TOWARDS CARBON NEUTRALITY:
Possibilities for North America's Suburban Residential Developments

by

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Abstract

The objective of the thesis *Towards Carbon Neutrality: Possibilities for North America's Suburban Residential Developments* is to develop a process by which an existing suburban residential development can be analysed for its potential to accept retrofit strategies towards the goal of meeting challenging sustainability targets. As a vehicle for this investigation, the thesis examines a representative residential subdivision and its ability to mitigate greenhouse gas emissions, proposing that more demanding, sustainability-based goals like emissions mitigation are attainable in contemporary suburban developments.

Following a review of suburban history and values and an examination of current building and community design strategies which affect energy consumption and emissions, the thesis assesses the existing conditions of the selected neighbourhood, a residential development in the Fleetwood district of Surrey, British Columbia, and describes both its physical qualities and its various contributions to carbon emissions in order to create a baseline for the study.

The thesis then concentrates on developing a range of targets, "solution spaces," and scenarios in order to fully depict the design possibilities available to a given development. By working with a scenario-based approach, the thesis provides a platform for the discussion of multiple strategies and a range of emission reduction goals. As a basis for scenario development, the thesis recognises and addresses two commonly cited "barriers" to residential retrofit projects: multiple, private owners and a resistance to change in many existing suburban communities.

The development of four different retrofit scenarios supports the conclusion that the study area and developments like it have the capacity to mitigate a substantial portion of their per capita greenhouse gas emissions through neighbourhood retrofits under a variety of contexts and suggests that other sustainability targets could also be successfully achieved in existing suburban conditions. The method of analysis and scenario-building described by the thesis has additional value as a useful and replicable strategy for target setting and sustainability planning in a community setting.

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CHAPTER 1:
INTRODUCTION

1.1 Defining the Problem

1.1.1 Background

A substantial body of scientific evidence now shows that the release of large amounts of carbon dioxide (CO_2) through the burning of fossil fuels such as coal and petroleum is a primary contributor to rising global temperatures and related environmental consequences. Human activity currently adds over 8 billion tonnes of carbon to the global carbon cycle every year – roughly 6.5 billion tonnes from fossil fuels and an additional 1.5 billion tonnes attributed to global deforestation[1]. Unused, this extra carbon has raised atmospheric CO_2 levels to points not approached in the past 160,000 years[2]. Since the Industrial Revolution, atmospheric CO_2 has risen from 280 parts per million to well over 360 parts per million, with levels estimated to reach somewhere between 450 and 600 parts per million by the year 2100[3]. Further increases in temperature, like those predicted over the next century, will have dramatic and potentially devastating effects on ecosystems worldwide[4].

In 2001, The U.S. Department of Energy ranked Canada as the seventh largest consumer of primary energy in the world, and first in North America for per capita energy consumption[5]. As greenhouse gas emissions are intimately linked to energy consumption, Canada has seen a total emissions increase of more than 20 percent since 1990, with an expected increase of 1.2 percent annually through 2025[6]. These increases are in direct contradiction to Canada's participation in the Kyoto Protocol, which committed the country to reducing greenhouse gas emission levels to below 1990 levels by 2012.

With Kyoto targets for emissions reductions in Canada moving farther out of reach, the consequences of global warming are becoming a major focus of many national and regional reports. The Government of British Columbia records the regional effects that have already taken place due to greenhouse gas emissions produced by society, including

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[1] Appenzeller n. pag.

[2] Mutel n. pag.

[3] Appenzeller n. pag.; Reid, et al. p. 18

[4] Reid, et al. p. 29

[5] U.S. Department of Energy, *Canada, Environmental Issues*

[6] Government of British Columbia

significant annual temperature increases and rising sea levels[7]. Additional information provided by the Cool Vancouver Taskforce illustrates many of the potential impacts of climate change that the Greater Vancouver Regional District will be facing in the coming decades[8]. With this scale of predicted impacts, the mitigation of emissions generated through human activity is a critical task.

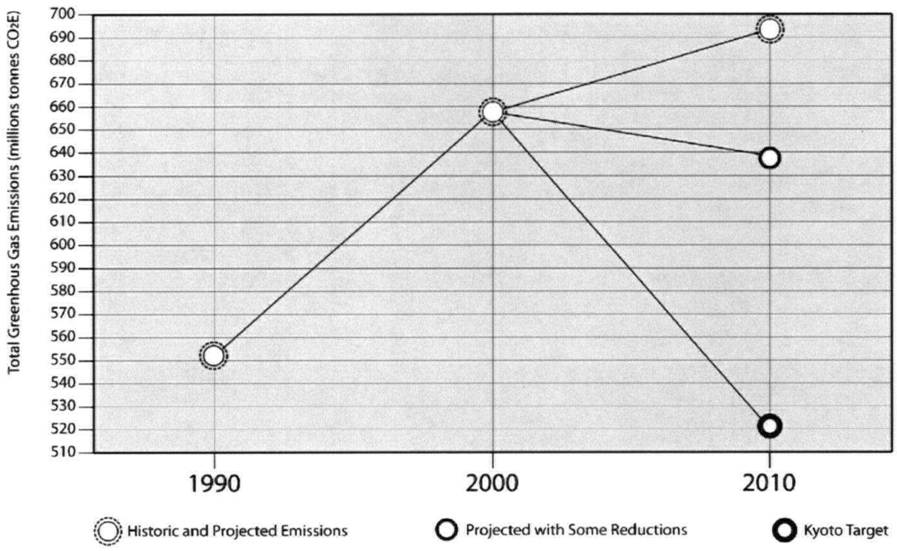

Figure 1.1 Canada's Greenhouse Gas Emissions, Historic and Projected, adapted from Drexhage p. 16

Table 1.1 Effects of Greenhouse Gas Emissions on British Columbia [a]

Average annual temperatures have warmed 0.6°C on the coast, 1.1°C in the Interior, and 1.7°C in Northern BC
Night temperatures have increased in most of BC in spring and summer
Precipitation has increased in Southern BC by 2-4% per decade
Lakes and rivers have become free of ice earlier in the spring
Sea surface temperatures have increased 0.9°C to 1.8°C along the BC coast
Sea levels have risen 4-12 cm along most of the BC coast
Two large BC glaciers have retreated over 1 km each
The Fraser River now discharges more of its flow earlier in the year
Water in the Fraser River is now warmer in the summer
More heat energy is available for plant and insect growth

[a] Source: Government of British Columbia

[7] Government of British Columbia

[8] Cool Vancouver Task Force

Table 1.2 Potential Impacts of Climate Change on the GVRD [a]

Flooding: Increased storm intensity, wetter winters, and rising sea levels are expected to increase the number and severity of floods in the area

Ocean level rise: Over the next 100 years, the ocean is predicted to rise between several inches and one meter, which may affect the area's waterfronts, marinas, ports, and low-lying properties, particularly if storm intensities also increase

Changes in water supply: A predicted reduction in snow pack in the North Shore mountains would impact both the quality and quantity of the area's water supply through increased runoff, increased landslides into reservoirs, and a reduction in late summer water supplies

Increase in number and intensity of storms: An increase in severe storms may bring extensive damage to property from wind and flooding

Longer hotter summers: Predicted longer, hotter summers will put a growing burden on water supplies and increase the risk of fires and heat related health problems

Shorter wetter winters: Predicted shorter, more intense winters may result in increased flooding and erosion due to temperature and precipitation fluctuations

Diseases: Warmer temperatures may allow diseases currently more prevalent to the south to migrate north

Health care issues: Increased temperatures, diseases, and storms are expected to increase local health problems like respiratory illness and stress, further burdening the health care system

Hydro-electricity fluctuation in supply and price: Changes to normal precipitation patterns will affect BC rivers, which may in turn impact the reliability of hydro-electricity supplies and rates

Land and aquatic species changes: Changes to normal temperature and precipitation patterns may affect the land and water habitats of many species, creating local scarcities, lowering ecological diversity, and allowing foreign species to overtake local systems

Agricultural production change: Changes to normal temperature and precipitation patterns may impact regional agriculture, as some crops thrive under new conditions, while others fail

Impacts on the economy: Climate changes could impact a number of economic sectors, including fishing, forestry, tourism, insurance, and others

Environmental refugees: As climate change yields an increasing effect on the rest of the world, it is likely that more prosperous areas such as the Vancouver region will be called upon to assist various groups through financial support and immigration

[a] Source: Cool Vancouver Task Force

1.1.2 The Built Environment

Modernisation and industrialisation occurring over the past two centuries have led to built environments and consequent lifestyles in North America and elsewhere which are no longer sustainable. In Canada, the building sector accounts for over 10 percent of total national greenhouse gas emissions[9], generated through the intensive use of fossil fuels for daily operations and for the processes of construction and demolition. The materials that go into the making of human structures represent a substantial portion of world resource consumption, while the organic and inorganic waste released into the natural environment from building systems cause significant harm to surrounding ecosystems. Expanding populations, a proclivity for mass consumption, and a seeming inability – at least in developed nations – to embrace consequences beyond a five year planning horizon[10] are indicators that humans and their developments are not yet existing sustainably within larger natural systems.

Yet the processes of design and construction of buildings and communities have great potential for change. Because modern cities and developments are relatively new, and have not yet faced major challenges brought about by resource scarcity, changes in settlement patterns, or environmental transformations met by older, more stable systems, there is still much opportunity for evolution and adaptation[11], including the mitigation of greenhouse gas emissions through improved energy performance, "clean," renewable energy generation, and carbon sequestration.

In Canada, 60 percent of emissions generated by the building sector (more than 6 percent of total national emissions) come from residential uses[12] and suburban residential developments in particular. These "subdivisions", heavily predominant in North American urban societies, have developed almost entirely within the past fifty years, and now house well over half of Canadians and Americans[13]. Currently the most energy, water, and land consumptive of all housing types, single family homes continue to increase in size, with

[9] Government of Canada

[10] Brand p. 8

[11] Chiras and Wann p. 2

[12] Government of Canada

[13] Campbell Goodell Consultants, Ltd. p. 5

structures today 49 percent larger than those built in 1960[14]. In addition, the larger pattern of suburban development, including low densities and segregated land uses, demands the utilisation of the private automobile, which further elevates energy consumption and emissions. Moreover, the trend towards suburban residential development continues to accelerate and expand, with over 1.5 million new single family homes completed each year by residential developers[15]. While suburbia has long been considered an ideal for family living, with plentiful space, relative safety, privacy, and independence[16], this rate of suburban growth, in the absence of efforts to improve environmental performance, will have devastating effects on natural systems worldwide, as well as human well-being. Recent studies have raised concerns that suburban development patterns are also connected to several adverse health effects for individuals, including asthma and diabetes, as well as decreased community engagement and diminished social connections[17].

The residential sector has already been given a significant amount of attention in regards to efficiency and more sustainable design. As early as the 1890s solar technology for homes was patented by an inventor in Maryland, while the 1940s saw solar home prototypes heated entirely without the use of auxiliary systems[18]. Following the energy crisis of the 1970s, studies on reducing the use of energy and fossil fuels exploded in both publications and design work. Particularly in the decade between about 1975 and 1985, new, more energy conscious information on housing and neighbourhood planning abounded. Reports during this time touted the benefits of passive solar design, building orientation strategies, vegetation for shading and wind blocks and simple building forms for maximum solar exposure[19]. Materials related investigations offered convincing

[14] Government of Canada

[15] Hayden p. 4

[16] Palen p. 3; Hayden p. 3

[17] Incremental Urbanism p. 52; Langdon p. 15

[18] Hayden p. 226

[19] Ministry of Municipal Affairs and Housing, Ontario. Vol. 1 and Vol. 3; Energy, Mines and Resources Canada

evidence for the benefits of additional insulation, vapour barriers, high performance windows, and more efficient appliances[20].

The reasons cited for these studies are ones familiar to contemporary society: reduction of fossil fuel use, lower utility bills, and mounting concerns over growing energy demands as populations increase. Ironically, more than twenty years later researchers and designers are still grappling with the same concerns. Now spurred by additional apprehension regarding global warming and greenhouse gas emissions, organisations such as the National Home Builders Association and the Department of Energy in the U.S. and the Canada Mortgage and Housing Corporation and Natural Resources Canada are conducting numerous housing and neighbourhood energy and emission related research projects. The sample of research arising since the turn of this century now focuses not only on the passive strategies of the previous decades, but also on new technologies including building integrated photovoltaics, ground source heat pumps, fuel cells and more. Technologies such as these, along with a better understanding of the previously developed passive systems, are enabling new forms of efficient homes and zero-energy developments paired with higher quality spaces and safer materials[21].

1.1.3 Neighbourhood Retrofits

An important component of building science, residential energy research contains a rich history of rigorous investigation and documentation, paired with the more recent addition of research on mitigating the effects of greenhouse gas emissions from both housing and personal transportation. However, an evaluation of existing work indicates that research tends to fall into one of two specific categories: (1) research on new construction and developments and (2) research on the renovation of a single home. Notably absent from existing work is a meaningful consideration of the existing suburban residential neighbourhood, although lessons can be drawn from both existing categories of research to inform changes in the existing suburban fabric.

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[20] Oak Ridge National Laboratory; Energy, Mines and Resources Canada, *The Effects of Re-Insulation on Some Houses in Winnipeg* and *The Effects of Re-Insulation on 8 Houses in Ottawa*; National Center for Appropriate Technology

[21] Roaf, Fuentes and Thomas; Townsend, Aaron, John Holton, et al.

As cited in much of the recent literature on suburbia and its future, the retrofitting of existing residential developments is an important, if underutilised, strategy for improving the current performance of the suburban environment. As the predominant residential pattern in North America, the suburban housing development has the capacity to make substantial contributions to emissions mitigation efforts, particularly if the private automobile use associated with the residential sector is also considered. Alex Krieger comments that a major flaw in North American efforts to improve suburban character is that designers and developers tend to start over with new ideas on undeveloped land. He writes, "We need to change the pitch that a new development farther afield is always the answer. We shouldn't be going farther out, spreading out metropolitan development. We should work in existing urban areas. We should try to fill them in and heighten the quality of the places that are already in existence[22]." Similar sentiments are beginning to surface in documents such as the new LEED Neighbourhood Design guidelines and various Greater Vancouver Official Community Plans which are calling for a higher level of infill development, while a recent *Places* journal devoted an entire issue to the topic of "retrofitting suburbia[23]."

The consideration of a neighbourhood as a system, rather than a collection of separate and independent units, exposes synergies and potentials occurring between and among individual dwellings, including the potential for on site, community energy generation. Many authors now recognise that retrofitting suburban residential neighbourhoods is not simply about renovating individual homes, arguing that the improvement a singular building will do very little in today's suburban context[24].

1.2 Objective and Scope

1.2.1 Objective

With current planning and design innovations centered mainly on new residential developments, existing low density, energy and resource intensive suburban

[22] Krieger, quoted in Langdon p. 219

[23] Lynden, *Retrofitting Suburbia*

[24] Gamble and Leblanc p. 51; Kim p. 18; Hayden p. 226, 229

infrastructure is largely left unconsidered as a site for intervention and innovation in sustainability and efficiency. Intensifying environmental issues such as global warming garner interest in inventive solutions including planned, sustainable neighbourhoods; however, the residential "subdivisions" so prolific in North America should not be abandoned in light of these new projects. Instead, existing suburban development must be re-examined for its own capacity to contribute to sustainability goals.

Under this reasoning, the objective of the thesis is to develop a process by which an existing suburban residential development can be assessed for its potentials to accept retrofit strategies towards the goal of meeting challenging sustainability targets. As a vehicle for this investigation, the thesis examines a representative residential subdivision and its ability to mitigate greenhouse gas emissions, an important indicator of sustainable communities, and proposes that more demanding, sustainability-based goals like emissions mitigation are attainable in contemporary suburban residential developments.

1.2.2 Scope

In order to focus the research topic, the thesis concentrates solely on analysing design issues that contribute to the reduction of greenhouse gas emissions within the study area. The thesis recognises and addresses two commonly cited "barriers" to residential retrofit projects: multiple, private owners and a resistance to change in many existing suburban communities[25]. Including these issues in the project ensures that retrofit design strategies remain grounded in the suburban context, translating many common "green" strategies advocated for new residential development in ways that are more appropriate to existing conditions. The thesis does not attempt to create a singular, masterplanned solution, but rather concentrates on developing a range of targets, "solution spaces," and scenarios in order to fully depict the design possibilities available to a given development. By working with a scenario-based approach, the project provides a platform for the discussion of multiple strategies and a range of emission reduction goals.

Several issues intrinsic to the subject of sustainable retrofit projects such as time and incremental implementation of strategies, equity, economics, policy, decision makers, and

[25] Lewis p. 27; Hayden p.17; Langdon p. 235; Baxandall and Ewen p. xv; Palen p. 103; Dunham-Jones p.9; Lyndon p.9

various social considerations, are limited within the design-focused scope of the thesis; however, these issues are considered important to the real-life applicability of the project and have been influential in shaping the research. Chapters 5 and 6 discuss how these issues might be more fully addressed in future research through variations in the process of analysis described by the thesis.

The thesis topic is further bounded by the consideration of a particular, common, suburban residential typology, although the thesis recognises that there are many different types of suburban residential developments, varying significantly in size, density, age, and demographics. The type of suburban development chosen for the thesis is characterised by a stable, upper-middle class population residing in single family, detached homes on private lots owned by the residents. The typology is also characterised by significant urban growth and new development in surrounding areas due to increasing trends toward multi-nodal cities and exurban expansion. This quality suggests that suburbs of this type will continue to be important and viable residential areas in the future as they become centralised within growing urban areas. The study area's location in a designated "municipal town centre[26]" within the Greater Vancouver Regional District is reflective of this characteristic.

1.2.3 Emissions Mitigation as an Indicator of Sustainability

Because so many human activities, including electricity consumption, space conditioning, and motorised vehicle travel result in the production of carbon dioxide through the consumption and burning of fossil fuels, the topic of carbon emissions mitigation necessarily addresses a variety of concerns simultaneously. Within a neighbourhood context, meeting emission reduction goals requires the consideration of issues such as energy source, building energy efficiency, transportation energy efficiency, transportation alternatives and carbon sequestration, making it a useful and inclusive indicator of community sustainability. Moreover, emissions mitigation is a quantifiable indicator. By recording energy consumption and consequent emissions within a study area, base conditions can be measured, targets set, and progress monitored through time.

[26] Greater Vancouver Regional District, *Livable Region Strategic Plan* p.32

As the title of the thesis suggests, an ultimate goal in the research is to achieve carbon neutrality within the study area. "Carbon neutral," the idea that no net carbon dioxide is generated within a given process or location, is a term that is being used with increasing frequency in reference to businesses, events, individuals, homes, and neighbourhoods. Typically, carbon neutrality refers to the mitigation and offsetting of generated carbon dioxide or greenhouse gas emissions through reductions in energy consumption, the generation or purchase of zero or low emission energy, or by the purchase of "carbon credits" by which organisations and individuals pay for tree planting or investment in renewable energy programs. Emissions reductions and purchased credits can be applied to emissions from travel, manufacturing processes, resource consumption, energy use, waste, etc. in order to bring total net emissions to zero. Projects such as the Beddington Zero Energy Development in London and Dockside Green, currently being developed in Victoria, British Columbia, are working towards this goal with the use of biomass cogeneration plants, energy efficiency measures, and the encouragement of alternative forms of transportation. Possibilities for achieving carbon neutrality within the Fleetwood study area are discussed in the concluding chapter of the thesis.

1.3 Methods

In order to fully consider the possibilities of retrofitting a suburban residential development to mitigate carbon emissions, the thesis utilises a three part methodology encompassing a combination of quantitative and qualitative strategies.

1.3.1 Literature Review

The literature review conducted throughout the course of the thesis encompasses two distinct topics: the history and values embodied by North American suburbs, and the common strategies utilised in sustainable or carbon-neutral development projects. Historical, cultural, and sociological characterisations of the suburbs, as presented in Chapter 2, help to identify the prospective challenges and potential opportunities of a suburban retrofit. Chapter 3 reviews sustainable design strategies, especially those focused on carbon reduction, along with associated studies and reports. This review directs the thesis in its target setting and strategy development, while calling attention to the differences between many of the design strategies seen in new projects, such as narrow, gridded street patterns and high density development, and the pre-existing form of the residential subdivision.

1.3.2 Study Area Assessment

Chapter 4 assesses the existing conditions of the selected neighbourhood, a residential development in the Fleetwood district of Surrey, British Columbia, describing both its physical qualities and its various energy-related contributions to emissions in order to create a baseline for the study. This inventory enables the project to assess the relative importance of various factors to greenhouse gas contributions, and enables prioritisation of the various neighbourhood interventions necessary to achieve a range of emission reductions. The data has been gathered and calculated from various regional authorities, and is considered to be the most accurate information publicly available at the time of the project. For all data concerning average energy use, conditions for the Lower Mainland and not data specific to the Fleetwood study area have been used, as these were the most complete data sets available for the project.

Physical Characteristics of the Neighbourhood

The physical characteristics and layout of a neighbourhood have a significant impact on the overall energy consumption and emissions generation of a community. Referenced in decades of research regarding both residential and transportation energy use, a neighbourhood's pattern, including street layout, housing density and diversity, and land use mix, has the capacity to affect a range of energy and emissions related issues, from solar gain on buildings to the need to drive private vehicles. Physical characteristics of the Fleetwood study area have been assessed through site visits, photography, measurements from GIS data accessed through the City of Surrey, and local census records.

Residential Energy Use

For residential energy use, including basic electrical loading, space heating and hot water, data on average use in single family homes in the Lower Mainland was provided by BCHydro and Terasen Gas based on 2004 records. These figures have been used to estimate an average energy use per capita, which is then translated into emissions per capita, calculated through the use of recent emission factors for electricity and natural gas in the Lower Mainland, as supplied by the *2000 Emission Inventory for the Canadian Portion of the Lower Fraser Valley Airshed.*

Transportation Energy Use

Transportation energy use is generally derived in one of two ways in community energy analyses, either by the number of vehicle kilometers traveled[27], or by the amount of fuel consumed[28]. This project measures the number of automobile vehicle kilometers traveled per capita per year and uses emission factors from the *2000 Emission Inventory for the Canadian Portion of the Lower Fraser Valley Airshed* for light duty vehicles, light duty trucks, and motorcycles to estimate annual transportation emissions for the study area.

Vehicle kilometers were chosen over fuel usage as the measure of transportation energy for the study area due to the difficulty of obtaining accurate fuel usage estimations, and the availability of CMHC software which enables neighbourhoods to estimate daily vehicle kilometers traveled per household. The software, *Greenhouse Gas Emissions from Urban Travel: Tool for Evaluating Neighbourhood Sustainability*, takes into account twenty-one factors including length and layout of streets, housing density, number of local jobs, and amount of public transit available in order to establish travel estimates for a given area[29].

1.3.3 Analysis

Following the literature and project reviews and assessment of study area, the thesis synthesises the collected information in three ways which support the development of scenarios representing the range of possibilities for the study area:

1. *Major areas of action for the study area:* Areas of action are defined as the general types of actions that can be taken within the study area to reduce greenhouse gas emissions. For the thesis, these include reducing housing related emissions, reducing

[27] Teed and Condon; Greater Vancouver Regional District *2000 Emission Inventory* p. C-11

[28] Earth Festival Society; The Sheltair Group, *Taking Stock*; Greater Vancouver Regional District *2000 Emission Inventory* p. C-10

[29] IBI Group, *Greenhouse Gas Emissions from Urban Travel*

transportation related emissions, and generating "clean" energy on site. The carbon emissions derived for the study area serve to define the areas of action and prioritise them for the thesis.

