhaus standards, with some relaxation of requirements for northern climates. New residences that add heating and hot water demand increase the GHG challenge rather than helping to solve it.

5. Where redevelopment occurs, rowhouses and low-rise multi-family, rather than single-family dwellings, should be built, with a move towards smaller rather than larger unit sizes, and compact geometrical form. Depending on the regional climate, rowhouses built to passivhaus standards could well require minimal space heating. Such redevelopment needs to consider proximity to high quality public transit, so that building GHG reductions are not offset by increased transportation

emissions ("a city should aim to locate the maximum number of people where their transportation energy is at a minimum" O'Brien et al 2010: 17).

Additional multi-family units would be ideally located in areas with access to renewable energy sources and/or district energy systems to reduce the impacts of population growth, the benefits of which are clearly demonstrated by the Prince George Neighbourhood Focused Approach. Re-zoning for multi-family could be clustered along District Energy corridor. Attached forms such as rowhouses offer particularly promising advantages: they provide significantly improved energy performance (in Prince George, rowhouses required roughly half the energy, or less, of a single family house for all scenarios) while maintaining many desirable characteristics of single family homes (e.g. private yards, ground-level unit access, reduced overshadowing for neighbouring buildings).

Beyond the initial "no regrets" steps, multiple pathways to achieving deep GHG reductions emerge, with multiple options available to communities, developers, and home-owners. The three case studies demonstrate that a single retrofit/redevelopment solution will not be applicable to every neighbourhood across BC. With no "one size fits all" solution, the choices are more complex and less easily replicable across all communities. Each neighbourhood will require a specific assessment of its particular potentials and constraints with respect to reducing GHGs. The analysis needs to consider the characteristics of individual homes (including age, orientation and construction details), the overall spatial configuration of the neighbourhood as well as its location, the age and condition of existing neighbourhood infrastructure, and the availability of local renewable energy sources. Development of neighbourhood archetypes could aid in assessing and choosing local GHG mitigation strategies.

Comparison of the Intensive Buildings Retrofits and Neighbourhood Focused scenarios demonstrate other considerations in choosing a low-carbon pathway, including which technological systems to use, who is responsible, quality of life considerations, and equity challenges. Costing, which was not included within the study's scope, is clearly a key consideration, and is discussed under Study Limitations.

Technological choices made now could aid or impede reaching deep GHG reductions. While envelope upgrades are required across all three scenarios, there are more complex choices involved with investing in new heating and hot water systems, and choosing renewable energy sources. Technology upgrades made in Scenario 1 under current policy directions (installing higher efficiency boilers and furnaces) could constrain the deeper GHG reductions required to get to 80% GHG reductions, given that moving from the baseline to Scenario 1 and then to Scenarios 2 or 3 would requir a 2-step change in technology, doubling the system changes, and potentially the costs. Once envelope upgrades are undertaken, it may be more beneficial to move from directly to super-efficient systems (well over

100%) such as heat exchangers (Scenario 2), enabling a change not from 84 to 96% efficiency, but from 84% to over 250%, or to District Energy with a low-carbon energy supply (Scenario 3).

One way to "future-proof" systems would be to use hot water as a heat carrier where possible, which allows for multiple heating systems and energy supplies to tie into the same buildings. Heat pumps, natural gas and biomass District Energy, solar hot water, and wood stoves can all tie in to a hot water as heat carrier system for individual buildings or for district energy systems.

Trade-offs around responsibility for residential building emission reductions are clearly illustrated by the different scenarios. Scenarios 1 and 2 assume that responsibility for implementation is taken by individual home-owners and builders, although municipal, provincial, and federal governments may play a role in regulatory requirements (such as energy audits for house sales), incentive programs such as LiveSmart, or retrofit financing. The Neighbourhood Focused Approach places responsibility for implementation at the strata council and municipal/regional district government levels, with some home-owner involvement, and provincial/federal governments possibly involved in financing. A key decision will be whether the required investment is done at the individual house scale by home-owners, or by some level of government.