2. *Solution spaces for emission reduction goals:* Solution spaces map the range of possible solutions which will achieve a given goal. For the thesis, solution spaces define the combinations of emission reductions and energy generation which will achieve 25, 50, 75 and 100 percent emission reductions. Based on the defined areas of action for the site and derived per capita carbon emissions, solution spaces indicate the intensity of mitigation required to achieve community emission reduction goals and aid in selecting neighbourhood specific emission reduction targets.
3. *Scenario mapping:* Scenario mapping serves to define a range of possible contexts for the study area in which design interventions might occur. Because future community circumstances cannot be known, investigating multiple futures becomes an important vehicle for the understanding of how similar strategies might be affected under different conditions. For the thesis, the scenario map explores whether design interventions will be able to challenge the present suburban form, and whether block or community scale design strategies will be implemented.

The analysis concludes with the development of four future scenarios for the study area, ranging from a "base case" retrofit, to a community whose home electricity demands are entirely met by renewable energy. The scenarios are each situated within a different future community context, and evaluated for their relative ability to reduce emissions, suggesting that the context in which design interventions take place will have a significant effect on the success of solutions in terms of emission reductions. The four scenarios consider the study area in isolation, outside the influences of regional or city assistance or limitations, in order to determine the neighbourhood's own capacity for change. A final scenario, presented in Chapter 6, considers how a more incremental, collaborative and regional approach to neighbourhood retrofits might provide the ability for the study area to achieve carbon neutrality.

1.4 Value of Thesis

The suburban residential development is a prolific and resource intensive design typology contributing over 6 percent of greenhouse gas emissions nationally. While national policies such as the Kyoto Protocol indicate a desire to reduce emissions, the rapid expansion of suburban infrastructure serves to bring Canada further from reduction goals. By developing a process of analysis and decision making through which suburban retrofit strategies can be examined, the thesis calls attention to the potentials of existing suburban communities to become more sustainable systems, and identifies their value as sites of innovation in place of further greenfield development. Similarities among residential developments throughout North America enable much of the thesis process to be replicated for other developments and for other sustainability issues and indicators.

CHAPTER 2:

THE NORTH AMERICAN SUBURB

2.1 History

The origin and history of the suburbs, from ancient times to the present, have often been a topic of research and writing, celebration and criticism. A review of this literature presents an image of suburbia that is familiar to many, often referred to as the "American Dream:" upper and middle class families in detached single family houses, set within in green lawns, along curving roads. In reality, this dream has today been surpassed, with contemporary suburbs now encompassing not just homes, but growing business and entertainment districts and a proliferation of goods and services; however, much of the traditional suburban imagery and related values persist. The continued inertia of the "American Dream," a preference for the house and lawn and a demand for autonomy and private property challenges efforts to change the suburban pattern. Robert Stern suggests that the suburb is both a planning type and a state of mind[30], and an understanding of both begins with a review of suburbia's history. Due to the existing wealth of information on the history of suburbia, the thesis provides only a brief synopsis as context for the chapter.

2.1.1 The Early Suburbs

Kenneth Jackson presents that the contemporary model of suburbanization, "a process involving the systematic growth of fringe areas at a pace more rapid than that of city cores, [and] a lifestyle involving daily commute," began as early as 1815 in the United States and Great Britain[31]. The written history of the North American suburban planning type often begins with the development of such early neighbourhoods as Llewellyn Park, New Jersey in 1853 and Lake Forest, Chicago in 1856[32]. These types of planned communities, often credited as being some of the "best and most comprehensively designed[33]" neighbourhoods even today, were the privilege of the upper classes who had the means to commute into the city.

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[30] Stern p. 5.10-2

[31] Jackson p. 13

[32] Martinson p. 18

[33] Stern p. 5.10-2

Residential suburban developments expanded as a development type after 1850[34], with a revolution in transportation technology that made commuting from home to the city an option for increasing numbers of people. Although automobiles were still a novelty for nearly two decades into the next century[35], mass transportation, beginning with omnibuses, horse-drawn streetcars, and eventually the electric streetcar, made it possible to live as far as twelve miles (19 kilometers) from the central business district[36]. Studies by Sam Warner show that streetcar lines in Boston extended the radius of the city from two miles (3 kilometers) in 1850 to over ten miles (16 kilometers) by 1900[37]. By 1904, the electric street car was claimed to be "the most potent factor in modern life[38]," opening a vast area to the development of new, middle class suburbs. Maintaining a residence within walking distance of one's work was no longer a requirement of daily life, and cheap land made accessible by streetcar lines offered the opportunity for larger homes and new developments segregated by race, class and economic status, setting early precedents for the zoning by-laws and neighbourhood covenants that would give rise to widespread suburban homogeneity in coming decades.

2.1.2 Pre-war Suburbs

Although the electric streetcar generally initiated the middle class move to suburbia, it is the automobile which established the suburb as the predominant North American residential development pattern. The 1920s marked a suburban housing boom that continued through World War II, and which was directly related to the widespread automobile purchases attributed to the same decade[39]. According to Kenneth Jackson, between 1920 and 1930, automobile registrations rose by 150 percent, in the same period when the suburban areas of nearly all large North American cities grew twice as fast as city cores[40]. Land between and beyond transit lines was now accessible by car for further

[34] Palen p. 27

[35] Jackson p. 114

[36] Palen p. 37

[37] Sam Warner cited in Palen p. 35; and Jackson p. 118

[38] Frank Sprague quoted in Jackson p. 115

[39] Palen p. 43

[40] Jackson p. 175

middle class development[41]; however, this lack of proximity to public transportation, paired with improving roads and abundant, cheap fuel, meant that the car was not only popular, but increasingly considered a necessity for daily activities. By 1925, studies out of Columbia University were reporting that the automobile "played either a contributing or dominant role" in six different components of daily life, including making a living and participating recreational activities[42]. By 1941, over 2,100 communities had been developed without any access to public transportation, and well over half of daily commuters in large cities were driving to work[43].

The emerging predominance of the auto-centric suburb, containing over 17 million residents by 1930[44], also had significant impacts on the form and pattern of housing throughout North America. The independence provided by the car meant that automobile suburbs could be built at much lower densities than those dependent on streetcars. Owning automobiles also lent importance to automobile storage, which began to be included with homes by the mid-1920s. By 1937, many homes were built with garages, and Architectural Record wrote that "the garage has become a very essential part of the residence[45]." Concurrent developments in mass production techniques led to the emergence of the standardised bungalow as a new housing form for the middle class[46], while new development and urban planning tools such as zoning kept commercial uses and undesirable dwelling types out of new and existing communities[47].

2.1.3 Post-war Suburbs

Despite increasing availability of suburban homes for the middle class, high costs and restrictive mortgage policies prevented many from owning new, suburban homes through the end of the Second World War[48]. At that point, over 14 million returning military

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[41] Palen p. 43

[42] Robert and Helen Lynd cited in Jackson p. 172

[43] Palen p. 44

[44] Palen p. 50

[45] *Architectural Record* quoted in Jackson p. 252

[46] Palen p. 52

[47] Palen p. 44; Chiras and Wann p. 5

[48] Palen p. 56

personnel and their families were in search of housing[49], and so, spurred by massive government incentives and loan programs from organizations such as the Federal Housing Administration in the U.S. and the Canada Mortgage and Housing Corporation in Canada, and later by the creation of the interstate highway system, the development of "new tract suburbs of standardised single family homes[50]" reached record highs. In the four years between 1944 and 1948, new housing starts in the United States alone jumped from 144,000 to 1,183,000[51] and by 1950, over 55 percent of households owned their own home[52]. It was during this time, in 1946, that one of the most studied suburban tract developments, Levittown, began construction with over 17,500 new homes on 4,000 acres of land outside New York City[53]. With new, mass-produced housing readily available, purchasing a tract home in the suburbs was often more affordable than renting in the city. As a result, suburban populations in North America increased 144 percent in the decade from 1950 to 1960[54].

The explosive growth of suburbia after World War II meant that issues of low initial cost and efficient mass production became the primary concerns for the housing construction industry. Although standardised, mass produced buildings were not new, never before had they been enacted on such a grand scale, leading to the common criticism that postwar subdivisions were little more than rows of identical boxes, with identical residents. Critics observe that at the height of suburbanisation, residential building was abandoned by architects, landscape architects, and planners and left to the speculative builder[55]. While the early twentieth century saw celebrated designers such as Frederick Law Olmstead and Frank Lloyd Wright involved in the design of suburbs, historians today indicate that residential suburban landscapes may have "fallen well short of their sublime potential[56]."

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[49] Chiras and Wann p. 3
[50] Palen p. 58
[51] Jackson p. 233
[52] Palen p. 57
[53] Palen p. 65
[54] Palen p. 58
[55] Martinson p. xxvi; Stern p. 5.10-6
[56] Martinson p. 28

2.1.4 Contemporary Suburban Development

After more than 150 years of evolution and growth, the suburbs have dwarfed major North American cities in land area and population. Since 1950, over 40 million suburban homes have been built in North America, in addition to millions of kilometers of road, billions of square meters of commercial space and more than 30 million acres (12 million hectares) of suburban lawn[57]. By 1970, 37 percent of Americans lived in the suburbs, and by 1990, 48 percent[58].

The comforts and amenities for the single family house have increased significantly since World War II, including larger spaces, more appliances, and increasingly sophisticated electronic equipment including televisions and personal computers. Automobile ownership has continued to expand, by as much as 200 percent between 1950 and 1980 compared to a 50 percent increase in population,[59] steadily raising the demand for roads, parking and fossil fuels while generating substantial amounts of carbon dioxide and other air pollutants. An ongoing accumulation of wealth and material goods has resulted both in a near doubling of house size and garage size, which even by 1960 had the capacity to house two cars in over 400 square feet (37 square meters)[60]. These changes have greatly affected land and energy consumption, creating greater demands for resources and generating record levels of greenhouse gas emissions.

Today, suburbs are much more than peripheral residential communities; rather, they have become places of commerce and entertainment, with many maturing into "regional destinations" in their own right[61]. Those residential neighbourhoods that are now being engulfed by increasing exurban development deserve particular attention in suburban retrofit research, as they will likely continue to be important and valuable residential locations in the future.

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[57] Chiras and Wann p. 6

[58] Palen p. 58

[59] Jackson p. 246

[60] Jackson p. 252

[61] Dunham-Jones p. 10

2.1.5 Decision Makers in Contemporary Suburban Development

Understanding the formation of contemporary residential suburbs also involves recognising the variety of players which control, influence, or otherwise shape suburban development. While the thesis will not look explicitly at these players in the remainder of the thesis, they are acknowledged here as important determinants in the possibilities and success of suburban retrofit projects, which can and should be a major part of future research[62].

Author Paul Lewis organises the "key actors" in suburban development into five general categories[63]:

1. *The City:* The municipal government and associated city officials control development through planning and engineering departments which mandate local building codes and zoning by-laws, control infrastructure and service delivery, determine expenditure patterns, manage local transportation decisions, and approve development projects. Lewis suggests that elected officials tend to try to "maximise their approval levels[64]" among groups who can influence their re-election, an effort that often affects land use decisions.
2. *Special Districts:* Specific government entities including water and sewer districts, public transit authorities and housing programs also affect suburban development and land use through the level and quality of services provided by these groups. These services are influenced by the city and by the districts' own interests in maximising revenues and local control[65].
3. *Developers:* Developers and builders directly affect suburban form through the projects they build, and most often choose those forms expected to maximise profits[66]. However, these actors are subject to public sector approval, as well as local by-laws and

[62] A study of the effects of multiple decision makers on urban form and greenhouse gas emissions has been undertaken by the University of Utah Urban Planning Program. A 2004 proposal for this research can be found in Emmi p.1-21.

[63] Lewis p. 25

[64] Lewis p. 26

[65] Lewis p. 25

[66] Lewis p. 25

building codes. Developers and builders not only affect land use and building type, as government organisations do, but also building related energy performance and emissions generation through design choices such as material selection, street layout, and building orientation.

4. *Private Groups:* Many private sector entities and organisations have local interest in suburban development. Groups such as local businesses, real estate brokers, construction trade unions and activist citizens may oppose or support development based on its perceived affects on congestion, quality of life, competition for business, safety, etc. As members of the voting public, these groups can sometimes affect government decisions on land use and project approvals.
5. *Residents:* Local residents influence the suburban form both through consumer choice and through individual actions within their own property. Residents tend to seek an "optimal balance" between a number of factors including increased property values and local services, the protection or enhancement of the neighbourhood and local lifestyles, and an improved urban region with increased economic and social opportunity[67]. Consumer choices often indicate to developers which suburban patterns and forms to build in the future, while individual actions such as renovations or landscaping can greatly affect the form and energy performance of individual homes.

These five categories of decision makers directly reflect the series of relationships determining suburban form within the selected thesis study area. However, in addition to these five "key actors," the thesis recognises the importance of larger, regional influences, such as the local example of the Greater Vancouver Regional District's *Liveable Region Strategic Plan*[68]. In order to successfully generate more sustainable communities, influence, planning, and consensus at the regional level, particularly regarding sprawl, population growth, energy and resource management and transportation, must be considerably expanded.

[67] Lewis p. 26

[68] Greater Vancouver Regional District, *Livable Region Strategic Plan*

2.2 Values

The historical development of the suburban form is directly related to a well-established set of values that carry forward into contemporary residential development despite changes in economic, social, political, and cultural contexts. Suburbia is not only a physical place, but also an ideology, representing upward mobility and independence, safety and consumption. In the most general terms, suburban values can be divided into two major categories: those values centered on issues of ownership, and those centered on a desire for stability. In reality, however, suburbs can be incredibly diverse places based on age, location, and background of residents; therefore, the values discussed here are only broad characterisations, which the thesis recognises will not be representative of every suburban residential development.

2.2.1 Ownership

In *The City in History*, Lewis Mumford argues that as early as the eighteenth century, having the wealth to own property outside the city was a "mark of success[69]." Not only has land ownership been an indicator of and basis for power throughout the centuries[70], but nature and open space have been historically touted as a source of moral living, family life, and serenity, according to the influences of both nineteenth century romanticism and Jeffersonian ideals, which often viewed the city as a place of unrest and impropriety[71]. By 1870, the expectations of suburban living demanded a large, private yard[72], while new developments mimicked natural settings with winding tree-lined roads and plentiful green space[73].

Attached to land ownership, the dream of home ownership has been the quintessential goal for generations of North Americans. As President Herbert Hoover stated in 1932, "to own one's own home is a physical expression of individualism, of enterprise, of independence, and of freedom of spirit[74]." According to urban sociologist J. John Palen,

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[69] Mumford p. 482

[70] Jackson p. 52

[71] Palen p. 25

[72] Jackson p. 58

[73] Palen p. 69

[74] Herbert Hoover quoted in Palen p. 51

survey data consistently shows "that Americans have a strong preference for single family homes on their own lots[75]," a penchant carried by several nations, including Canada and Australia[76]. Investigations into the attachment of North Americans to single family homes, such as Herbert Gans' study of Levittown residents, suggest that a significant factor in suburban migration is value, or the ability to get more space for one's money[77]. Earlier studies found that desires such as security, cleaner neighbourhoods and better schools also encouraged moves away from city cores[78].

The ownership of private, detached, single family suburban homes both supports and promotes the ideals of exclusivity, privacy, independence, and individuality commonly associated with the contemporary suburban lifestyle. Economically and often socially homogenous developments maintain exclusivity in part through the similarity of neighbourhood homes and the consequent consistency of local purchase prices, while increasing roles of technology within the home since the advent of television and air conditioning have created lives centered inside the house, rather than out in the community. Personal space within and surrounding the home holds the opportunity for self-expression, while the physical separation of yards and fences means that residents have the option of living almost entirely autonomous lives. As Lewis Mumford suggests, the original purpose of the suburbs was just this: "to be your own unique self; to build your unique house, mid a unique landscape: to live... a self-centered life... in short, to withdraw like a monk and live like a prince[79]. "Meanwhile, property ownership, and the backyard in particular, ensures that suburban homes can indeed become "small, private islands[80]" where functions of daily living as well as socialisation and recreation can be met within home boundaries. As social life becomes privatised, writes Kenneth Jackson, individuals and families tend to experience "a reduced feeling of concern and responsibility... for their neighbours and for the city[81]."

[75] Palen p. 61
[76] Jackson p. 7
[77] Herbert Gans cited in Martinson p. 54
[78] Mumford p. 487
[79] Mumford p. 486
[80] Jackson p. 280
[81] Jackson p. 273

2.2.2 Stability

Throughout the centuries, cities have been understood as dynamic and changing entities, growing and maturing through time in pace with culture, demographics, the environment and a variety of other major trends. Urban communities may decline and be rebuilt, migrate to new areas of the city, or become gentrified. The suburbs, on the other hand, many built in the past fifty years, are not overlaid with the same expectations; rather these areas are often seen as "locked in time[82]," as stable communities that can be counted on to perpetuate their image of success and family values.

Research on suburban residential neighbourhoods recognizes that residents tend to hold specific values regarding the stability of their environment. Besides assumptions of consistency, decades of surveys report that suburbanites overall are happier with their communities than city residents, although this result is likely due in part to a degree of wealth and choice associated with middle and upper class suburban living[83]. The fact that suburban residents "clearly and consistently indicate a preference for suburban living[84]," suggests that as long as the qualities of suburbia are maintained, little interest will be placed in change. Other researchers report that suburban stability is valued for its protection of particular lifestyles. Dolores Hayden suggests that change is avoided because "suburban houses and yards are infused with the pieties of... family values and also contain the purchases of a society inundated with advertising and consumer culture[85]." Attitudes reflecting a preference for the country and small towns[86] and a desire for the freedom and independence associated with suburban living[87] further solidify the value of a stable suburban pattern in North American culture.

2.2.3 Ideology and Reality

In reality, the values of ownership and stability associated with suburban neighbourhoods have endured far longer than the original rural-suburban forms which shaped them.

[82] Palen p. 103
[83] Palen p. 89
[84] Palen p. 89
[85] Hayden p. 17
[86] Palen p. 93
[87] Stern p. 5.10-4

Increasing land prices mean that smaller lots are hosting larger homes to the detriment of desired open space, while increased traffic and congestion brought about by automobile dependency limits mobility and convenience. In addition, while suburbanites have grown increasingly more prosperous, growing expenses mean there is now more anxiety and less peace of mind about maintaining the suburban standard of living[88]. Lewis Mumford criticises that at the moment the suburban pattern became universal, many of the ideals associated with historic suburban living were weakened, including freedom, privacy and solitude. He writes, "all that is left of the original impulse towards autonomy and initiative is the driving of the private motor car, which is itself a compulsory and inescapable condition of suburban existence[89]."

2.3 The Challenge for Suburban Retrofits

The history and values of suburban development play a significant role in creating the specific set of conditions that shape opportunities for retrofits within a suburban residential community. Cited by numerous designers and academics, the most significant hurdles for suburban retrofit projects, and residential suburban retrofit projects in particular, are multiple, private property owners and a culture adverse to change or to accepting risk[90].

It is no coincidence that these challenges so closely align to the suburban ideology discussed in Section 2.2. The value of ownership tends to limit cooperation among neighbours. Private property lines and a desire for autonomy mean that design strategies which extend beyond the scale of a single parcel are often resisted, while a detachment from community responsibility often precludes individual investment of time and capital in projects that benefit the entire community more than an individual property. The value of stability attempts to cling to symbolic forms and patterns that represent a suburban neighbourhood. For many who have enjoyed comforts and benefits provided by suburbia, change often seems unnecessary and undesirable, and reluctance is

[88] Palen p. 100
[89] Mumford p. 493
[90] Chiras and Wann p. 1; Gamble and Leblanc p. 54; Congress for the New Urbanism p. 14; Langdon p. 223

compounded by the fact that significant time, money, and emotion has been invested in decisions on home and lifestyle.

The challenge of suburban retrofits, then, is to neither discount the existing suburban values as illegitimate or wrong from the perspective of sustainable development, nor to accept them as barriers to design strategies. Rather, suburban retrofit projects must seek to understand suburban ideologies and values and learn to work within them as well as challenge them in order to maximise the potential of a given suburban site. A detailed consideration of specific design strategies and their opportunities to both challenge existing suburban forms and extend beyond the boundaries of privately owned property is provided in Chapter 5.

CHAPTER 3:

CURRENT SUSTAINABLE STRATEGIES AND SUBURBAN SITE RETROFITS

Strategies for the creation of more sustainable neighbourhoods have been well documented in a variety of design projects and related research. Although many projects do not deal explicitly with emissions mitigation, a great number do address issues of energy consumption and, by implication, greenhouse gas emissions. The strategies investigated in this chapter incur a relatively high level of consensus regarding their value in sustainable planning and design processes; however, their actual quantitative benefits in terms of energy or emission reductions are often inconsistent between reports. Despite discrepancies, examining the general set of tools for neighbourhood sustainability that has evolved over recent years is important to understanding the possibilities for more sustainable suburbs and suburban retrofits.

3.1 Sustainable Project Typologies

Projects that have dealt with enhancing the sustainability of neighbourhoods and communities are useful illustrations of the practical application of design strategies which improve community energy and emission performance. These projects tend to encompass a relatively consistent set of typologies including, but not limited to, traditional neighbourhoods, mixed use, urban scale mega-projects, and less frequently carbon-neutral or zero-energy developments. A review of the energy and emissions related strategies applied in these types of projects provides a basis for assembling a generalised set of strategic principles for mitigating emissions in the selected study area.

A majority of the projects described in this section have been selected for their location in the Lower Mainland in order to best reflect strategies appropriate to the region. However, further literature review does indicate that many strategies are universally applicable, as indicated by the utilisation of similar strategies for projects located within a wide variety of climates and contexts[91].

[91] Additional projects and documents on design strategies worldwide are included in the References section of the thesis.

3.1.1 Case Study, Traditional Neighbourhood: Greenhouse Neighbourhood Project

Victoria, Australia

Early in the 1990s, the state government of Victoria, Australia, committed to aiming for a 20 percent reduction in 1988 levels of carbon dioxide emissions by 2005, matching a pledge made by the City of Toronto in 1990. During this time, it was determined that reaching this goal necessitated changes in the way that residential neighbourhoods, particularly those on the edges of the metropolitan area, were developed. Consequently, the Greenhouse Neighbourhood Project was established "to explore and quantify the relationships between greenhouse gas emissions, energy requirements, and the form and design of new neighbourhoods on the urban fringe of Melbourne[92]."

The project, initiated in 1993, examined three alternative neighbourhood designs for their performance on a hypothetical site. The typologies studied include a conventional suburban neighbourhood, a "VicCode" neighbourhood representing what was considered "best practice" in Victoria at the time of the study, and a traditional neighbourhood, characterised by mixed uses, a grid-based street system and higher residential densities.

Each approach was assessed by its structure and street layout, public transportation provision, residential density, land use mix, solar access, and dwelling siting and design. The study found that substantial savings in energy and greenhouse gas emissions could be achieved through changes in urban form[93]. It concluded that the traditional neighbourhood form resulted in the best overall residential energy and transportation performance. Calculated performance results for a representative traditional neighbourhood included a 0.8 tonne reduction in annual greenhouse gas emissions, a 26 percent reduction in energy requirements, and a 55 percent savings in infrastructure costs over the conventional development model[94]. In addition, the traditional neighbourhood provided a 57 percent decrease in greenhouse gas emissions from transportation[95].

92 Loder and Bayly p. 1.1

93 Loder and Bayly p. 1.2

94 Loder and Bayly p. 5.22

95 Loder and Bayly p. 6.46

While the report makes conclusions based on Australian climates, culture, and contexts, the urban forms analysed in the Greenhouse Neighbourhood Project study are comparable to those common in North America, and therefore offer similar insights into the benefits of traditional neighbourhood characteristics within the Lower Mainland. A summary of design strategies considered in this report are summarised in Table 3.1.

Table 3.1 Greenhouse Neighbourhood Project, Design Strategies

Characteristic [a]
Greater land use mix including schools, retail, service, commercial, and industry
Employment opportunities for 50 percent of local workforce
Inclusion of a town centre
Average residential density of 25 units per hectare (10 units per acre)
Dwelling mix of detached homes, semi-detached, rowhousing, and three storey apartments
Good solar orientation for 70 percent of lots
Interconnected, gridded street pattern
Rear lanes for vehicle access
Minimised cul-de-sacs
Provision for public transportation, including bus and light rail

[a] Characteristics based on the description of a Traditional Neighbourhood, Loder and Bayly p. 4.8

3.1.2 Case Study, Traditional Neighbourhood: East Clayton Neighbourhood
Surrey, British Columbia

Initiated with a design charrette in 1995, the East Clayton Neighbourhood Project was developed by the City of Surrey and a variety of supporting organizations, including the Canada Mortgage and Housing Corporation, Environment Canada, the Greater Vancouver Regional District, and the University of British Columbia's James Taylor Chair in Landscape and Liveable Environments as a demonstration project incorporating a variety of green infrastructure strategies. The project illustrates seven principles of sustainable development as defined by project documents[96]:

- Increased density through the design of compact, walkable neighbourhoods
- A mix of housing types in the same neighbourhood and on the same street
- Dwellings designed to present a friendly face to the street, promoting social interaction
- Car storage and services handled in rear lanes
- An interconnected street network and public transportation provisions
- Narrow, tree-shaded streets
- Preservation of the natural environment, including natural drainage systems

The principles are applied on a 250 hectare site containing 142 lots and two multi-family residential developments. Illustrating that "green infrastructure creates more walkable neighbourhoods and is cheaper to build and maintain[97]," the project incorporates natural stormwater management, interconnected streets, pedestrian amenities, mixed land uses and affordable housing. A commercial "main street" and additional small commercial districts, along with several local bus stops ensures that many daily needs for shopping, services, and transportation will be met within a five minute walk of residences[98].

[96] James Taylor Chair in Landscape and Liveable Environments p. 9-11
[97] James Taylor Chair in Landscape and Liveable Environments p. 2
[98] James Taylor Chair in Landscape and Liveable Environments p. 19

Research associated with the project indicates that increased residential density, substantial land use mix, local employment opportunities, gridded street patterns and access to frequent public transit "can greatly reduce vehicle miles traveled[99]."
It is anticipated that, at build-out, vehicle miles traveled per capita and consequent greenhouse gas emissions will be reduced by 40 percent below conventional suburban patterns, while the number of vehicles per household will decrease by 0.6 cars compared to the average suburban home[100].

The East Clayton neighbourhood provides local insight into the benefits of traditional neighbourhood forms and characteristics, especially in relation to travel by private automobile and community walkability. A list of energy and transportation related design strategies utilised in the East Clayton project are summarised in Table 3.2.

Table 3.2 East Clayton Neighbourhood Design Strategies

Strategies [a, b]
Transit services located within a 400 meter walking distance of all residents
Commercial services located within a 400 meter walking distance of all residents
Availability of one job per 2.8 residents
Passive solar orientation for 100 percent of dwelling units
Average net residential densities of 27 units per hectare (11 units per acre)
Opportunities to incorporate secondary suites
Street-oriented buildings
Street network based on grid and modified grid patterns , including rear lanes
Bicycle and pedestrian paths and amenities, providing multiple alternatives for moving through community
Main street commercial district and high degree of land use mix
Shade trees planted to cover 40 percent of each lot at maturity

[a] Strategies summarised from James Taylor Chair in Landscape and Liveable Environments 2003
[b] Strategies listed above include only those affecting energy use and emissions. For full description of strategies, see The Headwaters Project document.

[99] James Taylor Chair in Landscape and Liveable Environments p. 18
[100] James Taylor Chair in Landscape and Liveable Environments p. 19

3.1.3 Case Study, Mega-Project: South East False Creek Redevelopment

Vancouver, British Columbia

Comprised of 80 acres (32 hectares) of industrial and commercial land along False Creek, the South East False Creek Redevelopment Plan is being developed as a "model sustainable community built on the last remaining tract of undeveloped waterfront land near downtown Vancouver[101]." As a part of this development, the site will also host the Olympic Village for the 2010 Olympic and Paralympic Games, beginning construction in early 2007.

The project's Official Development Plan (ODP) calls for an energy-efficient, mixed-use, family focused community with a high level of access to goods and services and a mix of residences ranging from market rate to social housing units. Designed to house approximately 15,000 people[102], the plan emphasizes walkability and public transit accessibility through connections to the existing street grid, expanded public transit service including street cars, and traffic calming pedestrian amenities. The Green Building Strategy adopted by South East False Creek requires that many of the buildings reach LEED Silver and Gold standards, while striving for Platinum[103]. In addition, the ODP calls for the community to be "greenhouse gas neutral[104]," although the plan does not specify how or when this would occur.

Various studies of the energy and transportation options conducted for the project in 2002 suggest that proposed design strategies, if implemented, would result in buildings that potentially use 50 percent less energy than conventional construction[105]. These reductions would be achieved through appropriate building orientation and solar control combined with landscaping strategies, natural ventilation, thermal massing, and building commissioning for mechanical systems. In addition, the harnessing of available on-site energy including ground source heat pumps and solar energy systems has been

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[101] City of Vancouver, "Creating a Sustainable Community"
[102] City of Vancouver, "Creating a Sustainable Community"
[103] City of Vancouver, "Creating a Sustainable Community"
[104] City of Vancouver, South East False Creek ODP p. 11
[105] Compass Resource Management, *Southeast False Creek* p. 6

considered. At the same time, automobile usage could be reduced by 23 percent with a combination of short term and long term trip reduction strategies[106] such as a new streetcar system, additional pedestrian and cycling paths, community transit passes and car sharing programs. In all, the expected mode share for automobile use in and out of the South East False Creek area is projected to be only 49 percent[107].

The South East False Creek redevelopment plan illustrates how more sustainable communities can connect into existing urban systems, providing greater accessibility and walkability for residents. Green building strategies and attention to building orientation further increase the overall energy performance of the project. A summary of design strategies planned for South East False Creek are summarised in Table 3.3.

Table 3.3 South East False Creek Design Strategies

Strategies [a, b]
Continuation of existing gridded street pattern
Diverse mix of land uses including residential, commercial, office, institutional, and light manufacturing
Availability of a variety of job opportunities within the community
High efficiency buildings and construction practices
Dense and diverse housing
Emphasis on building orientation for solar access and control
District energy and heating as well as ground and water source heat pumps considered
Development orientation towards walking, cycling, and transit, with adequate amenities
Support for transportation alternatives such as telecommuting and car cooperatives
Connection to regional transit network
Addition of local street car system

[a] Strategies summarised from City of Vancouver, South East False Creek ODP
[b] Strategies listed above include only those affecting energy use and emissions. For full description of strategies, see City of Vancouver, South East False Creek ODP, Compass Resource Management, and IBI Group

[106] IBI Group p. ES-4
[107] IBI Group p. ES-2

3.1.4 Case Study, Mega-Project: UniverCity Highlands, East Neighbourhood

Simon Fraser University, Burnaby, British Columbia

In 1995, Simon Fraser University and the City of Burnaby began planning for a new residential community within the Ring Road circling the university in exchange for 773 acres of mountain parkland to be preserved outside of the Ring Road. The university's objectives for the new development are to establish a "complete community that complements existing and future University development" and to create "sources of revenue to support University purposes[108]." When completed, the new community will provide 4,500 new residential units for both university and non-university affiliated families. The first phase of the project, currently under development in the East Neighbourhood, covers 61 acres (25 hectares) and will contain nearly 1,800 market and rental units[109] as well as a mix of retail and service establishments.

A process of intensive public consultation, including a design charrette, student involvement, and numerous public presentations has led to the conception of the UniverCity project as a "complete community, based on principles of sustainability[110]." The ten key design principles derived for the project are[111]:

- Plan a complete community with a wide range of land uses
- Create strong links with nature, including topography, water, trees, and views
- Pay careful attention to the mountain climate and design buildings accordingly
- Provide choice through a wide range of housing types and tenures
- Reduce automobile dependency with public transportation and pedestrian and cycling amenities
- Foster community through animated places and public streets
- Ensure new development relates to the SFU campus and its architecture
- Design with nature by protecting trees and incorporating indigenous species

[108] Burnaby Mountain Community Corporation, *Part 1* p. 1
[109] Burnaby Mountain Community Corporation, *Part 1* p. 23
[110] Burnaby Mountain Community Corporation, *Part 4* p. i
[111] Burnaby Mountain Community Corporation, *Part 4* p. 1-2

- Adopt sustainable strategies such as on site storm water management and the construction of green buildings
- Unite urban and natural responses to the site to create a "family of buildings"

Public documents for the UniverCity project do not make specific claims for energy and transportation performance. However, by connecting the new development to convenient public transit and robust pedestrian and cycling networks, and by promoting green buildings on site, the project intends to reduce automobile dependency and energy consumption and to provide residents with more opportunities to "live, work, and play[112]" within the new East Neighbourhood community. Design strategies utilised in the UniverCity Highlands project are summarised in Table 3.4.

Table 3.4 UniverCity Highlands Design Strategies

Strategies [a, b]
Public transportation infrastructure integrated with new development, including bus and shuttle service
Wide range of new land uses including retail, restaurant, office, academic, and childcare facilities
Bicycle and pedestrian routes and amenities throughout community
Retail space provided in central "town centre" location
Solar orientation for buildings and outdoor spaces
Efficient building performance
Consideration of renewable energy sources including geothermal, passive solar, and photovoltaics
Transportation alternatives such as telecommuting technology, cooperative car ownership and vanpooling
Comprehensive tree preservation and management program
Residential densities between 50 and 150 units per hectare (20 to 60 units per acre)
Interconnected street system with narrowed widths and calming measures to reduce speed

[a] Strategies summarised from the Burnaby Mountain Community Corporation, *Part 4*
[b] Strategies listed above include only those affecting energy use and emissions. For full description of strategies, see Burnaby Mountain Community Corporation, *Part 1* and *Part 4*

[112] Burnaby Mountain Community Corporation, *Part 4*, A Vision for the Future

3.1.5 Case Study, Carbon-Neutral Development: Beddington Zero-Energy Development

London, United Kingdom

The Beddington Zero Energy Development, located outside of London, is contained within a 1.7 hectare (3.5 acre) site purchased by the Peabody Trust and the BioRegional Development Group in 1998. Although the partners were not the highest bidders for the land, the proposal for a housing development that would reduce carbon emissions was considered so valuable according to environmental life cycle assessments that emissions mitigation potential was included as a part of the purchase price. As the first attempt at urban carbon neutral development in Britain, the project has won multiple awards including RIBA's Housing Design Award in 2000, and was completed and occupied in 2002[113].

In total, the development which is designed to provide sustainable living while maintaining a "modern, urban, and mobile lifestyle[114]," is comprised of 82 residential units with an additional 2,500 square meters of space for offices, shops, and community facilities. The units are a combination of one and two bedroom apartments and larger townhomes sited above office spaces, whose rentals bring additional income for building maintenance[115]. A sports field and village square provide open space for the community. The project's sustainability goals center on holistic strategies that combine a high quality of life with dense urban living and that support local economies and the environment[116].

Measured performance of the Beddington Zero Energy Development shows that units in the development use 60 percent less overall energy and 90 percent less heating energy than a standard suburban home[117] due to an efficient building envelope, solar orientation, and energy generation from photovoltaics and a combined heat and power facility fueled by biomass. Reductions to automobile use have exceeded expectations at 65 percent less

[113] Lazarus p. 1

[114] *General Information Report 89* p. 3

[115] *General Information Report 89* p. 8

[116] *General Information Report 89* p. 3

[117] *General Information Report 89* p. 12

fossil fuel car mileage than the national average[118]. In addition, the project predicts that within ten years, nearly one-third of transportation energy demand for the community will be met by renewable, on site generation[119]. The BioRegional Development Group estimates that, in total, carbon emissions for the community will be just 4 percent of emissions that would have resulted from a conventional development project[120].

The Beddington Zero Energy project illustrates many of the basic principles for energy efficient building and on site energy generation in a residential setting, and is already implementing small scale transportation initiatives that utilize renewable energy to power community vehicles. While the project is located within the climate and culture of the United Kingdom, general principles such as mixed use development, well insulated building envelopes and community energy systems can be applied to the Lower Mainland. The design strategies utilised in the Beddington project are summarised in Table 3.5.

Table 3.5 Beddington Zero Energy Development Design Strategies

Strategies [a, b]
Compact, mixed use development with residential, office, and live/work spaces
Average residential densities of 50 units per hectare (20 units per acre), and 120 workspaces per hectare
All residential units designed for solar access
High performance building design, with conventional heating system eliminated
Renewable energy including a wood fueled, combined heat and power system and photovoltaics (PV)
Green transport system including electric vehicles powered by PV, and proximity to bus and rail lines
Alternative transportation including telecommuting technology, grocery delivery, and car sharing
Road layout measures to keep vehicles at walking speeds
Prioritised cycling and pedestrian safety
Connections to wider city cycling network

[a] Strategies summarised from *General Information Report 89*

[b] Strategies listed above include only those affecting energy use and emissions. For full description of strategies, see *General Information Report 89* and Lazarus, and BioRegional Development Group

[118] Lazarus p. 3

[119] BioRegional Development Group n. pag.

[120] *General Information Report 89* p. 14

3.1.6 Case Study, Carbon-Neutral Development: Dockside Green

Victoria, British Columbia

Dockside Green, a new development planned for a 15 acre brownfield industrial site on Victoria's working harbour, is intended to be a community "that can create economic opportunities while promoting environmental responsibility and healthy, diverse, and dynamic urban living[121]." Developed by Windmill Development, the project's master plan seeks to foster synergies for green infrastructure at a site scale, rather than at the level of individual buildings. The project is supported by the Vancity credit union, which is providing a $25 million guarantee to the city of Victoria to cover the capital costs of major sustainability commitments[122].

When completed, the project will provide housing for 2,500 residents and cost over 350 million dollars[123]. The 26 buildings including residential, hotel, retail, office and industrial facilities will encompass 1.3 million square feet and are intended to each achieve LEED Platinum ratings[124]. Project developers state that this goal can be achieved through the use of an integrated design process and site-level design strategies. The project developers cite influence from several sustainability concepts and initiatives, including Smart Growth, New Urbanism, LEED, industrial ecology, and "waste as food." The project is scheduled to be built out over the next seven to ten years[125].

Carbon neutrality within the development is limited to the supply of heat and electricity for buildings and does not extend to transportation, although transportation reduction strategies, including a bio-diesel mini-transit system and community vehicles, shared neighbourhood electric vehicles, preferred parking for carpools and increased pedestrian and cycling amenities and included in the proposal. Carbon neutrality for building energy applications will be achieved through energy efficient building design and construction,

[121] Van Belleghem and Khouri n. pag.
[122] Van Belleghem and Khouri n. pag.
[123] Van Belleghem and Khouri n. pag.
[124] Van Belleghem and Khouri n. pag.
[125] Van Belleghem and Khouri n. pag.

as well as through geothermal heat pumps, solar hot water heating, photovoltaics and an on site combined heat and power plant fueled by biomass.

Dockside Green provides insight into the design strategies which may serve to mitigate greenhouse gas emissions within the context of British Columbia. The utilisation of a combined heat and power facility fueled with biomass from wood waste suggests the potential of biomass resources within the region, and the utilization of alternative fuel vehicles and community transportation programs illustrate new opportunities for personal travel. A summary of design strategies for the Dockside Green project are summarised in Table 3.6.

Table 3.6 Dockside Green Design Strategies

Strategies [a,b]
Commitment to high performance, goal of LEED Platinum on most buildings
Renewable energy generated on site for all electrical loads and space heating
Use of wood fueled, combined heat and power system with geothermal and solar installations
Commitment to purchase green power certificates for needs exceeding on site generation capacity
Bio-diesel used on site for shuttle service and car co-op vehicles
Alternative transportation such as electric and bio-diesel co-op cars, grocery delivery, and electric bicycles
Development of shuttle system to downtown and major grocery
Pedestrian and cycling amenities throughout community, and connection to regional cycling trail
Mixed use development including residential, live/work, retail, office, hotel, and light industrial
Tree planting on site in proportion to number of trees used in development

[a] Strategies summarised from Dockside Green

[b] Strategies listed above include only those affecting energy use and emissions. For full description of strategies, see Dockside Green's website, www.docksidegreen.ca

3.2 Common Design Principles

The case studies examined in the previous section share many commonalities in the strategies and forms utilised in the creation of more sustainable communities. Although specific forms and technologies may vary from project to project due to differences in climate, culture, local economy or resource availability, the general principles of these and many other projects are quite similar. For the purpose of energy and emissions reductions, projects tend to have all or many of eleven principles (Table 3.7) which are reviewed below. These principles can be broadly grouped into those that affect housing energy and emissions and those that affect transportation energy and emissions, although several can serve both when used to their greatest advantage. As substantial and well researched information is readily available on each of these topics, only a brief review is provided for the purpose of this thesis.

Table 3.7 General Principles for Energy and Emissions Reductions

Housing	Transportation	**Principles**
Housing		Highly efficient buildings or building retrofits
Housing		Solar orientation
Housing		District energy systems
Housing	Transportation	Renewable on site energy generation
Housing	Transportation	Higher densities
Housing	Transportation	A diverse mix of land uses
Housing	Transportation	Increased on site vegetation
	Transportation	A finer grained street and path system
	Transportation	Pedestrian and cycling amenities
	Transportation	Access to public transit
	Transportation	Alternative transportation options

3.2.1 Highly Efficient Buildings and Building Retrofits

Current research illustrates that utilising a combination of new technology and improved construction methods enables new buildings to achieve energy savings between 30 and

60 percent[126]. Within the single family housing context, programs such as the R-2000 initiative in Canada and Energy Star in the United States report that homes built to their standards will use 30 percent less energy[127] than conventionally built homes. A report by Temple for the U.S. Department of Energy illustrates homes which have achieved "a reduction approaching or exceeding 70 percent compared to a benchmark[128]" in a variety of climates by using advanced technologies such as high performance envelopes, passive solar design, and high efficiency mechanical systems.

Increased energy efficiency can also be achieved through the retrofit of existing buildings. According to the Canadian Energuide for Houses program[129], an average home with an Energuide rating of 68, could achieve an "energy efficient" rating of 80 by reducing energy consumption 37 percent. A "super energy efficient" rating of 91 could be achieved by reducing energy consumption 72 percent[130]. While these benchmarks are challenging, recent programs and research indicate that building retrofits such as increased insulation and high performance windows, upgraded heating and cooling systems, and the installation of high efficiency lighting and appliances, can achieve substantial energy savings in existing homes. While standard home retrofit initiatives tend to strive for and predict improvements of around 25 to 30 percent[131], a project by CMHC suggests that reductions of 40 percent are achievable and financially viable. The study found that the greatest energy savings were achieved through the installation of more efficient heating systems and large appliances, each offering "attractive simple payback periods[132]." Even greater reductions may be seen with the incorporation of advanced technology such as

[126] Loder and Bayly p. 5.22; Compass Resource Management, *Southeast False Creek* p. 6; *General Information Report 89* p. 12

[127] Natural Resources Canada, *The R-2000 Initiative*; Energy Star, *What are Energy Star New Homes?*

[128] Temple p. 7

[129] On May 12, 2006, the Energuide for Houses Retrofit Incentive Program was discontinued.

[130] Information on Energuide rating calculation can be found in Natural Resources Canada, *EnerGuide for Houses* p. 5

[131] Canadian Mortgage and Housing Corporation, *Post-60s Two Storey Homes* p. 2; NAHB Research Center, *PATH Technology Roadmapping* p.1; NAHB Research Center, *Field Evaluation of PATH Technologies* p. 22

[132] Canadian Mortgage and Housing Corporation, *Case Studies*

ground source heat pumps, which alone can reduce the energy consumption of space heating by 40 to 60 percent[133].

3.2.2 Solar Orientation

The concept of orienting buildings to utilise the energy of the sun is a design strategy that has been implemented for millennia, and which has been proven an important component for contemporary energy efficient buildings and communities. In the Greenhouse Neighbourhood Project (see Section 3.1.1), Loder and Bayly indicate that solar orientation and buildings designed to maximise solar access are key factors for energy and greenhouse emissions reductions. In their report, a comparison of a reference dwelling oriented in each of the cardinal directions found that the worst building orientation added 70 percent (1111 kWh) annually to the proportion of the heating and cooling load affected by windows[134]. Energy modeling done for the recent Sun City development in Phoenix, Arizona shows that a home's "winter performance" can be influenced by as much as 15 percent as a result of solar gain[135], while other neighbourhoods such as Village Homes in Davis, California have benefited from similar strategies for decades.

While the Lower Mainland's climate varies significantly from Arizona and California, particularly in the intensity of solar gain during winter months, buildings oriented to take advantage of the sun also have the potential to utilise passive daylighting techniques as well as solar technologies such as photovoltaics which decrease housing energy consumption and related emissions by harnessing the renewable energy available on site. Design guidelines indicate that a community layout which keeps building orientations within 30 degrees of due south will "enable 80 percent of dwellings to have access to unobstructed sunlight[136]."

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133 Compass Resource Management, *Sustainable Energy Technology* p. iii

134 Loder and Bayly p. 5.11

135 Tully p. 5

136 Shaw p. 20

3.2.3 District Energy Systems

A district energy or district heating system "distributes thermal energy from a central source to residential, commercial, and/or industrial consumers for use in space heating, cooling, potable water heating and/or process heating[137]." Distributed through a network of underground insulated pipes, heating energy is typically generated by a centralized boiler, or reclaimed from an electricity generation process, such as a micro-turbine, on site[138]. Due in part to rising prices for fossil fuels, an increasing number of district energy systems are being converted or developed to use alternative fuels such as wood waste, which not only insulates against fuel costs, but further reduces greenhouse gas emissions[139].

Systems throughout Europe already utilize significant amounts of biomass in their own district energy systems. In Sweden, the town of Degerfors converted their fossil fuel based system to biomass fuel sources and achieved a 30 percent reduction in total greenhouse gas emissions over the first year, while the town of Övertorneå now supplies energy for heating and operation of all municipal buildings without consuming any fossil fuels[140]. Over 3,000 district energy systems within North America are used mainly in compact development areas, such as "the central business districts of larger cities, on university or college campuses, and on hospital or research campuses, military bases, and airports[141]," although design guidelines indicate that residential developments with densities over 30 dwellings per hectare (12 dwellings per acre) are suitable for similar energy distribution systems[142]. Municipalities such as Eugene, Oregon, Lansing, Michigan, and Boise, Idaho use similar technologies, some even incorporating geothermal heat as a local energy source. In Canada, provinces including Prince Edward Island and Quebec have biomass-powered district heating systems incorporated with their traditional energy supplies.