Quality of life trade-offs are most clearly seen in the differences between Scenarios 2 and 3, due to the amount of effort required by the individual homeowner. The intensive retrofits in the second scenario are intrusive, requiring changes to the living space and, in the Kimberley case study, significant behavioural changes with respect to maintaining the heating system. Switching to biomass, whether using woodstoves (as modeled) or even pellet stoves, requires more attention and time from the homeowner than the conventional furnace. It is unlikely that all residents would be willing to switch to the considerable inconvenience of wood stoves to keep the heating system running. Additionally, for communities with many second home-owners, where houses are only occupied part of the year, individual wood stove heating systems present a serious drawback. It is likely that in reality, the backup systems (electrical) would be used more, lowering the potential GHG reductions offered by the move to woodstoves.

In contrast, the community-scaled biomass systems modeled in the Neighbourhood Focused Approach scenario for Kimberley and Prince George allow the home-owners to benefit from low-carbon fuel without having to change their behaviour. District systems, which connect homes to a hot-water distribution system fed by a central plant, provide similar controls and comfort to current systems. Thus, Kimberley's Scenario 3, which moves to a district energy system, achieves similar or better GHG reductions, with fewer lifestyle changes than Scenario 2.

The Neighbourhood Focused Approach scenario also assumes less intrusive demand reduction strategies than the Intensive Building Retrofits scenario (e.g. window size and location are maintained, insulation is inside existing walls). This reflects a trade-off between improvements at the individual building-scale and GHG reduction techniques at the neighbourhood scale. All three case studies reach the 80% target, but with fewer changes to the internal living space. Because fewer behavioural changes and individual commitments are required, and quality of life changes are fewer, neighbourhood scaled systems and approaches may be more effective in achieving reduction targets.

Finally, equity questions arise when looking at how GHGs are measured for building emissions. This study used percentage reductions from the baseline in order to assess reductions, without assessing the fairness or equity of the baseline. For example, smaller, older homes may have fewer overall emissions than larger, newer homes, but their per square meter emissions will likely be higher. Single-family homes generally have higher emissions per square meter than do multi-family homes, although they may also have more people per unit. Should all residences reduce GHGs by a certain percentage, regardless of their total baseline emissions; should they meet specific targets, such as a per square meter energy and GHG performance targets; or should each residence have a "cap" on emissions? A related question is whether allowances should be made for residences in more climatically difficult areas.

4.3 Study Limitations and Further Research

The study has focused primarily on technological strategies at the building and neighbourhood scales in order to achieve deep GHG reductions. The study used GHGs as its main evaluative criteria; decision-making on pathways beyond current policy will require economic and other criteria such as other environmental impacts, quality of life, and financing options as well. There are thus several clear limitations to the study, and areas where further research is warranted.

While an economic analysis of the different scenarios was beyond the scope of this study, it is an obvious shortcoming of this work. The different scenarios are likely to have very different economic implications. Without a detailed economic analysis of each case study, it is not possible to state which approach would be more cost-effective, although Scenarios 2 and 3, which achieve 80% GHG reductions, are both likely to be expensive.

An analysis of the costs of the different retrofit strategies is particularly important as they are likely to be quite variable. One complicating factor is that many of the retrofit upgrades, particularly those that involve changes to the building envelope, are difficult to project without a detailed analysis of the residences' current conditions. New construction, on the other hand, is much easier to calculate. For example, the incremental costs of meeting Passivhaus standards are currently estimated to be in the range of $10-15/sq. ft. (Parker 2009, Versele 2008, Brach 2009). Given that low-energy and GHG strategies are easier to incorporate in initial design and construction phases, and are likely more cost effective as an incremental cost to new construction than as retrofits to existing housing stock, increasing the GHG performance of new construction is an obvious starting point. The trade-offs between increasing upgrades and costs, and diminishing GHG reduction returns, also needs to be better understood.

In addition, current economic considerations will change considerably by 2050. The impacts of peak oil, government regulation of carbon such as carbon taxes or cap and trade regimes, and rising energy prices in general will alter what is considered feasible over the next 40 years, and different retrofit scenarios may become more cost effective. Any detailed financial analysis would need to investigate the implications of different energy and carbon pricing over the long term.

The research study had several other gaps as well. The modeling did not deal with the considerable range in behavioural energy use, which represents another, complementary approach to demand reduction. Passive solar offers opportunities that were not explored due to modeling constraints, but should be considered as viable options for some neighbourhoods and housing types, given that there are proven precedents for passive solar within BC. Further full life-cycle assessments should be undertaken to consider the embedded GHGs in new and existing housing. This would help to determine if it may be more GHG efficient to accelerate the redevelopment of existing neighbourhoods, particularly for neighbourhoods that currently perform poorly with respect to GHG emissions, rather than to retrofit very poorly performing housing. The impacts of changing demographics and unit occupancy over time, and how this relates to the effect on absolute GHG reduction targets, should also be considered in future research.