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[137] ASHRAE cited in Andrews, *Buried Commitments* p. 3

[138] Shaw p. 26

[139] International District Energy Association n. pag.

[140] James p. 40

[141] International District Energy Association n. pag.

[142] Shaw p. 26

3.2.4 Renewable On Site Energy Generation

The technology necessary to generate significant amounts of renewable energy on site is available and improving constantly. The *Renewables 2005 Global Status Report*, published by the Worldwatch Institute, states that "the fastest growing energy technology in the world is grid-connected solar photovoltaic (PV), which grew in existing capacity by 60 percent *per year* from 2000-2004[143]." Other renewable technologies such as wind power and biofuel technologies have also achieved substantial growth. In addition, renewable energy technologies are becoming cheaper and more efficient, and "under good conditions" are beginning to compete with conventional energy prices[144]. The wide variety of technologies available, including geothermal systems, combined heat and power systems utilising biomass as a fuel source, wind energy, photovoltaics, small scale hydroelectricity, and newer ideas for waste utilization such as pyrolysis, are each appropriate to different settings, in different combinations, and with greater or lesser extents of investment in infrastructure, space, and system design[145]. Public resistance to certain technologies, especially wind power, has been a challenge in implementing renewable energy systems; however, the continued growth of the renewable energy market indicates that such systems are rapidly gaining acceptance.

Small scale renewable energy systems for individual buildings and small developments have proven successful in projects such as Muir Commons, a cohousing project in Davis, California, which provides electricity through a photovoltaic system installed on the roof of the common house and the Sun and Wind cohousing project, which uses the roof surfaces of the common house and fifteen detached homes for community solar water heating[146]. On a larger scale, communities such as the Bo01 Sustainable District in Malmö, Sweden, provide energy to residents through a combination of sources. Malmö utilises photovoltaics, solar collectors, a wind turbine, heat pumps, and biogas generated from household waste[147].

[143] REN21 Renewable Energy Policy Network p. 4
[144] REN21 Renewable Energy Policy Network p. 5
[145] Shaw p. 32
[146] Wann and Chiras p. 140
[147] Shaw p. 33

Once energy is generated on site, it can be used for several different applications. Most often, renewable energy is applied to residential energy loads, with generated electricity powering lights and home appliances. However, greater emissions reductions could be achieved by applying energy to transportation, should appropriate technology become readily available. A long term priority for decreasing fossil fuel consumption and greenhouse gas emissions is the phasing out of internal combustion engines in favour of hybrid technology and electric, fuel cell, and alternative fuel vehicles[148]. Transportation technology analyses presented as a part of Sheltair's Long Term Plan for Greater Vancouver indicate that hydrogen, ethanol or methanol powered fuel cells "may dominate technology, allowing transportation to move to renewable energy use[149]." Recent research indicates that 52.5 kWh of renewable electricity can generate one kilogram of hydrogen fuel[150], enabling a fuel cell vehicle to travel 100 kilometers[151] and eliminating over 25 kilograms of transportation related carbon emissions. Electric vehicles, which can travel 100 kilometers on only 30 kWh (0.5 kWh per mile) according to the California Air Resources Board[152], could have the capacity to serve residents on short, local trips. Small scale efforts towards transportation from renewable energy can be seen in the Beddington Zero Energy Development, where electric vehicle charging stations are provided for personal vehicles[153].

3.2.5 Higher Densities

Increasing housing density within existing suburban areas not only prevents extensive greenfield development, but can impact local greenhouse gas emissions levels through its reduction in transportation and energy use within a community. A recent study by Norman reports that "on a per capita basis, low-density developments comprising single-detached dwellings in Canada used 1.8 times more energy for building operation in 1997

[148] Sheltair, *The Story Behind the Energy Backcast Scenario* p. 4

[149] Sheltair, *The Story Behind the Energy Backcast Scenario* p. 5

[150] Levene p. 2

[151] Fuel efficiency based on the Honda FCX, available in limited markets in 2005-2006. U. S Department of Energy, *Model Year 2006* p. 19

[152] California Air Resources Board p. 2

[153] *General Information Report 89* p. 15

than did high density apartment developments[154]." This result is attributed to greater heating and cooling loads from the increases in exposed wall area for low-density, detached homes. These findings are supported by earlier research by Loder and Bayly, who found that increasing the area of shared walls, floors and ceilings through stacked and attached housing configurations reduced dwelling energy requirements[155]. Increased residential densities also provide opportunities for the implementation of technologies like district heating systems, which are not possible at typical suburban densities[156].

Projects such as Cranberry Commons in Burnaby, British Columbia illustrate the ability of previously developed areas to accept additional density while preserving green space, providing safe play areas for families with children, and maintaining the scale of the surrounding neighbourhood. Following Burnaby's Official Community Plan's and the Hastings Street Area Plan's goals of increasing density in designated areas, the project combines five single family residential lots totalling one-half acre in size and contains 22 residential units including apartments and two and three level townhouses. Smaller scale intensification projects, particularly secondary suite additions, are now being supported by many municipalities such as Santa Cruz, California, as well as the Greater Vancouver Regional District which estimates that up to 69,000 secondary suites existed in Greater Vancouver by 2000, or 25 percent of rental households[157].

Additionally, a higher density of development can serve to "restrain automobile use[158]" through greater levels of congestion and the promotion of walking and cycling, while supporting public transit. Pushkarev and Zupan's studies directly relating residential densities to the type of public transit that can be sustained[159] are now a standard in planning literature[160]. Likewise, Holtsclaw found that "population density and transit service quality affect annual vehicle mileage per household, holding constant

[154] Norman p. 17

[155] Loder and Bayly p. 5.17

[156] Sheltair, *Land Use Foundation Pape* p. 33

[157] Greater Vancouver Regional District; *Review of Municipal Secondary Suite Policies* p. i

[158] Feigon p. 5

[159] Pushkarev and Zupan

[160] Feigon p. 6

demographic factors such as household size and income[161]". Further studies correlate higher densities with reduced automobile ownership[162], "such that residential density offers a basis for predicting ownership with 86 to 99 percent accuracy[163]."

3.2.6 A Diverse Mix of Land Uses

Like density, an increased diversity of land uses within existing suburban neighbourhood conditions affects local greenhouse gas emissions through enhanced opportunities for reduced energy use and transportation. From the perspective of housing energy, a diversity of land uses can provide important opportunities for sharing resources including heat generation and cascading energy quality. These synergies are not often possible in a homogenous development, where buildings generally all have similar energy requirements and waste flows.

Concerning transportation, Ewing states that "fine-grained land use mixes" keep trips more direct and offer some of the best alternatives for reducing vehicle mileage[164]. Studies conducted by Susan Handy find that "appropriately designed, well-integrated local commercial areas will be used by local residents who will walk, rather than drive, for the most part[165]," although she does not claim conclusively that car trips are reduced. Litman, on the other hand, finds that a mix of uses does seem particularly effective at reducing car trips from shopping and recreation[166], while evidence on reductions for commute travel has been less certain.

3.2.7 Increased On Site Vegetation

Within the topic of greenhouse gas emissions, increasing the number of trees and plants on site has the capacity to mitigate significant amounts of carbon dioxide through photosynthesis and through carbon sequestration in plant - and especially tree - biomass. A medium to large size evergreen or deciduous tree in the Pacific Northwest climate will

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161 Holtzclaw cited in Litman, *Land Use Impacts* p. 9

162 Litman, *Land Use Impacts* p. 9 cites several studies on density.

163 Feigon p. 6

164 Ewing p. 47

165 Handy, *Regional Versus Local Accessibility* n. pag.

166 Litman, *Land Use Impacts* p. 7

sequester between 0.0495 and 0.1324 tonnes of carbon dioxide per year[167], an average of 92 kilograms annually. In addition, plants and trees provide innumerable other services to a site, such as erosion protection, stormwater retention and filtration, and overall neighbourhood appeal. Incorporating trees into a site provides home energy savings and further greenhouse gas emission reductions through microclimatic improvements such as shading and wind blocking, which can reduce heating and cooling loads for a building as well as create more pleasant exterior spaces[168].

Incorporating trees into the street right of way is important to the maturing of the neighbourhood into a more diverse, walkable community. Tree-lined streets are a common and desirable component of walkable neighbourhoods, enhancing comfort and aesthetics, and providing a barrier between sidewalks and streets. Great care must be taken in the placement of trees on site however, as placing the wrong tree in the wrong place can also increase building energy consumption by preventing solar gain during the winter or limiting solar access to photovoltaic arrays[169].

Other types of plantings, including woody plants and productive, edible gardens can also contribute to the reduction of greenhouse gas emissions. Bamboo, for example, has been shown in Japanese studies to sequester carbon at a rate of 12 tonnes per hectare annually (1.2 kilograms per square meter)[170]. Vegetable gardens, occurring at the parcel scale or shared between neighbours could further sequester carbon, as well as reduce the number of automobile trips to the local market.

3.2.8 A Finer Grained Street and Path System

Neighbourhood and regional connectivity can be defined as "the degree that roads and paths are connected and allow direct travel between destinations[171]," and is commonly used in relation to many modes of travel including automobiles, bicycles, public transportation and pedestrian traffic. Finer grained street and path systems at the

[167] McPherson and Simpson Appendix A, Pacific Northwest Climate Region

[168] McPherson and Simpson p.2

[169] McPherson and Simpson p. 9

[170] Environmental Bamboo Foundation

[171] Litman, *Land Use Impacts* p. 3

neighbourhood scale can generally be organized into two physical typologies: roads and their right-of ways, and paths, including multi-use green corridors. Low-connectivity locations are often characterized by disconnected, curvilinear streets and cul-de-sacs and minimal pedestrian amenities such as paths and sidewalks, making travel without a car difficult. Conversely, high-connectivity locations typically provide an interconnected street system and well-developed pedestrian and bicycle networks, enabling travelers of most economic and physical means to get safely to their destinations. Because the ultimate goal of transportation is to allow people to reach their destinations[172], the greater choice of route and mode provided by increased connectivity of both roads and pathways is essential for a robust and effective transportation system.

A common indicator of sustainable community planning, connectivity is relevant at a range of scales from regional transportation networks to local paths and pedestrian shortcuts within a single block. The issue of connectivity within a neighbourhood has important implications for greenhouse gas emissions, as this factor has been strongly linked to automobile mileage, numbers of trips, travel time, and cold starts, each of which contribute to air pollution[173]. High levels of street connectivity tend to lead to less congested streets and more opportunities for pedestrian and bicycle movement[174], while path and greenway connectivity can provide areas of habitat, stormwater infiltration, and community engagement.

3.2.9 Pedestrian and Cycling Amenities

Increased path and cycling lane connectivity within neighbourhoods can make important contributions to the reduction of greenhouse gas emissions through providing more options for travel to local destinations. Connectivity reduces walking and cycling distances in and among local neighbourhoods by creating more direct routes, encouraging walking and biking for short trips, which when taken by car, have been shown to be the most polluting on a per mile basis. In his paper, "Land Use Impacts on Transport: How Land Use Factors Affect Travel Behaviour," Todd Litman states that walking

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[172] Litman, *Pedestrian and Bicycle Planning* p. 5

[173] Frank, Stone and Bachman cited in Litman, *Land Use Impacts* p. 11

[174] Girling and Kellett p. 78

and cycling are three times more likely in a well-connected, pedestrian friendly community[175], while in another study, Handy finds that two-thirds of walking trips to local stores replace trips that would have otherwise been taken by car[176]. Cycling and pedestrian activities are further supported by amenities in addition to a path network, including traffic calming measures, bike storage and showers at appropriate destinations, and stronger links between cycling and other forms of transportation such as buses and light rail[177].

3.2.10 Access to Public Transit

Increasing the access to and availability of public transit and other alternative travel options reduces the need to utilise personal automobiles, thereby cutting energy use and emissions. In the case of public transit, reports have shown that improved service and accessibility reduces automobile trips, particularly commuting trips, which increasingly occur in single occupancy vehicles[178]. Of course, successful public transportation relies on several conditions, the most important of which is automobile ownership, a factor closely tied to density[179]. Pushkarev and Zupan note that "only as auto access becomes more difficult do riders by choice begin to switch to transit[180]." Public surveys conducted in the Greater Vancouver Regional District indicate that public transit such as buses and the SkyTrain could increase current ridership rates of 11.5 percent[181] by providing more frequent service, closer transit stops, more express services and more direct routes[182]. Successful transit systems in the region and in cities like Portland and Salt Lake City indicate that public transit is a desirable form of transportation and that many people will utilize services when they are available[183].

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[175] Litman, *Land Use Impacts*

[176] Handy, *Urban Form and Pedestrian Choices*

[177] Pucher p. 19

[178] Litman, *Land Use Impact* p. 6

[179] Pushkarev and Zupan cited in Feigon p. 6

[180] Pushkarev and Zupan cited in Feigon p. 5

[181] Statistics Canada, *2001 Census Data*

[182] Mustel Group Market Research p. 4

[183] Litman, *The Future* p. 9

3.2.11 Alternative Transportation Options

In addition to public transit, a wide range of alternative transportation options have been included in many transportation management plans. One common strategy is carpooling and car sharing. As many private automobiles spend a majority of the day idle, organised systems of sharing can reduce vehicle ownership, combine trips and decrease parking requirements[184]. Alternatively, the development of "paratransit" systems[185] or private shuttle services, can provide more flexible, door to door transit appropriate for moderate ridership[186]. Other strategies such as grocery delivery, flexible work hours, guaranteed rides home, and compressed work weeks have also been utilised and are suited to lower densities[187].

To reduce the need for commuting travel, telecommuting technologies are often incorporated into transportation management plans to enable employees to work from home; however, this option may not reduce overall driving distances, as other trips may increase "from errands no longer done on the way home, or extra availability of the car[188]." In addition, telecommuting is limited to those workers involved in information based business[189], although this sector is growing quickly.

3.2.12 Energy and Emissions Reductions from Housing Principles

The form, density, and arrangement of housing greatly determine the amount of energy consumed by daily household uses and activities[190]. While more demanding building codes and government initiatives such as Energy Star have improved home performance in recent decades, overall energy consumption in the housing sector continues to rise[191]. New home construction methods and technologies, as well as increased interest in home energy retrofit programs are useful, but address energy only at the building scale. Greater

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184 Sheltair *Mobility Systems Foundation Paper* p. 38
185 Litman, *You Can Get There from Here* p. 15
186 Ewing p. 53
187 Litman, *Land Use Impacts* p. 22
188 Handy, *Accessibility vs. Mobility Enhancing Strategies* p. 17
189 Ewing p. 47
190 Shaw p. 4
191 Natural Resources Canada, *Energy Efficiency Trends* p. 13

gains in efficiency will be made through larger planning efforts that affect building orientation, the arrangement of housing units, and the capacity for entire communities to generate their own renewable energy on site.

On site energy production, in combination with sufficient efficiency measures, has already made carbon-neutral and zero energy developments possible, particularly in projects where these goals are in place from the outset. It is important to note, however, that many of the design principles discussed in this chapter are interrelated, and are necessarily utilised in combination to achieve desired emissions reductions. For example, district energy and combined heat and power systems require appropriately high densities to be practical. At the same time, all of these principles are in part dependent on the knowledge and participation of the user for success. Studies on housing energy by the CMHC and others show a high correlation between occupant behaviour and energy performance[192]. A combination of increasing fossil fuel prices and decreasing costs for new energy efficiency and energy generation technologies may have a greater impact on occupant behaviour and on energy consumption and emissions in the future.

3.2.13 Energy and Emissions Reductions from Transportation Principles

Low density, sprawling, homogenous development has been the standard pattern of suburban neighbourhoods for over fifty years. Today, this type of development is considered a direct cause of increased automobile travel and consequent fuel consumption and emissions[193], as well as a factor contributing to increased household transportation costs and health issues such as obesity, diabetes, and asthma[194]. When analysed in isolation, design strategies intended to reduce automobile travel are often discovered to have impacts of no more than a few percent[195]; for example, Litman discusses that density itself has relatively little impact on travel when analysed alone[196].

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192 Canada Mortgage and Housing Corporation, *Case Studies*; Canada Mortgage and Housing Corporation, *Energy Needs and Availability*; Canada Mortgage and Housing Corporation, *Energy Use Patterns*; Campbell Goodell Consultants Llimited, *1990 Residential End Use Survey*

193 Handy, *Regional Versus Local Accessibility*; Feigon

194 Ewing and McCann; Frumkin, et al; Bray, et al.

195 Ewing p. 1

196 Litman, *Land Use Impacts* p. 11

However, a combination of strategies within a neighbourhood, including compact development, higher residential densities, a mix of land uses, and pedestrian friendly environments, can help to reduce automobile travel, and especially non-work travel, by increasing the internalization of trips within a neighbourhood and by promoting cycling and walking as modes of transportation[197].

The overall magnitude of travel reductions resulting from neighbourhood design is still unclear. A comparative study of six Florida communities by Ewing, Haliyur and Page finds that communities with the lowest density and accessibility generate 63 percent more vehicle hours per person than those communities with the highest density and accessibility[198]. In another analysis, the developers of the East Clayton neighbourhood predict a 40 percent reduction to automobile use and emissions[199]. More conservative results have been indicated by Litman, who finds that "feasible land use management strategies which affect local factors (density, mix, design, etc.) can reduce per capita vehicle travel by 10 to 20 percent[200]," although he acknowledges that greater results may be found at smaller, neighbourhood scales.

The level of uncertainty surrounding the influence of community design strategies on travel indicates that "transit its not a purely derived demand," and that there is "no guarantee that planning for accessibility will actually reduce driving even if it succeeds in reducing the need for driving[201]," as many people will still choose to use their cars. Handy argues that, currently, "discouragements" such as additional taxes or road restrictions are needed in addition to design solutions to reduce automobile travel[202]. However, developing trends such as an aging population, increasing energy prices, and related market changes may mean that design strategies will have greater affects on reducing transportation energy use in the future[203]. New and improving transportation

[197] Handy, *Regional Versus Local Accessibility*; Litman, *Land Use Impacts*

[198] Ewing, Haliyur and Page cited in Litman, *Land Use Impacts* p. 12

[199] James Taylor Chair in Landscape and Liveable Environments p. 19

[200] Litman, *Land Use Impacts* p. 33

[201] Handy, *Accessibility vs. Mobility Enhancing Strategies*p. 5; see also Handy, *Driving by Choice or Neccessity*

[202] Handy, *Accessibility vs. Mobility Enhancing Strategies* p. 18

[203] Litman, *The Future*

technologies and increased generation of renewable energy may also serve to reduce greenhouse gas emissions from transportation over time.

3.3 Compatibility with Suburban Site Retrofits

The preceding review of principles and strategies affecting the energy consumption and emissions generation of residential developments reflects the current best practices for more sustainable community design. However, as evidenced in the introductory case studies, these practices are being implemented almost without exception – at least in North America – in new, master planned development projects. The formal, spatial patterns of the existing Fleetwood study area, as well as certain socio-economic and cultural attitudes surrounding the suburban lifestyle, will unquestionably influence the manifestation of design strategies. Because the thesis investigates the retrofit of an existing suburban residential development rather than new construction, it is essential to examine the appropriateness of various principles and strategies to the suburban form and context.

3.3.1 Issues of Existing Form

The North American residential subdivision development holds as its hallmark a distinctive set of formal characteristics. Single family houses on generously sized lots are commonly set far back from the street, buffered by a large garage and swath of paved driveway. Homes are sited along wide, often winding and disconnected streets terminating in cul-de-sacs, with few connections to main roads or adjacent developments. These formal qualities paired with the suburb's pattern of private parcel ownership both limit and extend the possibilities for retrofit and change within the residential development.

For the thesis study area, certain design strategies described this chapter will not be compatible with the existing suburban form. An interconnected, gridded street system, for example, does not represent a plausible retrofit strategy due to existing street infrastructure and building and parcel layouts. Similarly, as building orientation has been previously established within the study area, solar orientation for buildings is only possible where it has been unintentionally provided, meaning that opportunities for passive solar strategies and energy generation through photovoltaics will be limited and unevenly distributed among homes. These principles and the goals they imply may have to be met in new ways for the site. Conversely, other energy and emission reducing principles such as home energy upgrades and increased housing density through the use of secondary suites are entirely compatible with the existing form of the study area. A full review of compatibility between energy and emissions reductions principles and the typical suburban form will be presented in Chapter 5.

Although the existing form of the suburban residential development appears to present significant obstacles to the implementation of many standard energy and emission reduction strategies, the low density subdivision form also intrinsically offers many opportunities for improvement due to its very density, amount of open space, and existing infrastructure. These opportunities and resources will be examined in greater detail in Chapter 4.

3.3.2 Issues of Acceptance

Meeting the challenge of reducing energy consumption and greenhouse gas emissions within a residential neighbourhood retrofit project is as dependent on a community's acceptance of design strategies as it is on the strategies themselves. Currently, residential subdivisions are among the least common retrofit projects[204], due in large part to issues of acceptance, namely a neighbourhood's attachment to the prototypical suburban form, as well as the complication of private ownership the expectation of household autonomy, which limits the opportunities to extend design strategies beyond the parcel scale[205].

The thesis will illustrate in Chapter 5 that the limitations to retrofit design strategies imposed by current issues of acceptance are not absolute barriers to emissions reductions within the study area. However, greater results can be achieved should these limitations, particularly the ability to challenge the existing suburban form and implement strategies at the block and neighbourhood scale, be challenged.

204 Lyndon p. 9

205 See Chiras and Wann, Martinson, and *Places* 17.2 *Retrofitting Suburbia* for further discussion on suburban obstacles to retrofit projects.

CHAPTER 4:

ANALYSIS OF A SUBURBAN RESIDENTIAL DEVELOPMENT

4.1 Background

As a nation, Canada produces only about 2 percent of global greenhouse gas emissions[206]. However, the country is still one of the world's highest per capita emitters, with British Columbians emitting about 16.2 tonnes of greenhouse gases per person annually[207], indicating that there is significant room to improve individuals' impacts on global warming. Home to the project's study area, the City of Surrey, British Columbia emits over 2 million tonnes of greenhouse gases each year, while the *Forecast and Backcast of the 2000 Emission Inventory for the Lower Fraser Valley Airshed* predicts that under current scenarios, greenhouse gas emissions within the Greater Vancouver Regional District will have increased another 20 percent by 2025[208].

The information analysed in this chapter represents those factors deemed most relevant to both the production and mitigation of greenhouse gas contributions within the study area. Understanding the consequences of each of these factors – including physical pattern, housing energy, transportation and future trends – is essential for achieving emission reduction goals.

4.1.1 Site Context

The study area chosen for the project is located in Fleetwood, a community in Surrey, British Columbia composed of a large-scale suburban block representing a development typical of many found throughout North America in its housing and land use patterns. Comprised of an assemblage of winding streets and terminating cul-de-sacs, the site contains single family homes of a fairly standard size and value. The site has moderate topography with a total elevation gain of 50 meters from the lowest point at the northeast corner of the site, and contains a centrally located seven acre park. Its location near the edge of the Agricultural Reserve Land lends particular local importance to the site as populations in the Lower Mainland continue to grow, threatening further expansion into protected areas. In addition, the Fleetwood study area represents many of the transportation issues prevalent to outer-ring suburbs; its distance from the downtown

[206] U. S. Department of Energy, *Canada: Environmental Issues*

[207] Taylor and Langlois p. 3

[208] Greater Vancouver Regional District, *Forecast and Backcast*

core, limited public transit, and auto-centric streets provide an appropriate representation of the North American "status quo." Complete data on the characteristics of the Fleetwood study area are presented in following sections.

4.1.2 Site Location

The site is located in the Fleetwood community, a part of the City of Surrey in the Lower Mainland of British Columbia. Just north of the Fraser Highway, it is bounded by four arterial roads (88 Avenue to the north, 84 Avenue to the south, 164 Street to the west, and 168 Street to the east) which bound its approximately 800 meter by 800 meter area. The site is situated within the limits of the Fleetwood Town Centre, a 350 acre (142 hectare) planning area focused on the "designated centre of Fleetwood" at the intersection of Fraser Highway, 160 Street and 84 Avenue. The study site comprises the extreme north-eastern corner of this designated area.

Figure 4.1 Study Area and Surrounding Context

4.2 Fleetwood Study Area, General Characteristics

4.2.1 Area and Densities

The total land area of the Fleetwood study site is 162.77 acres (65.87 hectares), made up of 121.08 acres (49.0 hectares) of privately owned lots, 33.27 acres (13.47 hectares) of streets and their right of ways, 6.93 acres (2.81 hectares) contained in Bucci Park, and 1.45 acres (0.59 hectares) of paved paths. The low-density development pattern and acreage lots on the north end of the site yield a gross housing density of only 3 units per acre (7.5 units per hectare) and a gross population density of approximately nine persons per acre (22.5 persons per hectare). Excluding acreage lots, the fully developed southern half of the study area reaches densities near 5 units per acre (12.5 units per hectare). Average household size is assumed to be three persons per household, consistent with the City of Surrey and Fleetwood area census records.

Table 4.1 General Characteristics, Area and Density

Area [a]	Acres	Hectares	Notes
Gross Area	162.77	65.87	Total area
Net Area	121.08	49.00	Lot areas only
Area of Park	6.93	2.81	Bucci Park
Area of Streets	33.27	13.47	Including right of way
Area of Paths	1.45	0.59	Between houses
Average Lot Area	0.24	0.10	
Density			
Gross Housing Density	2.77 dua	6.86 uph	Density in relation to total area
Net Housing Density	3.73 dua	9.22 uph	Density in relation to lots only
Gross Population Density	8.70 ppa	21.50 pph	Population in relation to total area
Net Population Density	11.20 ppa	27.67 pph	Population in relation to lots only
Household Size	3 persons [b]	3 persons [b]	

[a] Areas are taken from measurements provided through COSMOS, GIS mapping software provided by the City of Surrey. Measurements were inputted into a 3D computer model, and areas calculated accordingly.

[b] This is consistent with both Fleetwood and Surrey census data. Household size calculated by dividing area population by number of private dwellings (Fleetwood census district C11 – 14,160 /4,660 = 3.04 persons per household; City of Surrey – 347,825/115,715 = 3.01 persons per household), and also comparable to similar studies including those by Financial Services, HRM and Teed and Condon.

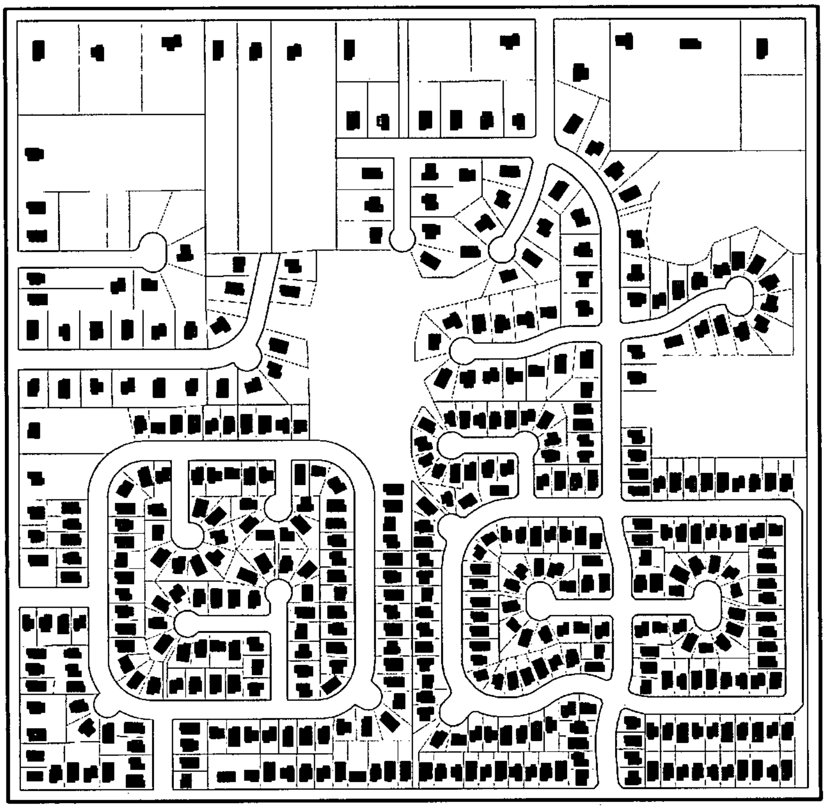

Figure 4.2 Fleetwood Study Area, Residential Pattern

4.2.2 Streets

The street system in the Fleetwood study area is a typical subdivision pattern of wide, disconnected, curvilinear streets edged by arterial roads on all four sides. The neighbourhood is currently accessible from six points along the bordering arterial roads, although the broken internal street pattern makes travel through the neighbourhood difficult without entering back onto major roads. The site contains a small number of pedestrian paths linking the residences to Bucci Park, although the paths do not generally extend to surrounding developments. Bike routes are designated only along arterial roads and not through the residential area.

Table 4.2 General Characteristics, Streets

Street Characteristic	**Measure**	**Notes**
Street Layout	Random curvilinear	Visual assessment
Street Length	27,621 feet (8,419 meters)	Calculated from model
Street Right of Way	52.5 feet (16 meters)	City of Surrey, COSMOS
Number of Intersections	19 intersections	Visual assessment
Length of Arterials	5,335 feet (1,626 meters)	Calculated from model
Length of Bike Paths	4,000 feet (1,219 meters)	Designated bike routes, calculated from model

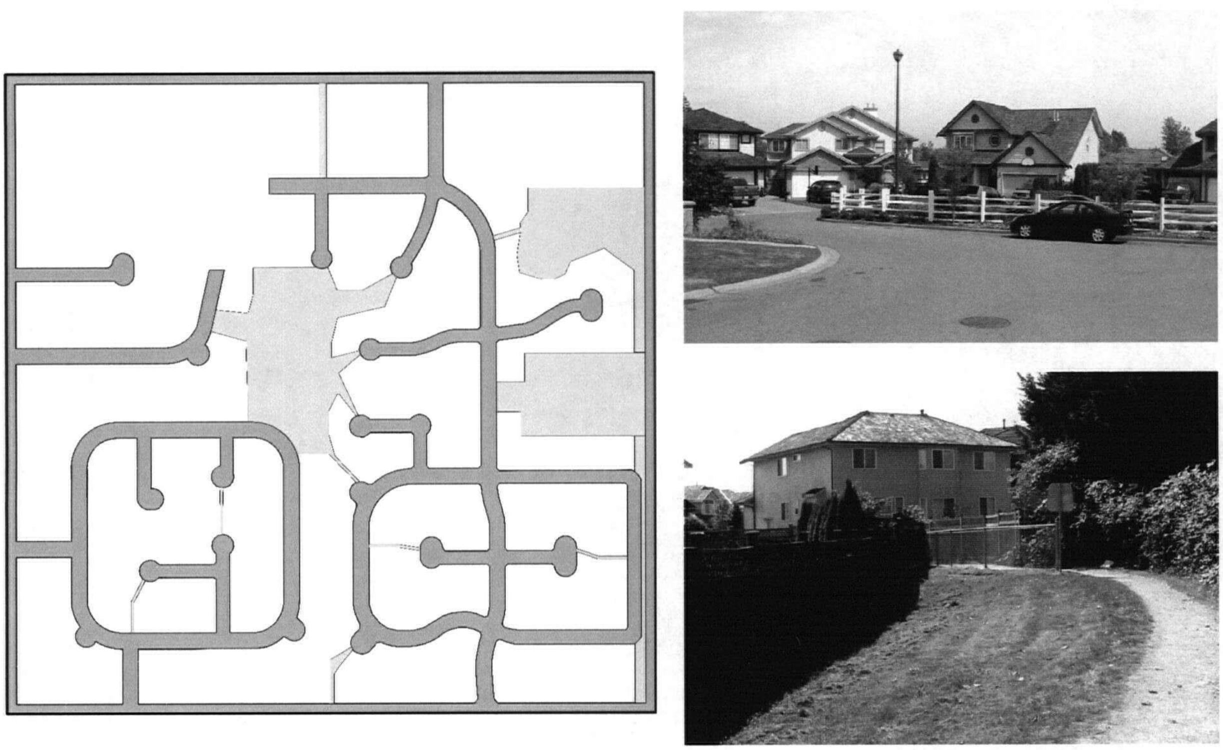

Figure 4.3 Fleetwood Study Area, Street and Path Typologies

4.2.3 Housing Stock

Housing stock in the Fleetwood study area is generally of consistent size, quality, and market value, with homes typically between 10 and 15 years old. The typical home for the area is two stories, contains at least eight rooms totalling over 2000 square feet (186 square meters), and has a two-car attached garage. A small number of newer homes built on infill lots also exist, but maintain similar characteristics to the original neighbourhood. Housing values in the area have increased dramatically in recent years, with home values assessed at an average of $416,000[209], with an average increase in value of nearly 36 percent since 2002. There are currently 452 homes located within the study area boundaries, with several more under construction.

Figure 4.4 Fleetwood Study Area, Typical Housing

[209] City of Surrey, *Property Taxation*

Table 4.3 General Characteristics, Housing Stock

Housing Characteristic	Measure	Notes
Number of Housing Units	452 units	Visual assessment
Housing Types	100% detached single family	Visual Assessment
Average Unit Value	$416,000 (2005)	City of Surrey, *Property Taxation*
Average Unit Value Increase	35.7% (2002-2005)	City of Surrey, *Property Taxation*
Age of Units	10 to 15 years	City of Surrey Planning Dept.
Average Size of Units	2,500 ft^2 (232 m^2)	Estimated, visual assessment
Average Number of Rooms	8 rooms	Estimated, visual assessment

4.2.4 Employment

Typical of many suburban residential housing developments, no employment opportunities are currently available within the Fleetwood study area boundaries. Assessment of the surrounding area suggests that there are approximately 4,300 jobs available within a one kilometer radius of the site and 33,000 jobs within a five kilometer radius. Many of these jobs are connected to local shopping centres, schools, and strip retail and service development. Only a few small industrial parks and one office park are located within the five kilometer radius, indicating that relatively few professional employment positions are locally available. As income levels and occupation data for the study area indicate that many residents hold professional positions, the thesis assumes that most employment for study area residents is more than five kilometers away from home.

Table 4.4 General Characteristics, Employment

Employment Characteristic	Measure	Notes
Number of Jobs, 1 km radius	4,300 jobs	Estimate [a]
Number of Jobs, 5 km radius	33,000 jobs	Estimate [a]

[a] Jobs calculated by locating pertinent zoning areas through GIS information from COSMOS, City of Surrey. Areas of the buildings in these areas were estimated with air photos, and job densities were assessed using data from The Institute of Transportation Engineers and Yee and Bradford.

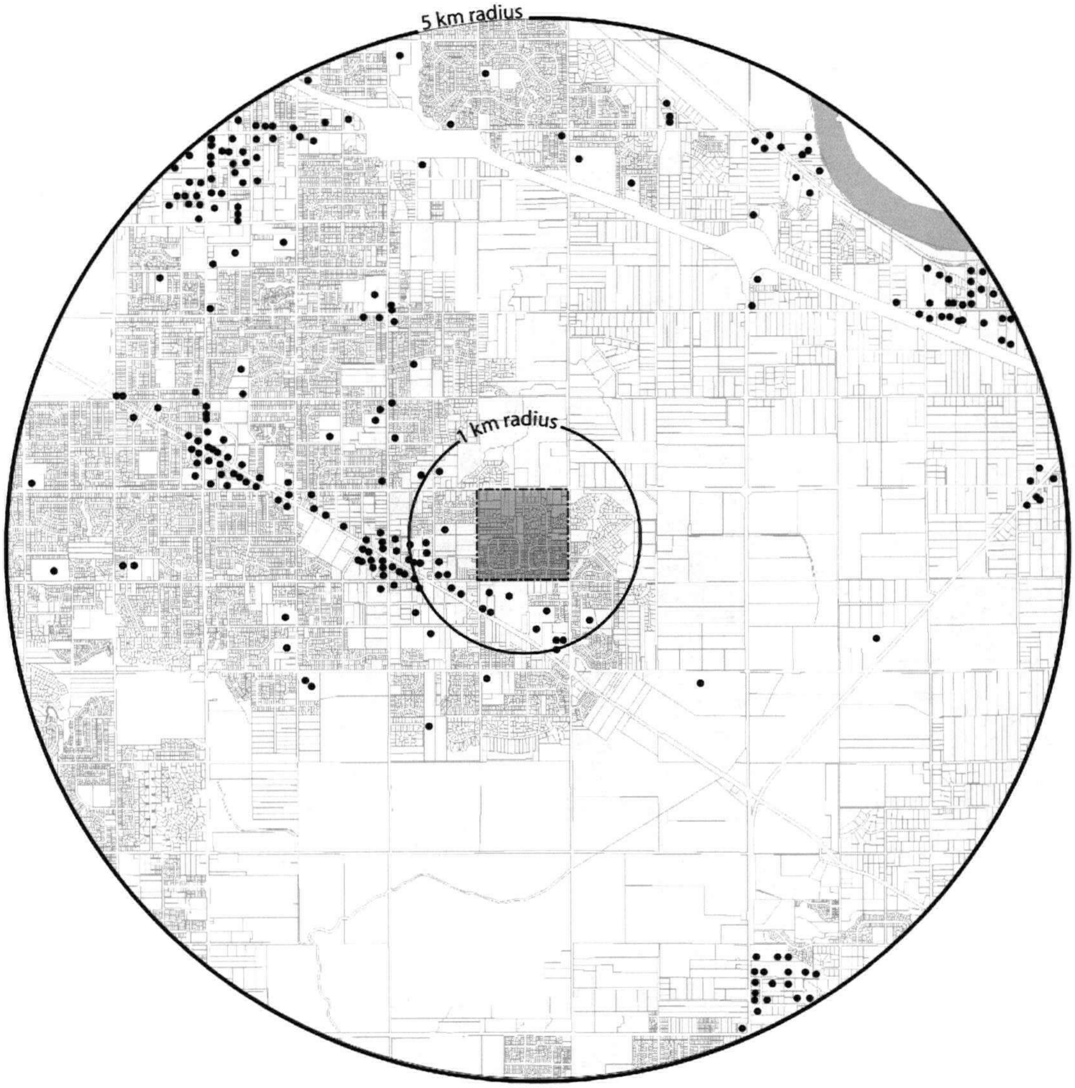

Figure 4.5, Fleetwood Study Area, Employment Locations, 1 and 5 km radius

4.2.5 Demographics

The demographics of the census area containing the Fleetwood study site are relatively mixed. Within the census area, ethnic minorities represent approximately one-third of the population, the largest ethnic group being South Asian. Age statistics show one-quarter of the population to be under the age of sixteen, and an equal number to be over the age of fifty. The remainder fall between these two age groups. The population in the census area has a greater than average income for the City of Surrey at $76,161 per year, which is also indicated by the high rate of home ownership in the area at 87.1 percent, although within the study area, ownership is assumed to approach 100 percent. The population is also extremely stable, with 86.8 percent of the population considered to be "non-movers," or residents who have lived in the same place for at least five years, for census purposes.

Table 4.5 General Characteristics, Demographics

Demographic Characteristic	Measure	Notes
Percent Home Owners	87.1% (100%) [a]	C11 Area Profile, 2001 Census
Percent Non-Movers [b]	86.8%	C11 Area Profile, 2001 Census
Percent Minority Population	32.3%	C11 Area Profile, 2001 Census
Percent Population Under Age 16	24.1%	C11 Area Profile, 2001 Census
Percent Population Over Age 50	27.3%	C11 Area Profile, 2001 Census
Average Household Income	$76,161	C11 Area Profile, 2001 Census
Average Household Income from Employment	$64,508	C11 Area Profile, 2001 Census

[a] Census data reports that over 87% of residents in the Census area own their homes. However, the census area includes a number of apartment buildings outside of the project's study area. These apartments are assumed to account for nearly all rental units in the area, so the study area has been adjusted to 100% ownership.

[b] Non-movers are defined by the census as persons who, on census day, are living at the same address at which they resided five years earlier. This is an indicator of the level of transience within a given area.

4.2.6 Transportation

The average household in the Fleetwood study area drives over 90 kilometers per day, or more than 30,000 kilometers per year[210]. This figure is not unusual for suburban drivers, and is certainly not surprising for the study area, as it is expected that residents must travel at least five kilometers, and likely much more, to work and back each day. The nearest light rail station, King George, is over seven kilometers away, while the nearest bus stop is 750 meters away geographically, or nearly 1.5 kilometers by actual travel route from the center of the study area. Serviced by only three bus routes with buses typically thirty minutes apart during peak hours, residents of the study area have little choice but to drive personal vehicles to carry on daily activities. Even tasks such as grocery shopping are most often done by car, as the nearest major store, at one kilometer away, is located on a major highway with few amenities for pedestrian traffic.

[210] IBI Group, *Greenhouse Gas Emissions from Urban Travel*

Table 4.6 General Characteristics, Transportation

Transportation Characteristic	**Measure**	**Notes**
Daily Vehicle Kilometers Traveled per Household	92.3 km (57.4 mi)	Calculated [a]
Daily Vehicle Kilometers Traveled per Capita	30.8 km (19.1 mi)	Calculated [a]
Percent Trips by Automobile	87.3%	Statistics Canada
Percent Trips by Public Transit	8.3%	Statistics Canada
Percent Trips by Walking and Cycling	4.4%	Statistics Canada
Distance to Nearest Transit Stop	750 m (1.5 km)	City of Surrey, COSMOS
Transit Service Hours	6.3 hours	Calculated [c]
Distance to Central Business District	22.1 km (13.7 mi)	Estimate [d]
Number of Stores, 1 km radius	4 grocery stores	Estimate [e]
Distance to Light Rail	7.8 km (4.8 mi)	Calculated [f]
Distance to Commuter Rail	None	Not considered to serve to study area

[a] Vehicle kilometers traveled calculated using the "Tool for Evaluating Neighbourhood Sustainability," developed by CMHC.

[b] Surveyed travelers are employed persons traveling to work. This data is assumed to be comparable to overall total travel habits in area, and results are similar to survey results found in Translink, *1999 Regional Travel Survey*.

[c] Service hours calculations are based on route operation, average time between buses, and average bus speed, calculated with the "Tool for Evaluating Neighbourhood Sustainability," developed by CMHC.

[d] Driving distance to Central Business District is presented as an average of distances to both downtown Vancouver and Surrey Central, in recognition of newer multi-nodal commuting patterns. Citing Vancouver alone is considered to over-represent the distance to the CBD.

[e] Grocery store estimate based on a phone directory survey of area retail establishments.

[f] Distance to light rail is measured from 16680 85A Ave. (center of study area) to the Sky Train, King George Station, the nearest station to the study area.

4.2.7 Surrounding Local Context

The larger Fleetwood community is comprised of relatively low-density residential and commercial development centered on the Fraser Highway. This major thoroughfare can be characterised by its "auto-oriented, commercial strip development" which constitutes a majority of locally available retail and services. Upon the request of the Fleetwood Community Association, a new land use plan developed for the area[211] is now promoting the creation of a mixed-use, higher density, pedestrian oriented town centre, although built projects reflecting these goals have not yet been realised.

[211] See City of Surrey, *Fleetwood Town Centre Land Use Plan* for complete description.

Figure 4.6, Fleetwood Study Area, Local Amenities Affecting Transportation

4.3 Fleetwood Study Area, Housing Related Emissions

A detailed inventory of greenhouse gas emission contributions at the scale of a neighbourhood encompasses a wide range of factors ranging from immediate contributors like home energy consumption to a variety of upstream and downstream sources for the community, such as manufacturing processes for consumer goods, food production and waste disposal. For the thesis, energy related sources remain leading emissions contributors; however, other sources such as household waste and landfill contributions, construction practices, and building materials, which contribute further emissions, are also examined. When adequate information is available, the emissions measured in the following sections are presented in terms of kilograms of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) per capita, constituting the major greenhouse gases occurring in the Lower Mainland[212]. In addition, a total figure, presented in kilograms of carbon dioxide equivalent (kg CO_2E), indicates the amount of CO_2 plus CH_4 and N_2O in terms of their global warming potential.

4.3.1 Materials and Construction

The greenhouse gas emissions contributed by housing begin at construction with the type and amount of materials used along with the energy consumed during the building process. A report by Seo and Hwang estimates the emissions of various housing typologies by analysing the mass of common building materials utilised in home construction (Table 4.7) along with their embodied energy from manufacturing, transport, and utilisation or installation on a building site. The report finds that, in total, a single family house generates 620.9 kg of carbon emissions for every ten square meters of floor area constructed[213], meaning that the construction of a 2,500 square foot (232 square meter) home generates nearly 14.5 tonnes of carbon emissions.

However, the emission contributions from construction only occur once during the lifetime of a building. Assuming a building life of fifty years within the Fleetwood study area, the overall contribution of materials and construction to annual household emissions can be quite small, although still important to total per capita emissions calculations for the study area. The energy embodied in the construction of buildings will comprise a much larger portion of total life-cycle emissions as the operational energy efficiency of homes and other buildings continues to improve.

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[212] GVRD, *2000 Emission Inventory* p. 4

[213] Seo and Hwang p. 416

Table 4.7 Main Materials Required for Single Family Home Construction [a]

Material	**kilograms of material per 10 square meters**
Concrete	1,129.3
Steel	53.0
Brick	580.0
Tile	17.9
Glass	26.7
Mortar	108.2
Wood	43.5
Miscellaneous	6.9
Total	***1,965.5***

[a] Source: Seo and Hwang p. 415

Table 4.8 Materials and Construction Emissions, Single Family House [a]

Avg. Unit Size, ft^2	Avg. Unit Size, $10m^2$	kg CO_2E/unit	kg CO_2E/unit/year	**kg CO_2E/capita/year**
2,500 [b]	23.2 [b]	14, 400 [c]	288.0 [d]	**96.0** [e]

[a] Source: Seo and Hwang

[b] Unit size based on average estimate for study area. Unit size presented in $10m^2$ to conform to conversion factor presented in study.

[c] Emission calculation based on emission factor for materials and construction associated with single family house, 620.9 kg/$10m^2$.

[d] Emissions per year estimated to be 1/50 of total emissions, assuming 50 year average lifespan for study area buildings.

[e] Emissions per capita per year are one-third of annual unit emissions, based on average household size of three persons.