While the report has focused on climate change mitigation, the modeling itself did not account for changes to heating demand due to climate change impacts, i.e. projected changes in heating degree days. Research into the implications of such changes on residential building emissions could provide a more nuanced picture of potential building emissions out to 2050.

Critically, this report only modeled the emissions reductions related to building energy use, and did not deal with related transportation emissions. Given that the transportation emissions intensity of the various neighbourhoods was not accounted for, this study must be seen as dealing with only one piece, albeit a large one, of the emissions reductions required of our current residential neighbourhoods and communities[11]. Consideration of transportation emissions will also impact scenario trade-offs and choices, given that locationally distant neighbourhoods with low-density and poor transit options should not necessarily redevelop to multi-family as a GHG solution. Doing so could greatly increase related transportation emissions.

A final challenge for the study was addressing GHG emissions from electricity. Calculating the GHG emissions from electrical power is complex, and in British Columbia particularly so. While BC's average electricity emission factor is very low due to the abundance of hydro-power within the province, there is no guarantee of what future emissions from electricity might be, particularly if demand for electricity continues to grow. Meeting large proportions of residential energy demand with electricity (e.g. such as space heating and hot water) to avoid the use of fossil fuels and reduce GHG emissions may not be successful if electrical demand is raised to such an extent that the use of fossil fuels becomes necessary in the generation of electricity. Increasing demands may also by placed on the electrical supply by the transportation sector, if there is a large-scale shift to electric vehicles. While it is beyond the scope of this report to predict the future sources of electricity in BC, it was assumed that any new electrical load would be met by sources with higher than current emission levels, in order to illustrate the potential impact of such large increase in electrical demand due to residential sector increases.

Lastly, given BC's specific low-carbon electrical situation, the results from this study are not easily transferable to other jurisdictions. In some parts of North America, electrical loads are met with coal-fired plants; in these areas, electricity might have more emissions than natural gas furnaces or hot water tanks in individual homes. Findings from this study should not be transferred to jurisdictions outside BC without careful consideration of the GHG emissions factors of the local electrical grid.

11 See the Community Energy and Emissions Inventories for each BC community for the breakdown for buildings and transportation (www.toolkit.bc.ca/ceei), and the national Urban Archetypes Project for neighbourhood emissions including transportation (http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/buildings_communities/communities/urban_archetypes_project.html)

5. CONCLUSION

This study explores different approaches to achieving significant GHG reductions in residential neighbourhoods in support of the province's targets (80% absolute reduction by 2050). The scenario analysis indicates that the current policy direction is unlikely to meet these aggressive targets. Both the Intensive Building Retrofits scenario, and the Neighbourhood Focused Approach demonstrate that the targets are achievable using today's technology; they will, however, require substantial investment by individual homeowners and/or in neighbourhood scale solutions by local governments.

The three case studies demonstrate that one type of retrofit/redevelopment solution will not be applicable to every neighbourhood across BC. Each neighbourhood will require a specific assessment of its particular potentials and constraints with respect to reducing GHGs. This analysis needs to consider the characteristics of individual homes (including age, orientation and construction details), the overall spatial configuration of the neighbourhood, age and condition of existing neighbourhood infrastructure, as well as the availability of local renewable energy sources.

Institutional and costing factors, rather than technology development, are the likely barriers to overcome in realizing deep greenhouse gas reductions within existing residential neighbourhoods. Further research is needed into the economic viability of the different strategies, particularly in relation to changing energy and carbon pricing over the long term. Other issues that need to be investigated are the impacts of changing demographics and unit occupancy over time, and how this relates to the effect on absolute GHG reduction targets.

Builders, developers, realtors, local governments, home-owners and others are critical players in forwarding the strategies for meeting the challenges posed by climate change mitigation within existing BC communities. Additional work should focus on how best to achieve the building and neighbourhood changes required for the Intensive Building Retrofit and Neighbourhood Focused Approach scenarios as it is clear that implementing the strategies presented in this report will require substantial buy-in from individuals, the real estate industry, and local and higher levels of government. How best to achieve this buy-in remains an open question; at a minimum, it will require informed, engaged, and motivated community members - residents, developers, realtors - working closely with local government.

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