4.3.2 Waste and Landfill Contributions

Housing also contributes to the generation of greenhouse gas emissions through the generation and disposal of household waste, a significant portion of which ends up in landfills. The Energy Star program in the United States reports that for every person in the U.S., approximately 550 pounds (0.25 tonnes) of carbon equivalent are generated from the garbage thrown out every year[214]. This figure is based on a per capita waste disposal rate in the U.S. of 1600 pounds (0.726 tonnes) annually, indicating that approximately 0.34 pounds (0.15 kilograms) of carbon equivalent can be attributed to each pound of waste. Within the GVRD, waste disposal figures are similar, with each person disposing of 0.678 tonnes in 2002[215], despite high recycling rates. Greenhouse gases from household waste

[214] Energy Star, *In the Home*

[215] Greater Vancouver Regional District, *Solid Waste Management* p. iii

are generated in several ways, including the incineration and transportation of waste, as well as the manufacture of new products to replace those thrown away. Further greenhouse gases are generated through the anaerobic decomposition of waste in landfills, which produces methane, a greenhouse gas with 21 times as much global warming potential as carbon dioxide[216].

Table 4.9 Per Capita Emissions from Household Waste

Waste/year/capita, tonnes	Waste/year/capita, kg	**Emissions/year/capita, kg CO_2E**
0.678	678.0	**231.5** [a]

[a] Calculation based on estimated emission factor of 0.34 kilograms CO_2E per kilogram of waste.

4.3.3 Energy Consumption

Residential energy use is one of the major contributors to housing related greenhouse gas emissions within the Fleetwood study area. For the purpose of the thesis, these emissions are addressed in three parts: household electricity use, electricity transmissions and distribution losses and natural gas use for space heating and hot water. These three uses are considered to be consistent among all study area homes for the thesis; however, in reality some homes may differ particularly in terms of heating systems, as BCHydro notes that between 13 and 29 percent of Lower Mainland dwellings utilise electric heating rather than natural gas according to billing and survey records[217]. These discrepancies are not considered problematic for the thesis, as the goal is to represent a broad estimate of emission contributions for the study area based on the "average" household. All greenhouse gas emissions data in this section is taken from the *2000 Emission Inventory for the Canadian Portion of the Lower Fraser Valley Airshed*, which was commissioned by the Greater Vancouver Regional District.

[216] U.S. Environmental Protection Agency
[217] Meyer

4.3.3.1 Electricity

Based on energy consumption averages provided by BCHydro, the normal electricity use in single family homes in the Fleetwood study area is approximately 11,000 kWh per year, or roughly 30 kWh per day. While this estimate is high compared to several Canadian reports on home energy use[218], it is assumed to be appropriate for the thesis, considering the size and age of the homes. In most cases the study area homes are too new to have undergone major upgrades yet, but old enough to contain many inefficient appliances and lower quality building components, such as insulation and windows.

Electricity is used for most of the basic daily activities in study area households, excluding heating and hot water, which is assumed to be supplied by natural gas. Major electricity users include electric lighting, clothes dryers, refrigeration, and television. Another significant portion of electricity goes to the support of "extras" within the home, including second refrigerators, heated waterbeds, pools, and air conditioning. For each resident of the study area, the attributed amount of CO_2-equivalent emissions for general electricity use is 155 kg, or nearly one-half tonne of greenhouse gases per year per household.

4.3.3.2 Electricity Transmission and Distribution Losses

An additional factor to consider for greenhouse gas emissions associated with electricity production is the extra amount of electricity lost during transmission from the power generation facility. This transmission loss occurs due to the often long distances that electricity must travel from source to destination. On average, transmission and distribution losses for electricity are approximately 7 percent for distribution systems in North America[219]. These losses are considered significant enough to include in emissions calculations for the project, particularly since they can be eliminated by on site energy generation. Per capita, electricity transmission and distribution losses contribute an additional 11.7 kilograms of CO_2-equivalent gases to the atmosphere annually.

[218] BCHydro p. 1; Canada Mortgage and Housing Corporation, *About Your House* p. 4

[219] U.S. Climate Change Technology Program p. 34

Table 4.10 Electricity Use and Emissions per Capita

	Energy			**Emissions per Capita**			
End Use[a, b]	% total	kWh/year	**kWh/year/cap**	kg CO_2[c]	kg CH_4[c]	kg N_2O[c]	**kg CO_2E**[d]
Cooking	7.3%	807	**269**	11.3	0.0003	0.0003	**11.4**
Dishwasher	2.8%	304	**101**	4.2	0.0001	0.0001	**4.3**
Dryer	11.7%	1,294	**431**	18.1	0.0004	0.0004	**18.2**
Freezer	7.2%	796	**265**	11.1	0.0003	0.0003	**11.2**
Lighting, Compact	0.9%	101	**34**	1.4	0.0000	0.0000	**1.4**
Lighting, Fluorescent	2.3%	252	**84**	3.5	0.0001	0.0001	**3.6**
Lighting, Incandescent	13.1%	1,441	**480**	20.1	0.0005	0.0005	**20.3**
Lighting, Spot	1.3%	146	**49**	2.1	0.0000	0.0000	**2.1**
Lighting, Other	0.9%	95	**32**	1.4	0.0000	0.0000	**1.4**
Microwave	1.7%	185	**62**	2.6	0.0001	0.0001	**2.6**
Refrigerator	10.7%	1,178	**393**	16.5	0.0004	0.0004	**16.6**
Television	11.1%	1,222	**407**	17.1	0.0004	0.0004	**17.2**
Ventilation	7.2%	788	**263**	11.1	0.0003	0.0003	**11.1**
Washer	1.4%	150	**50**	2.1	0.0001	0.0001	**2.1**
Other	10.3%	1,136	**379**	15.9	0.0004	0.0004	**16.0**
Other, proportioned							
Secondary Heat	1.1%	25	**8**	0.3	0.0000	0.0000	**0.3**
Central AC	0.2%	43	**14**	0.6	0.0000	0.0000	**0.6**
Room AC	0.2%	455	**152**	6.4	0.0002	0.0002	**6.5**
Second Refrigerator	1.1%	17	**6**	0.3	0.0000	0.0000	**0.3**
Pool	4.1%	125	**42**	1.8	0.0000	0.0000	**1.8**
Waterbed Heating	0.4%	457	**152**	6.4	0.0002	0.0002	**6.5**
Total[e]	*100%*	*11,017*	***3,673***	*154.3*	*0.0038*	*0.0038*	***155.5***

[a] Breakdown according to BCHydro's residential forecasting models for single family homes and duplexes in the Lower Mainland, provided by BCHydro (Meyer, email correspondence). Data was calibrated by BCHydro to match weather normalized billed sales for fiscal year 2004/2005.

[b] Electricity uses included in this section are assumed to be consistent across all homes in study area, based on significant majorities indicated in BCHydro data. "Other, proportioned" indicates uses that are considered significant in energy use, but not consistent among all homes. These uses are proportioned according to their distribution among the population.

[c] Calculated with emission factors as presented in "2000 Emission Inventory for the Canadian Portion of the Lower Fraser Valley Airshed" – CO_2: 42 g/kWh; CH_4: 0.001 g/kWh; N_2O: 0.001 g/kWh. These factors account for all BCHydro sources for electricity generation within the province.

[d] CO_2E is defined as the total emissions calculated in units of CO_2 based on CH_4 and N_2O having global warming potentials of 21 and 310 times CO_2 respectively.

[e] Numbers data may have slight deviations among and within charts due to rounding.

Table 4.11 Electricity Transmission Losses and Emissions per Capita [a]

Energy		**Emissions per Capita**			
kWh used/cap	**kWh lost/cap [b]**	kg CO_2 [c]	kg CH_4 [c]	kg N_2O [c]	**kg CO_2E [d]**
3,673	**276**	11.6	0.0003	0.0003	**11.7**

[a] Transmission and distribution losses for electricity generation are approximately 7% with current systems in North America. The losses incurred from electricity transported to the study area must be included in calculations of greenhouse gas emissions.
[b] kWh lost are calculated by assuming that electricity used is 93% of the energy sent to study area.
[c] Calculated with emission factors as presented in "2000 Emission Inventory for the Canadian Portion of the Lower Fraser Valley Airshed" CO_2: 42 g/kWh; CH_4: 0.001 g/kWh; N_2O: 0.001 g/kWh. These factors account for all BCHydro sources for electricity generation within the province.
[d] CO_2E is defined as the total emissions calculated in units of CO_2 based on CH_4 and N_2O having global warming potentials of 21 and 310 times CO_2 respectively.

4.3.3.3 Natural Gas

According to Terasen Gas, the average single family home uses 108 GJ of natural gas every year, which is equivalent to 2,754 cubic meters of gas. Two-thirds, or 66 percent of natural gas usage goes towards heating, while the remaining 34 percent is used for domestic hot water[220]. For comparison, 108 GJ of natural gas energy is roughly equivalent to 30,000 kWh of electricity (1 J = 2.77×10^{-7} kWh), indicating that energy use for space heating is substantially greater than energy use for appliances, lighting and other daily activities. Because British Columbia uses mainly hydro-electricity, natural gas actually generates significantly more greenhouse gas emissions than electric power for the region. In total, natural gas heating and hot water emit 1,777 kilograms – nearly 2 tonnes - of CO_2 equivalent greenhouses gases per capita annually. As natural gas is a non-renewable resource consumed at high rates, it is expected that natural gas use will be phased out over time as supplies diminish and increase in price. In the future, more heating energy in the Lower Mainland may be supplied by electricity or waste heat from the municipal grid or renewable sources.

[220] Terasen Gas

Table 4.12 Natural Gas Use and Emissions per Capita, heat and hot water

	Energy			**Emissions per Capita**			
End Use [a]	% total	10^6m^3/year	**10^6m/year/cap**	kg CO_2 [b]	kg CH_4 [b]	kg N_2O [b]	**kg CO_2E** [c]
Space Heating	66%	0.00182	**0.00061**	1,171.2	0.02	0.02	**1,178.3**
Domestic Hot Water	34%	0.00093	**0.00031**	595.2	0.01	0.01	**598.8**
Total [d]	*100%*	*0.00275*	***0.00092***	*1,766.4*	*0.03*	*0.03*	***1,777.1***

[a] Breakdown according to Terasen Gas, in phone interview. No studies or data provided. Average annual natural gas use for single family homes and duplexes reported to be 108 GJ. According to the Terasen website, 1 GJ of natural gas is equal to approximately 25.5 m^3 of gas. The actual volume of gas varies according to variations in amounts and types of energy gases (methane, ethane, propane, and butane) it contains. Therefore, 108 GJ is approximately 2,754 m^3 per year, or .00275 10^6 m^3 which is the emissions factor unit provided.
[b] Calculated with emission factors as presented in "2000 Emission Inventory for the Canadian Portion of the Lower Fraser Valley Airshed" – CO_2: 1,920,000 kg/10^6m^3; CH_4: 36.8 kg/10^6m^3; N_2O: 35.2 kg/10^6m^3
[c] CO_2E is defined as the total emissions calculated in units of CO_2 based on CH_4 and N_2O having global warming potentials of 21 and 310 times CO_2 respectively.
[d] Numbers data may have slight deviations among and within charts due to rounding.

4.3.4 Housing Trends

Over recent decades, several trends have been evident in housing energy and emissions, and will likely continue to effect housing in the future. Natural Resources Canada reports that between 1990 and 2003, residential energy use increased 13 percent, increasing related emissions by 15 percent; however, without the energy efficiency improvements that did occur, energy consumption could have risen by 32 percent[221]. Energy consumption increases are attributed mainly to increases in the number of Canadian households, as well as to an increase in the average floor area of residential units. Changes to housing form, including increased use of glazing, more complex building perimeters, more exterior lighting and more household machines, such as computers and new appliance types, also serve to increase housing energy loads.

Although energy efficiency improvements in terms of building envelope, standard appliances and heating and cooling systems have made some difference, a study by the National Association of Home Builders reports that very little actual housing energy reductions have been made since 1987. In the United States, average energy use per

221 Natural Resources Canada, *Energy Efficiency Trends* p. 13

housing unit in both 1987 and 1997 were approximately 30,000 kWh[222]. Housing energy may see more substantial improvements as fossil fuel supplies dwindle, making intensive consumption less affordable. In this situation, electricity from hydro-power or renewables and the use of waste heat may take on a larger role in space and water heating as natural gas supplies wane.

Energy efficiency and consequent emission reductions will also be affected in coming years as household characteristics change. Studies by Natural Resources Canada suggest that decreasing household sizes, including a 15 percent drop in the number of children per household, may reduce energy requirements for uses such as hot water and clothes washing[223]. However, these reductions could be offset by a concurrently aging population who, according to studies in both Canada and the U.S., use more energy for space heating than younger occupants[224].

4.4 Fleetwood Study Area, Transportation Related Emissions

Transportation, and particularly the use of private automobiles, is the largest per capita greenhouse gas contributor for the Fleetwood study area. Although the Greater Vancouver Regional District has among the highest public transportation riderships in Canada at 12 percent with an additional 14 percent mode share for walking and cycling[225], within the study area, over 80 percent of trips are still made by car, and often in vehicles in which the driver is the only occupant[226]. The amount of driving done by study area residents has significant impacts on the emissions produced for the region, as cars contribute enormous amounts of CO_2 to the atmosphere through the burning of gasoline.

4.4.1 Vehicle Kilometers Traveled

According to calculations made using the *Tool for Evaluating Neighbourhood Sustainability* developed by CMHC, the average household in the Fleetwood study area drives 92.3

[222] NAHB Research Center, *PATH Technology Roadmap* p. 3

[223] Natural Resources Canada, *Energy Efficiency Up Close* p. 3

[224] Natural Resources Canada, *Energy Efficiency Canada* p. 7-9; Liao and Chang p. 267-284

[225] Translink, *Regional Travel Survey* p. 7

[226] Statistics Canada, *2001 Community Profiles*

kilometers per day, or more than 11,000 kilometers per year per capita[227]. This number is calculated through the consideration of many neighbourhood characteristics that contribute to daily driving habits: neighbourhood street layout, length of residential roads, number of intersections, length of arterial roads, length of bike routes, daily bus service, land area, number of housing units, average housing unit size, housing mix, housing density, number of jobs in both one and five kilometer radii, number of grocery stores in a one kilometer radius, distance to the central business district, distance to a rapid transit station, availability of commuter rail, and distance to commuter rail station. This data has been previously examined in Section 3.2.

The kilometers traveled per capita are split proportionately among the common personal vehicle types - light duty gas vehicles, light duty gas trucks, and motorcycles – in order to more accurately portray the emissions contributions of a variety of vehicles. The vehicle breakdown is based on the ratio of vehicles present in the Lower Mainland, as reported in the *2000 Emission Inventory for the Canadian Portion of the Lower Fraser Valley Airshed.* Only those vehicle types common to residential situations were included.

Based on this data, per capita emissions from personal transportation total 3,368.7 kilograms of carbon equivalent greenhouse gas emissions per year, which equates to over 3 tonnes per person annually. This figure makes personal transportation by far the most substantial contributor to neighbourhood greenhouse gas emissions, and places the reduction of transportation emissions at the forefront of goals for the project.

227 For greater detail on this software and VkmT calculations, please refer to IBI Group, *Greenhouse Gas Emissions from Urban Travel: Tool for Evaluating Neighbourhood Sustainability Research Report.*

Table 4.13 Personal Transportation and Emissions per Capita

	Distance [b]		**Emissions per Capita**			
Vehicle Type [a]	% total	**VkmT/year/cap**	g CO_2 [c]	g CH_4 [c]	g N_2O [c]	**g CO_2E** [d]
Light Duty Gas Vehicle	57%	**6,401.1**	1,529.9	0.2	0.3	**1,622.6**
Light Duty Gas Truck	42.5%	**4,772.8**	1,598.9	0.2	0.4	**1,739.7**
Motorcycle	0.5%	**56.2**	6.3	0.0	0.0	**6.4**
Total [e]	*100%*	***11,230***	*3,135,045.3*	*0.4*	*0.7*	***3,368.7***

[a] Breakdown based on ratio of vehicles present in Lower Mainland, as reported in "2000 Emission Inventory for the Canadian Portion of the Lower Fraser Valley Airshed." For study area, assumed that only light duty gasoline vehicles, light duty trucks, and motorcycles are present.

[b] Vehicle kilmotres traveled calculated with "Greenhouse Gas Emissions from Urban Travel: Tool for Evaluating Neighbourhood Sustainability" software, which provides VkmT/household/day. This was divided by 3 to estimate VkmT per capita and multiplied by 365 to determine per capita travel contributions per year.

[c] Calculated with emission factors as presented in "2000 Emission Inventory for the Canadian Portion of the Lower Fraser Valley Airshed" – Light Duty Gas Vehicles - CO_2: 239 g/VkmT; CH_4: 0.026 g/VkmT; N_2O: 0.045 g/VkmT Light Duty Gas Trucks – CO_2: 335 g/VkmT; CH_4: 0.046 g/VkmT; N_2O: 0.092 g/VkmT Motorcycles - CO_2: 112 g/VkmT; CH_4: 0.095 g/VkmT; N_2O: 0.002 g/VkmT

[d] CO_2E is defined as the total emissions calculated in units of CO_2 based on CH_4 and N_2O having global warming potentials of 21 and 310 times CO_2 respectively.

[e] Numbers data may have slight deviations among and within charts due to rounding.

4.4.2 Transportation Trends

Between 1990 and 2003, the amount of energy used by the transportation sector increased by 26 percent, resulting in related greenhouse gas emissions rising by 25 percent[228]. Passenger transportation, which comprised 56 percent of transportation energy consumption in Canada, increased emissions by 14 percent[229], although this increase would have been much greater without the automobile efficiency improvements which occurred over the same time period.

Many efficiency improvements have been the result of new technologies such as electric and hybrid vehicles brought about by fuel consumption and emission standards; however these improvements have been offset by the popularity of larger, more powerful vehicles, especially sport utility vehicles. Natural Resources Canada reports that the average "horse power" of Canadian cars has increased 32 percent between 1990 and 2003, severely

228 Natural Resources Canada, *Energy Efficiency Trends* p. 35

229 Natural Resources Canada, *Energy Efficiency Trends* p. 36

limiting overall efficiency improvements[230]. The report concludes that if the power of cars had stayed at 1990 levels, with the same level of efficiency improvements, today's cars would be another 33 percent as efficient as current levels[231]. In coming years, this trend towards more powerful, fuel intensive vehicles may be reversed by the limited availability of fossil fuels and rising fuel prices.

4.5 Total Measured Emissions for Study Area

4.5.1 Emissions and Carbon Flows

In total, per capita emissions considered for the Fleetwood study area are 5,640.5 kilograms of carbon equivalent, or nearly 6 tonnes per capita per year. By mapping the total flow of carbon emissions through its various contributors, an idea of the relative proportions and sources of emissions can be more clearly established. As Figure 4.8 illustrates, within the study area transportation accounts for almost 60 percent of total greenhouse gas emissions, followed by natural gas with 31.5 percent of total emissions, or 78 percent of housing related emissions. These emissions are released almost entirely into the atmosphere, although approximately 0.5 percent can be estimated to be sequestered by trees already existing on site. Figure 4.8 will be re-examined later in the thesis for potential changes to local carbon flows as retrofit strategies are incorporated within the study area[232].

[230] Natural Resources Canada, *Energy Efficiency Trends* p. 39

[231] Natural Resources Canada, *Energy Efficiency Trends* p. 39

[232] Carbon flow maps have been generated using Metaflow software, provided by Sebastian Moffatt of the Sheltair Group, Inc.

Table 4.14 Total Annual Emissions per Capita

	Annual Per Capita Emissions
Emissions Contributors	kg CO_2E
Materials and Construction	96.0
Household Waste	231.5
Electricity Use	155.5
Electricity Transmission and Distribution Losses	11.7
Natural Gas Use	1,777.1
Personal Transportation	3,368.7
Total	***5,640.5***

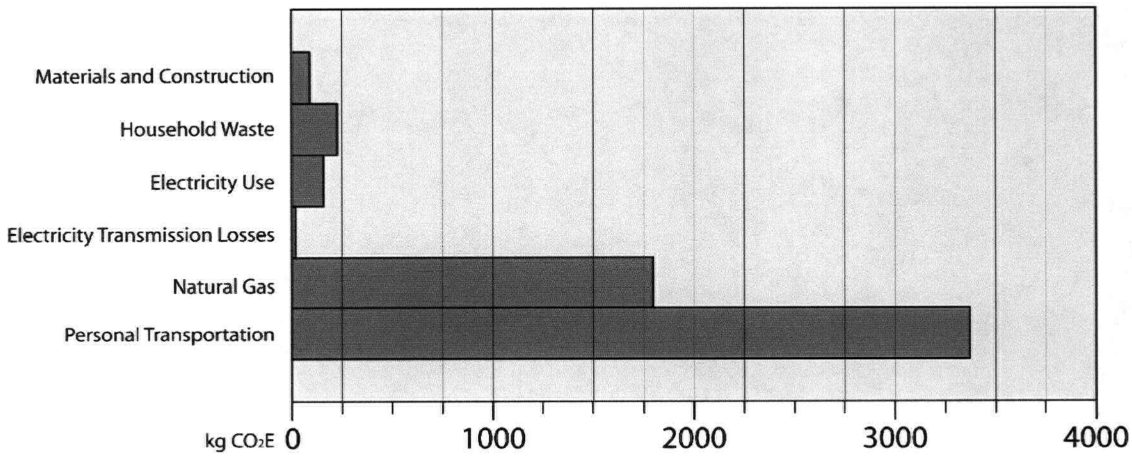

Figure 4.7 Total Annual Emissions

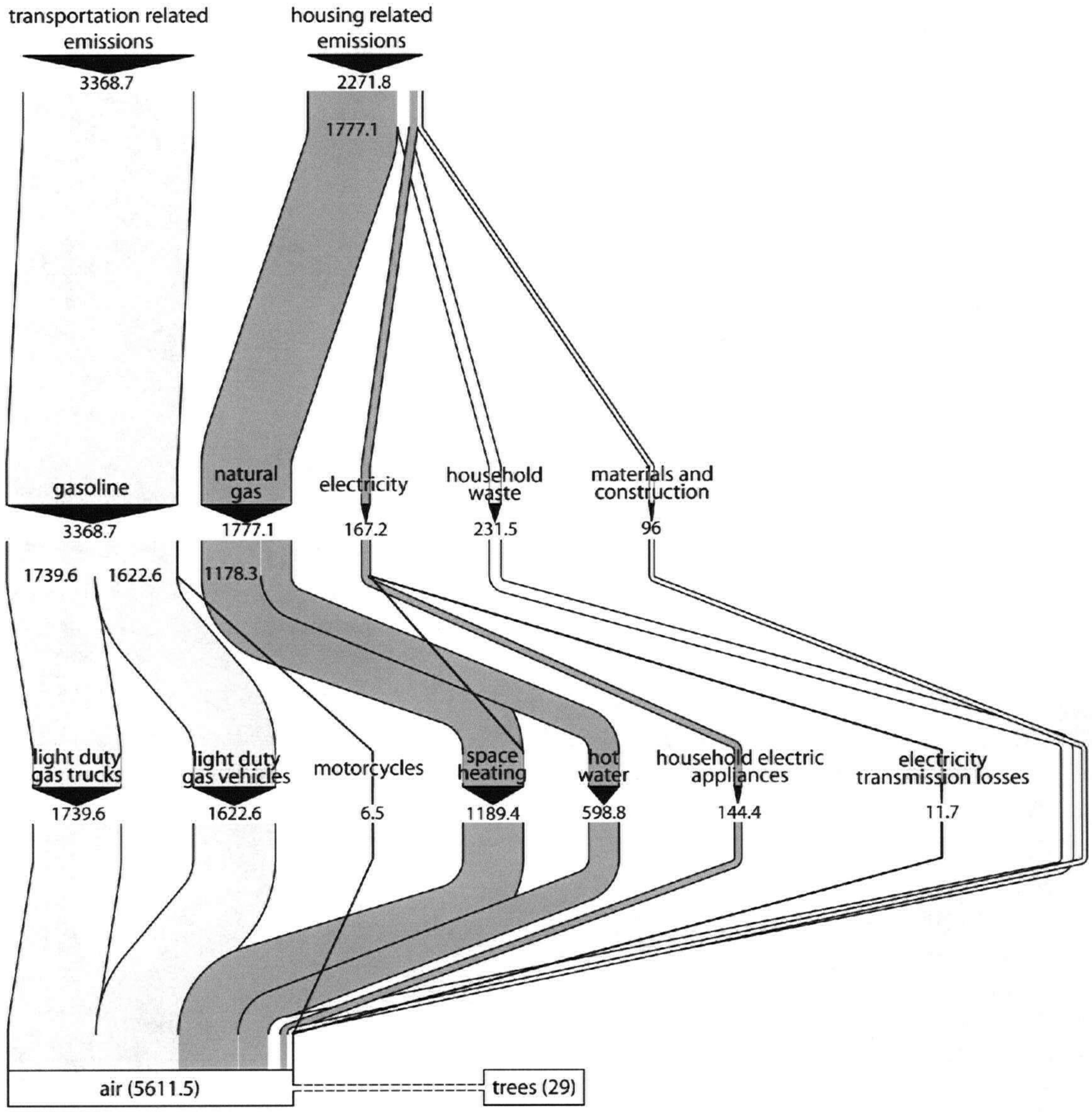

Figure 4.8 Map of Study Area Carbon Emissions, kg CO_2E per capita

4.5.2 Emissions not Included in Thesis

The thesis recognises that residents in the Fleetwood study area also contribute to greenhouse gas emissions in ways not explicitly considered in this chapter. These contributions include per capita food production and consumption, goods purchases, recreational activities, employment related activities and many others. These emissions contributions, while important, are considered outside the scope of the project due to their seeming level of disconnect from the built environment, as well as their greater level of uncertainty at the level of generalisation established by the thesis.

4.5.3 Emissions Caveat for British Columbia

While this project is distinctly situated in British Columbia, information provided through this research will also be applicable to the many other regions of North America containing similar suburban development patterns. For this reason, it is important to note that in many parts of North America electricity is not generated by hydro-power, the predominant generation method for the Lower Mainland, but rather through much more carbon-intensive methods such as coal-burning power plants. In these situations, home electricity consumption takes on a much larger role in greenhouse gas contributions, while natural gas becomes a significantly lower emitter of greenhouse gases than electricity, until the time that renewable electricity sources become readily available. Figure 4.9 illustrates the proportional differences between identical home energy use patterns utilising hydro-power (left) and coal-generated electricity (right). For comparison, transportation emissions, illustrated in light grey, are equal in both figures, while housing emissions, illustrated in dark grey, have increased nearly 300 percent, from 2,272 kilograms per capita to 6,547 kilograms per capita.

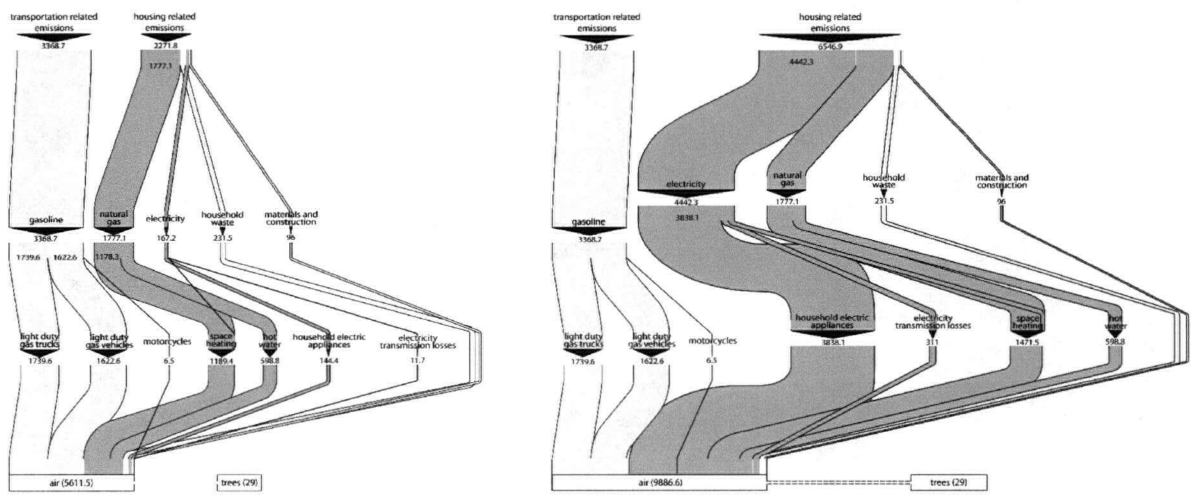

Figure 4.9 Comparison of Carbon Flows, Hydroelectricity vs. Coal Power

It should also be noted that large scale hydro-electricity plants, such as the generation systems located in British Columbia, while very low in greenhouse gas emissions, create conditions that are harmful to the environment in other ways. In particular, large scale hydro-dam projects severely disrupt local ecosystems and natural communities, destroying habitat and altering hydrological cycles. For these reasons, it is just as important to reduce electricity consumption and develop renewable power sources in British Columbia as in other regions of the world.

4.6 Identifying Local Resources and Opportunities

Suburban single family residential areas are often discounted as sites for retrofit projects due to issues which are seen to limit opportunity, such as private ownership and low density community layouts. However, a deeper analysis of such areas reveals that these same developments, with their open space, low population densities, and existing, often oversized infrastructure, actually contain a wide variety of characteristics that can be seen as resources for implementing new retrofit strategies. Systems engineer Jon Schulz offers a similar view, concluding that "suburbs are places of tremendous unrealized benefit and opportunity[233]." An inventory of the resources and opportunities inherently available within a suburban residential site will have significant influence on determining the types of strategies most appropriate for various neighbourhood retrofit scenarios.

The thesis does not suggest that the resources and opportunities identified in following sections for the Fleetwood study area are characteristics so beneficial in nature that they should be perpetuated in new development. For every benefit of low densities or suburban block patterns described here there are also detriments, such as intensive land consumption and automobile dependency, which could be avoided through more thoughtful design. Rather, the thesis attempts to look at the development's existing conditions and determine in what ways its potential can be maximised.

233 Jon Schulz, cited in Chiras and Wann p. 38

4.6.1 Space

Currently, privately owned lots within the Fleetwood study area encompass 121 acres (49 hectares) of land, and accommodate 452 single family homes. If the thesis assumes an average of 3,000 square feet (279 square meters) of lot space is taken by each home, including living space, garage space, pavement, patios, etc., then nearly 90 acres (36.5 hectares) still remains held as privately owned open land. Although some of this space is collected in larger acreage lots on the northern end of the study area, a majority of open space currently resides in landscaped, often fenced, private yards. The availability and arrangement of undeveloped land is such that, if properties boundaries are ignored, at least eleven pieces of continuous open space exist within the study area which are one-half acre or larger in area. Many other smaller spaces also exist between and among homes. This amount of land can be considered a resource and opportunity for a number of reasons, including infill development potential for larger areas, as well as space for accessory units, urban forestry initiatives, ground source heat pump installation, or community gardens.

Land is not the only way in which the suburbs amass large amounts of space. The existing single family homes within the Fleetwood study area accommodate an average of three people, often in living spaces exceeding 2,000 square feet (186 square meters). This estimate does not account for basement and garage spaces, which add another 1,900 square feet (176.5 square meters) of additional space, assuming an average 400 square feet (37 square meters) for a two car garage and 1,500 square feet (139 square meters) in basement capacity[234]. While current available living space is certainly used by neighbourhood residents, some of this resource might be put to new purposes, such as secondary rental suites, in the future. The space available in 452 basements and garages alone totals over 850,000 square feet (79,000 square meters) – enough for more than 1,500 one bedroom apartments[235].

[234] Estimates are based on field measurements and observations in the Fleetwood study area.

[235] Based on apartment sizes between 500 and 600 square feet.

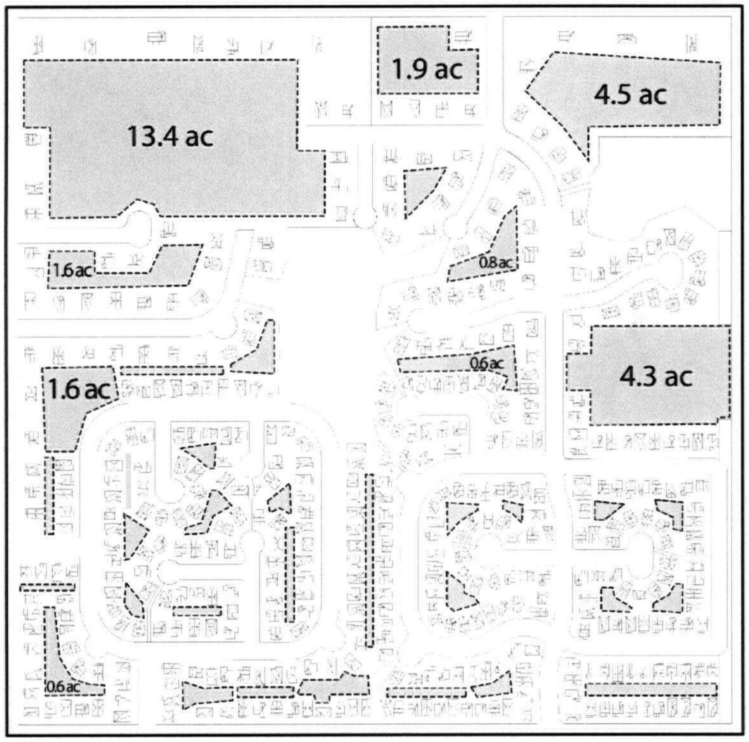

Figure 4.10 Fleetwood Study Area, Open Space

4.6.2 Density

Current net residential densities within the study area are less than four units per acre (10 units per hectare), or 11 persons per acre (27.5 persons per hectare) in population density. While these densities are often considered detrimental to sustainability goals due to transportation implications and sheer resource consumption, low density developments also offer unique advantages in the form of the amount of resources available per capita.

One of the most compelling instances of resource allocation in a low density development is the total amount of available south facing roof surface available within the study area. Analysis by computer modeling shows that within the study area, 252,430 square feet (23,452 square meters) of south facing roof area exists. With a current estimated population of 1,356 residents, each resident has the potential to personally benefit from 183 square feet (17 square meters) of roof area. If this amount of roof space were installed with high-efficiency photovoltaics[236], the energy generation capacity under local climate conditions could be as much as 3,773 kWh per capita annually[237]. This amount of energy actually exceeds current per capita electricity uses for the neighbourhood, which total 3,664 kWh annually. In higher density situations, such as stacked apartments, significantly less area per capita is available for photovoltaic electricity generation, decreasing the opportunity to meet energy needs with this technology alone. While covering every available south facing roof surface with photovoltaics is an extreme example of utilising resources, the calculation illustrates the potential of available resources per capita on site.

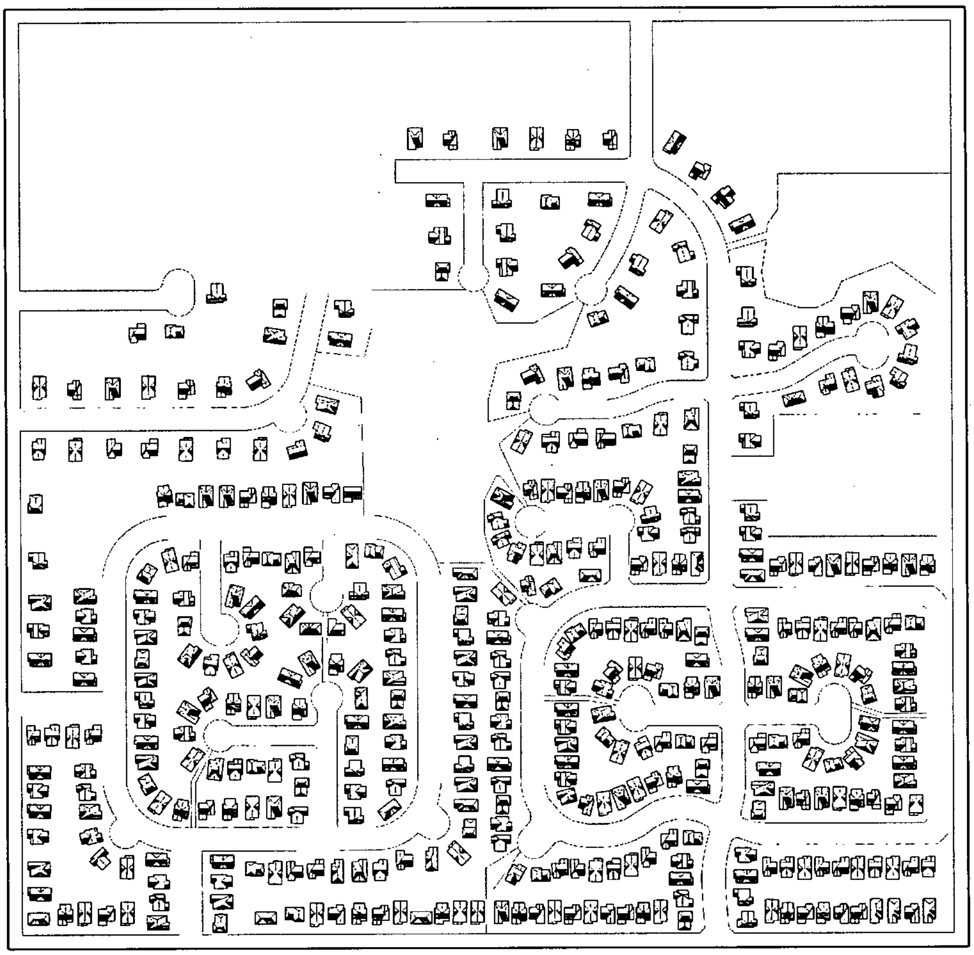

Figure 4.11 Fleetwood Study Area, Available South-Facing Roof Area

[236] Thesis assumes 17% efficiency, as described in REN21 Renewable Energy Policy Network p. 12

[237] Photovoltaic generation capacity is estimated using an Excel-based energy generation calculation program derived from Vancouver International Airport insolation data.

Lower residential densities mean that other neighbourhood resources, particularly land area, are also proportionately high per capita. The amount of open space per person may enable additional trees to be planted for the purpose of carbon sequestration, while an adequate amount of street space per person may ensure residents' parking needs can be met even if many garages are converted into secondary suites.

4.6.3 Location and Layout

One of the inherent benefits of existing suburban residential developments is the fact that they have already been developed. Unlike greenfield development projects, existing subdivisions have already made the capital investments in necessary infrastructure such as streets, electricity transmission, sewer and stormwater. Often, these systems are oversized, meaning that even at increased densities, little or no extra infrastructural investment is needed.

In addition, previously developed areas are often closer to established amenities such as community centers, commercial areas, and schools. This is certainly the case for the Fleetwood study area, where the Surrey Sports and Leisure Complex has been developed just a few blocks to the south, and the nearest elementary school is less than one kilometer away. The Fleetwood study area will also benefit directly from new development planned several blocks to the west. Outlined in the Fleetwood Land Use Plan and Urban Design Concept Plan, efforts to create a "compact, pedestrian-oriented community[238]" include a new commercial core, on and off-street pedestrian and bicycle networks, designated "shopping streets," and higher density residential developments. In conjunction with design strategies to promote safe walking and cycling conditions in the study area, these amenities will serve to promote alternative transportation, as well as enable more community needs to be met within walking and cycling distances. . While the existing plan explicitly protects existing residential developments and does not propose significant changes to the study area, the site's immediate proximity to the planned commercial core may allow for important connections to be made between the two areas in the future.

[238] City of Surrey, *Fleetwood Town Centre Land Use Plan* p. 7

The location of the Fleetwood study area within a typical suburban block, approximately 800 meters by 800 meters in size can also be considered an asset when considering possibilities for neighbourhood retrofits. A block depth and breadth of 800 meters means that no resident of the study area lives more than 400 meters from an arterial road. This distance is important, as it is considered the maximum distance appropriate for pedestrian travel[239]. Therefore, the site's proximity to arterial roads holds important implications for accessible public transit stops, as well as the potential for walkable, commercial development along more widely traveled streets.

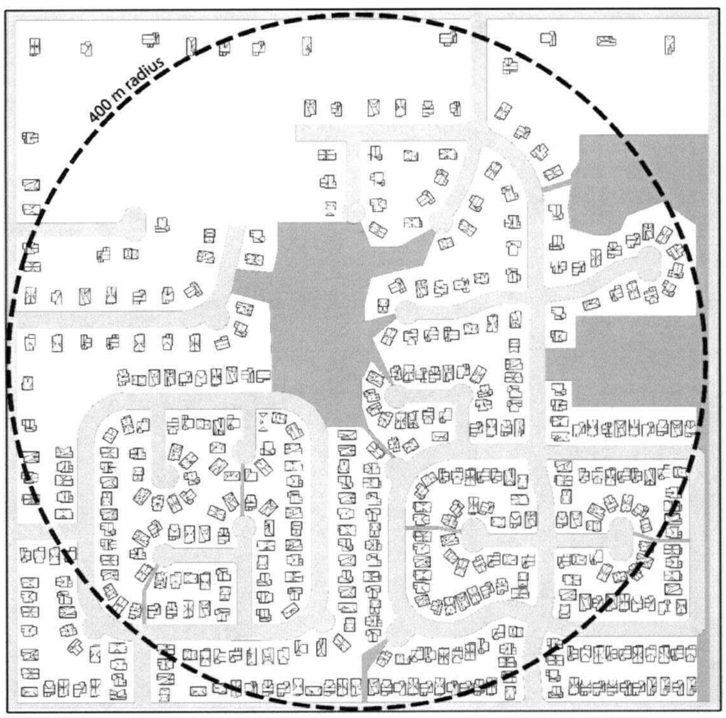

Figure 4.12 Fleetwood Study Area, Neighbourhood Layout

4.6.4 Housing Stock and Local Residents

The housing stock of the Fleetwood study area can also be seen as a strong opportunity for neighbourhood retrofit scenarios. Homes within the study area were built in the early

[239] Teed and Condon p. 22

and mid-1990s[240], meaning the homes are between ten and fifteen years old. While the homes are relatively new and in good condition, local housing stock is approaching an age at which many upgrades, including heating systems, appliances, and envelope components such as windows become common. If home energy retrofit strategies are enacted in conjunction with required maintenance and upgrades, many improvements to performance may be achieved with less effort and with less incurred costs.

Additionally, residents of the study area have a greater than average income for the City of Surrey at $76,161 per year, which is also indicated by the high rate of home ownership in the area, at 87.1 percent. Within the study area, home ownership is assumed to approach 100 percent, as the census area includes several apartment buildings that affect ownership percentages. The population is also extremely stable, with 86.8 percent of the population considered to be non-movers, or residents who have lived in the same place for at least five years, for census purposes. A financially successful, stable population can be seen as an ideal situation for efforts to improve the community, as one could assume that residents have some commitment to the area, and the financial means to incite change. These characteristics are considered "necessary conditions" in a report in the Journal of the American Planning Association, which describes "residents...who are attached to their current place of residence" and "households with adequate steady income" as important neighbourhood qualities when attempting to implement large scale improvements[241].

4.7 Wider Contexts and Trends

The Fleetwood study area and overall suburban development are and will be shaped by a diverse range of world and regional trends in the coming decades. While not all of these trends have a direct impact on the built world, they do establish the setting in which city and suburb planning take place. Each should be clearly understood prior to implementing future development plans.

[240] City of Surrey Planning and Development Department

[241] Carmon p. 427

4.7.1 Population

Within the past four decades, the global population has doubled from three to six billion people, and is continuing to expand[242]. Current estimates predict that a population peak could occur at nine million and then decline back to current levels by the year 2100[243]. While developing countries have accounted for most contemporary population growth, highly developed countries, such as the United States and Canada, are also experiencing continued population growth due to high levels of immigration[244].

Over the same time period, the population of the Lower Mainland of British Columbia has increased "continually, but not steadily" from less than one million in 1964, to 2.43 million in 2004[245]. Analysis of birth, death, and immigration/emigration rates within the region have lead to current projections that the region's population will increase from 2.43 million people to 3.29 million by 2024 and to 4.02 million by 2044, a total addition of 1.59 million people, or 65 percent of the current population[246].

Over the five year period from 1996-2001, Fleetwood's population increased 18 percent, or 3.6 percent each year. According to City of Surrey information, this growth is expected to continue, with a total population growth of over 33 percent by 2021. Meanwhile, the population of the City of Surrey as a whole, which increased 14 percent over the 1996-2001 time period, is expected to reach populations 53 percent higher by 2021[247]. With this amount of growth, current Surrey development will either have to become denser or continue to move out into more and more undeveloped and agricultural land. Given this expansion in population, plans for how to accommodate future residents sustainably within the region will be essential. For the thesis, increasing populations lend added importance to intensifying existing residential densities within the study area, enabling more people to be accommodated within existing development.

242 Reid, et al. p. 75

243 The Sheltair Group, *A Sustainable Urban System* p. 4

244 Reid, et al. p. 114

245 Urban Futures Institute p. 6

246 Urban Futures Institute p. 28

247 City of Surrey, *Surrey Population Estimates and Projections*

4.7.2 Demographics

Populations within the Lower Mainland are also changing in their demographics, particularly age, ethnicity, and household composition. According to one a report by the Urban Futures Institute, the region's population "is currently older than it has ever been, to the extent that the youngest age groups have the smallest share of the population, and the oldest age groups the largest share on record[248]." This is easily explained by the post-WWII "baby boom," whose resulting generation is now entering retirement. Even with the expected influx of young immigrants, who most commonly range in age from 25 to 39, current trends will more than double the number of residents age sixty and older in the region. The smallest increases in population will be in the youngest age groups, namely those under the age of twenty-nine[249].

This aging of the population is expected to alter housing and transportation markets, as well as energy consumption, as life styles and daily needs change for the average Lower Mainland resident. Recent research discusses the links between an aging population and decreasing automobile use[250], while others find a growing interest among older adults for transit-accessible housing[251]. A report by Natural Resources Canada indicates that seniors over the age of 65 spend more time at home and consequently "have different energy consumption profiles than other types of households, particularly with respect to larger end uses such as space and water heating[252]," suggesting that overall household energy consumption will continue to change with demographics.

At the same time, household composition has changed significantly in recent decades, with young singles and elderly outnumbering the nuclear family, now that 65 percent of households are without children[253]. In addition, newer family structures such as single parent families, same sex partners, and working mothers may lead to new desires in the

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248 Urban Futures Institute p. 8

249 Urban Futures Institute p. 31

250 Litman, *Transportation and Land Use*; Litman, Blair, et al., *Pedestrian and Bicycle Planning*; Handy, *Understanding the Growth in Non Work VMT* and others.

251 Dorn address

252 Natural Resources Canada, *Energy Efficiency Up Close* p. 7

253 Dunham-Jones p. 11

housing market[254]. Recent investigations into the future of suburbia have anticipated interest in down-sizing opportunities such as condominiums and rental apartments, lofts, and combined living and working arrangements[255], even within the suburbs, where a majority of North Americans now reside. For the thesis, changing demographics imply an increasing demand for housing, transportation and lifestyle alternatives, which can be addressed through a variety of retrofit design strategies within the study area.

4.7.3 Urban Sprawl and Land Scarcity

According to the Millennium Ecosystem Assessment, approximately half of the six billion people currently living on the planet reside in urbanized areas, up from less than 15 percent at the turn of the past century[256]. In highly developed nations, the percentage of people in urban areas often exceeds 80 percent[257]. These urban areas, however, are often not designed to accommodate people efficiently, and therefore alarming rates of forests, grassland, productive farmland, and other valuable ecosystems are lost every day to new, low-density urban development.

Within the GVRD, land use is limited by mountains, water, and the Agricultural Land Reserve; however, within these limitations not all municipalities are using land resources wisely. BC's Sprawl Report for 2004 indicates many areas performing poorly in terms of sprawl indicators, including Maple Ridge, Chilliwack, and the City of Surrey[258]. For example, the City of Surrey expects to accommodate an additional population of 200,000 by the year 2021[259]. At the city's current population densities, this would require an additional 8,000 hectares of land for development, compared to only 1,800 hectares at the City of Vancouver's significantly more intensive housing densities. For the thesis, the issue of sprawl and land scarcity makes intensifying land uses and residential densities within the study area an essential task in preventing further encroachment on the region's agricultural land and natural areas.

[254] Hayden p. 14
[255] Dunham Jones p. 13
[256] Reid, et al. p. 114
[257] Reid, et al. p. 114
[258] Smart Growth BC, *BC Sprawl Report*
[259] City of Surrey, *Official Community Plan*

4.7.4 Resource Depletion and Energy Costs

As world populations grew to six billion people between 1960 and 2000, the global economy "increased more than six-fold," consuming raw materials and natural resources at unprecedented rates[260]. Pressures to meet the demands for both renewable and non-renewable resources, from fresh water to fossil fuels, have been the cause of great ecosystem change and degradation[261], as supplies of these resources continue to decline.

Among North Americans and most of the developed world, people are generally accustomed to having unlimited access to resources, and rarely recognize approaching limits[262]. Within Canada, natural gas use continues to increase by 1 percent every year[263], while gasoline use increased 7 percent in five years during the period of 1995-1999[264]. As many studies indicate, these resources are at or near declines in availability, with natural gas potentially depleted by 2050-2060[265]. Regionally, hydro-electricity capacities in British Columbia are reaching their limits under current levels of consumption, while reduced precipitation has made power capacity for hydro plants less predictable[266]. Further resource scarcities could affect food and water supplies, create added pressure for land and timber, and raise prices for goods and services.

Consequently, resource prices, and natural gas in particular, have been rising throughout North America. Some of these increases, as reported in local news, add as much as $250 to the standard home heating bill[267]. For British Columbians, natural gas prices have more than tripled over the historically high rates experienced in the 1990s, and the Canadian National Energy Board reports that gas prices have become more volatile, suffering from sharp price spikes in recent years[268]. Although short term forecasts predict a leveling of gas prices, longer term investigations predict lower production rates, depleted wells, and

[260] Reid, et al. p. 19

[261] See Reid, et al., full report for details

[262] The Sheltair Group, *A Sustainable Urban System* p. 4

[263] The Sheltair Group, *Energy Foundation Paper* p. 15

[264] The Sheltair Group, *Energy Foundation Paper* p. 17

[265] The Sheltair Group, *The Story Behind* p. 8

[266] The Sheltair Group, *Energy Foundation Paper* p. 14

[267] *The Unnatural Price of Natural Gas*

[268] National Energy Board p. 1

continual increases in consumption, paired with prices much higher than historical averages. Similar scenarios are occurring with gasoline, as summer 2005 prices beat the record Canadian average that has held for twenty years[269]. For the thesis, continued increase in energy prices over the long term may become another incentive for new development patterns within the study area, as current suburban-residential ways of life become unaffordable for a growing percentage of the population.

4.7.5 Technology

Throughout the twentieth century, the development of scientific knowledge has enabled profound advances in humankind's control of the physical world. Although these advances have generally allowed people to expand and consume new things, current and future technologies are developing to work against that pattern. Trends such as miniaturization, the movement of information, economies of scope, networks and distributed systems, multiple and synergistic functions, and decentralization will serve to increase productivity and resiliency while having less impact on surrounding ecosystems[270]. Within the thesis, technologies that support a transition from carbon to hydrogen based fuels, particularly concerning transportation and the elimination of internal combustion engines, and technologies that support the adoption of renewable energy sources are considered especially important for the reduction of greenhouse gas emissions.

The Sheltair Group's paper *The Story Behind the Energy Backcast Scenario* predicts the emergence of numerous transportation and building technologies that serve these purposes, including various fuel-cell and hybrid vehicles, active solar systems, and district energy systems within the next five to forty years[271]. These predictions are supported by continued growth in investment in renewable energy technologies, and the increasing sales and marketability of existing technologies such as photovoltaics. The *Renewables 2005 Global Status Report* states that nearly thirty billion dollars was invested in renewable

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[269] Centre for Energy

[270] The Sheltair Group, *A Sustainable Urban System* p. 2

[271] The Sheltair Group, *The Story Behind* p. 4-12

energy capacity in 2004, up from less than ten billion dollars ten years ago[272], while photovoltaics and wind power have increased worldwide generation capacity 60 and 30 percent per year respectively since 2000[273]. For the thesis, the development and increasing availability of new technology expands the possibilities for energy generation and emission mitigation for the study area over time, and necessitates careful incremental planning for retrofit strategies to avoid limiting future opportunities.

272 REN21 Renewable Energy Policy Network p. 14

273 REN21 Renewable Energy Policy Network p. 8

CHAPTER 5:
THE FLEETWOOD RETROFIT

5.1 Targets for Emission Reductions in the Fleetwood Study Area

Having reviewed a range of energy and emission reduction principles and strategies in Chapter 3 and having analysed current energy consumption and emission patterns for the Fleetwood site in Chapter 4, the thesis can now establish the possibilities for carbon emission reductions within the Fleetwood site. An essential first step in this process is understanding the various types of emissions reductions that can be made within the study area, followed by an exploration of the levels of reduction targets required to meet overall emissions related goals. As the thesis recognises that a wide range of reductions in emissions for the study area, from 25 percent mitigation to achieving carbon neutrality, would be a positive contribution to overall environmental conditions, the possibilities of multiple emission reduction goals – 25, 50, 75, and 100 percent reductions – are considered.

5.1.1 Areas of Action

Areas of action are the types of actions that can be taken within the study area to reduce greenhouse gas emissions. As illustrated in Chapter 4, the highest priority areas of action for significantly reducing emissions in the study area are:

1. Decreasing the amount of emissions generated from housing energy consumption
2. Decreasing the amount of emissions generated from transportation energy consumption
3. Generating clean, renewable energy on site

These general areas of action can be supplemented by carbon sequestration efforts such as the incorporation of trees and substantial landscaping throughout the study area. A combination of each of these areas of action is imperative to maximising carbon reductions within the study area, as well as creating an overall more stable and resilient community which both limits its impact on the surrounding environment and has the ability to meet its energy needs on site.

Reducing the amount of energy consumed on site can be achieved in several ways. Previous chapters have discussed the ability of design solutions to mitigate energy consumption and emissions within a project; however, even in the absence of design changes, technological improvements such as more efficient appliances or automobiles can contribute to overall neighbourhood performance. Similarly, resident behaviour, such as the choice to drive less or turn down the thermostat, can significantly reduce household energy consumption. Although design related reductions remain the focus of this project, any combination of these factors – design, technology, and choice – can serve to meet emission reduction goals.

5.1.2 A Solution Space for Emissions Reduction

Achieving significant carbon emission reductions within the study area does not have a singular design solution; instead, there are numerous combinations of strategies that can achieve equal or similar results. The intensity of reductions and offsets may be evenly distributed across each area of action, or solutions may emphasise a particular action, such as energy generation, in order to achieve reduction goals. A range of appropriate permutations can be diagrammed as a "solution space" for the project, within which any combination will yield desired results. For example, carbon neutrality (a 100 percent reduction) might be achieved by a 60 percent reduction in both housing and transportation emissions, while generating 120 percent of current home energy loads (Figure 5.1, point A), or by reducing emissions from home energy consumption 40 percent and generating 60 percent of current energy loads, if emissions from driving are completely eliminated (Figure 5.1, point B). These combinations of reductions provide targets for design strategies as various retrofit opportunities for the neighbourhood are considered.

The solution space for carbon neutrality, along with solution spaces for 75, 50, and 25 percent reductions, have been generated by calculating the range of reductions and offsets possible for each area of action. Housing and transportation emissions were taken as simple reductions at 10 percent intervals (Table 5.1), while offsets from on site energy generation were considered at 20 percent intervals ranging from zero to 200 percent of current housing energy requirements. For the purpose of defining the solution space, emission offsets from energy generation are assumed to be equivalent to reductions in housing emissions (i.e. a 60 percent housing emission yields the same result as generating

60 percent of energy), although in application, how on site energy is used can greatly affect the emissions offsets achieved. For example, zero-emission electricity from photovoltaic generation will offset substantially more carbon emissions if used to power an electric vehicle which replaces a gasoline powered vehicle, than if used to run appliances typically powered by hydroelectricity.

Table 5.1 Emissions Reductions by Area of Action

Housing Emissions per Capita			1,944.3	
Transportation Emissions per Capita			3,368.7	
Total per Emissions Capita			**5,313.0**	
Reductions			**Generation**	
Percent Reduction	1. Housing Emission Reduction (kg)	2. Transportation Emission Reduction (kg)	Percent Current Housing Energy Load Generated	3. Emissions Offset Through Generation (kg)
0%	0	0	**0%**	0
10%	194.4	336.9	**20%**	388.9
20%	388.9	673.7	**40%**	777.7
30%	583.3	1,010.6	**60%**	1,166.6
40%	777.7	1,347.5	**80%**	1,555.5
50%	972.2	1,684.4	**100%**	1,994.3
60%	1,166.6	2,021.2	**120%**	2,333.2
70%	1,361.0	2,358.1	**140%**	2,722.0
80%	1,555.5	2,695.0	**160%**	3,110.9
90%	1,749.9	3,031.8	**180%**	3,499.8
100%	1,994.3	3,368.7	**200%**	3,988.6

The figures provided in Table 5.1 were run through a computer to generate 1,331 possible combinations of reductions and offsets, with one figure coming from each of the three areas of action. The sums of these permutations were organised by value and those sums equal to or greater than the total emissions per capita were considered to achieve carbon neutrality, or a 100 percent reduction. The process was repeated for smaller reductions, delineating those combinations which yielded 75, 50 and 25 percent emission mitigation. The permutations meeting the requirements for each carbon reduction goal were then graphically represented in Figures 5.1 and 5.2, where the dark grey fields show possibilities for achieving reduction goals while generating 100 percent or less of current housing energy requirements. The adjacent light grey fields highlight additional potentials for achieving goals if higher levels of energy generation are achieved.

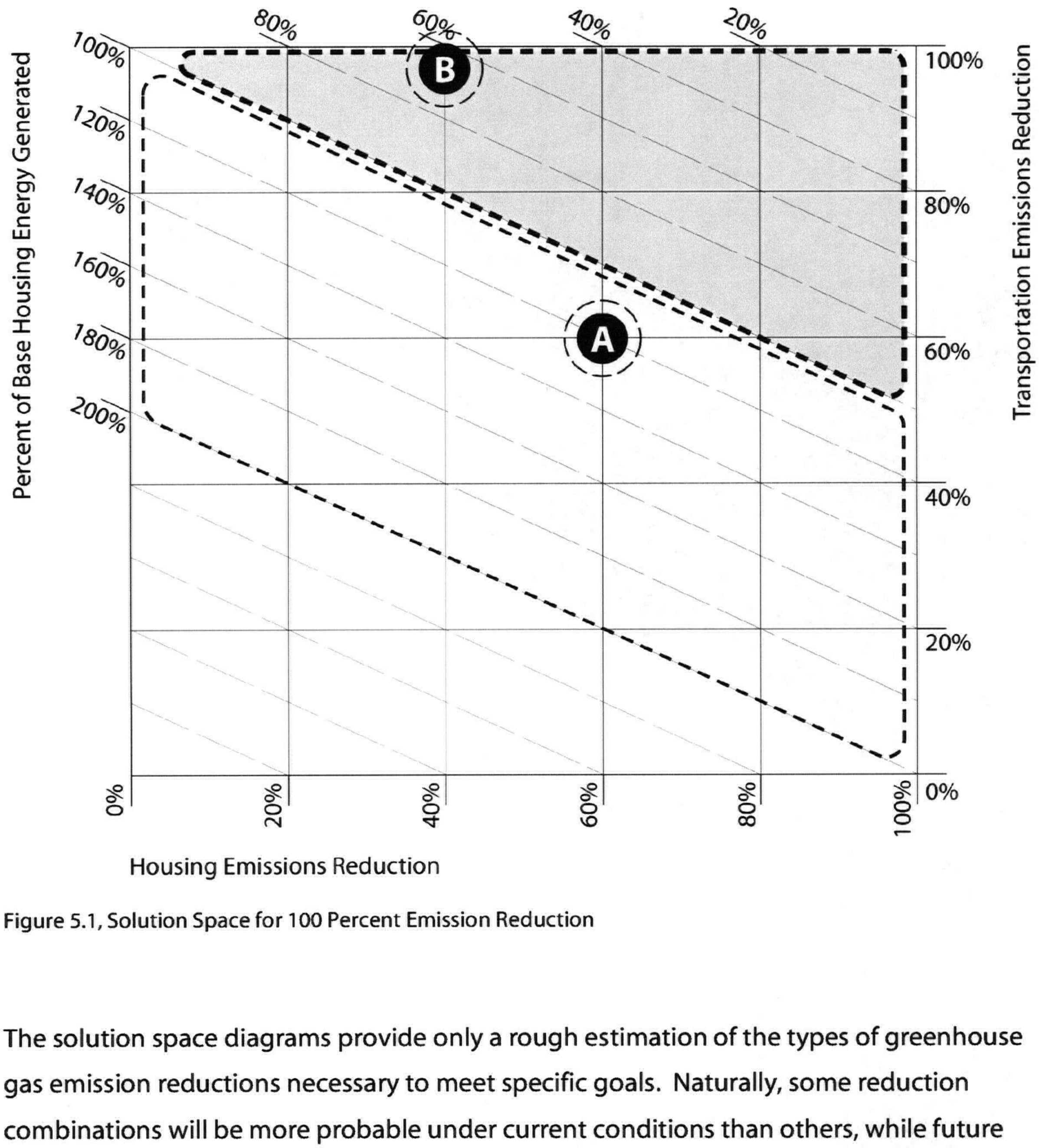


Figure 5.1, Solution Space for 100 Percent Emission Reduction

The solution space diagrams provide only a rough estimation of the types of greenhouse gas emission reductions necessary to meet specific goals. Naturally, some reduction combinations will be more probable under current conditions than others, while future advances such as hydrogen fuel cells may change the nature of possibilities dramatically. It is essential to note that the solution space diagrams are target setting tools only, and that choosing a combination of targets within a solution space does not guarantee that a specific reduction will be achieved. Because offsets from energy generation in particular have been derived from housing emissions that encompass both hydroelectricity and natural gas, simply contributing generated electricity to the municipal hydroelectric grid, rather than applying it to more emissions intensive uses such as space heating or transportation, will reduce overall reductions. Despite this limitation, charting solution spaces for the study area confirms that achieving more ambitious sustainability goals like emissions mitigation is theoretically possible and delineates the range of targets that will result in achieving those goals.

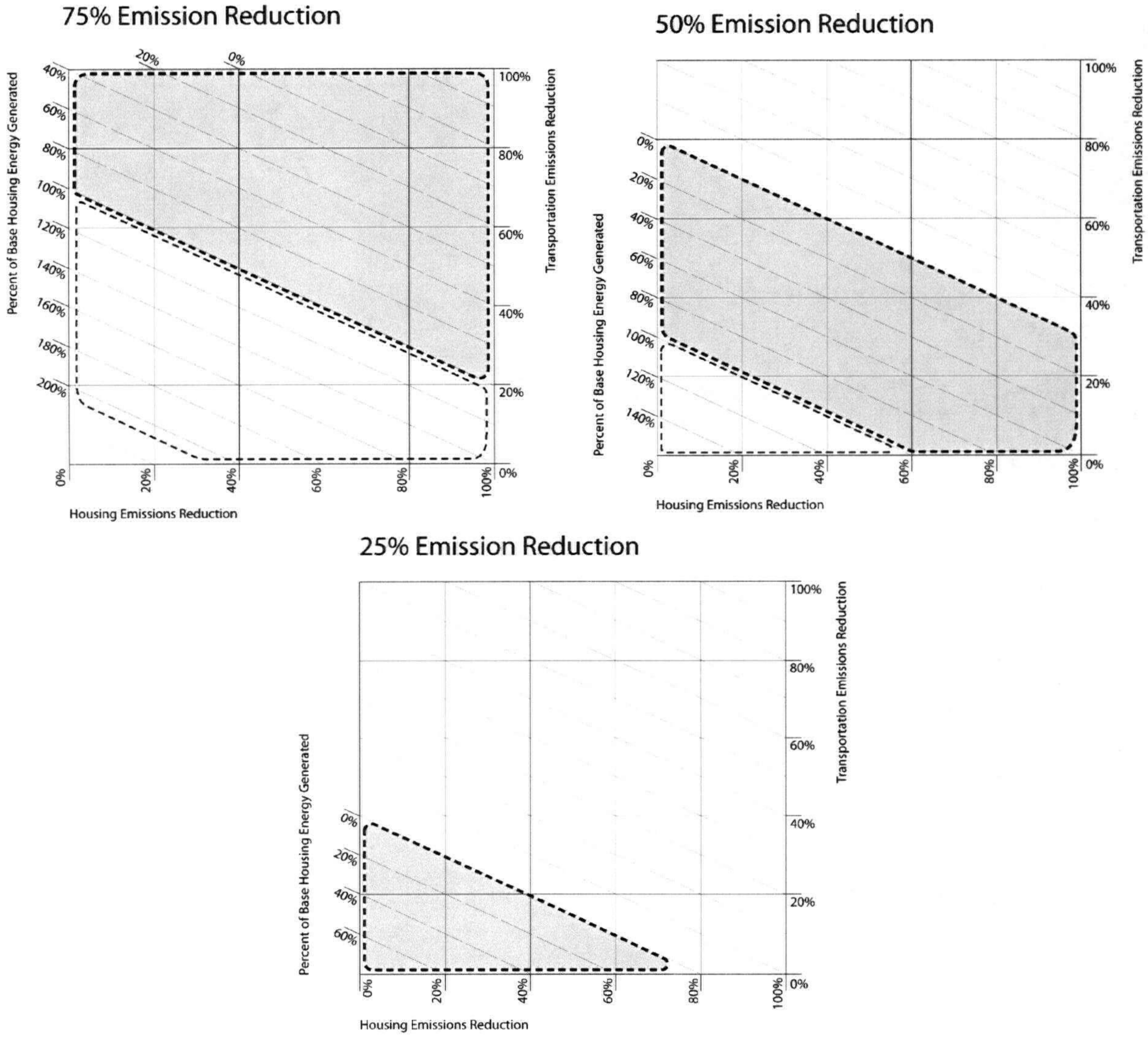


Figure 5.2, Solution Spaces, 75, 50, and 25 Percent Reductions

Considering solution spaces for the study area, rather than a singular retrofit design, also enables greater flexibility in the application of design strategies when considering issues of resident acceptance and uncertain futures for the thesis. Mapping multiple possibilities for emissions mitigation has the potential to provide households or individuals with greater choice regarding how emission reduction goals will be met in ways that compliment varying lifestyles within the study area. For example, to reduce emissions a retired couple may find that eliminating driving is an appropriate and economical option if adequate public transportation and basic services are provided within walking distance, while a working family with children may choose to invest heavily in energy generation, using an electric vehicle to run daily errands.

Similarly, neighbourhood targets may be adjusted over time depending on future occurrences. A community working towards the target of a 60 percent housing emissions reduction, a 60 percent transportation emissions reduction and 120 percent energy generation (as described by point A, Figure 5.1) may find that in the coming decade internal combustion engines have been phased out of use, eliminating driving related emissions. In this case, the neighbourhood might be able to reduce further capital investment in energy generation capacity while still meeting carbon neutrality goals.

The issues of diverse, individual choices for emissions mitigation within the study area and the ability to adjust targets over time are not further considered within the scope of the thesis. Instead, the scenarios developed in Section 5.3 deal only with average per capita reductions for the study area and reduction targets which are feasible within current contexts based on existing research. However, future research into the immense complexities of emission reduction targets, as suggested by the solution spaces developed in this section, is essential.

5.2 Possibilities for Change in the Suburban Context

Implementing design strategies for mitigating emissions within a community is largely dependent on residents' willingness to accept changes to the typical suburban form, and their willingness to accept strategies that extend to the block or neighbourhood scale, requiring a level of cooperation among neighbours (See Section 2.3, The Challenge for Suburban Retrofits). The willingness to accept change within a community may result from any number of occurrences: increasing energy and fuel prices could make current lifestyles unaffordable, or deteriorating health from diminished environmental quality and an aging population could make walkability, public transportation, and local amenities high priorities for the future. Demographic changes including an increase in "empty nesters," growing numbers of non-family households and expanding immigrant populations may also make neighbourhood retrofits more compelling by creating the need for new suburban housing types. The 2004 American Community Survey found that already 48 percent of the U.S. housing market is "looking for shorter commutes than existing suburban locations offer[274]," while a report from the American Association of Retired Persons finds that 71 percent of "older households" want to live in walking distance of transit[275]. Certainly, some level of emission reductions can be achieved within the current suburban community pattern; however, to achieve more substantial results the limitations of acceptance and scale must be addressed.

5.2.1 Challenging the Suburban Form

The contemporary suburban form is a strong influence on the types of design strategies that can be implemented within the study area. While some strategies fit easily into the suburban context, others, such as a gridded street system, are excluded by physical and technical limitations (Table 5.2). Still others can be implemented but involve challenging the existing form; often, these strategies offer new opportunities for emissions mitigation in the neighbourhood. For the purpose of the thesis, "compatible" strategies are defined as those which do not change significantly the visual appearance of the neighbourhood, nor greatly affect current daily lifestyles. "Incompatible" strategies are defined as those measures which would involve significant destruction of existing neighbourhood elements and those which are physically not feasible for the site, such as micro-hydroelectricity generation. However, the thesis recognises that nearly any design strategy may become compatible within longer time frames as community needs change and urban infrastructure requires repair or redevelopment.

[274] Dunham-Jones p. 13

[275] Dorn address

Challenging the suburban form implies a reconsideration and reuse of many long-cherished physical characteristics of the residential subdivision, along with the ideals and values those formal manifestations have come to represent. While the thesis does not propose a wholesale redevelopment of the study area, many of the common attributes of a subdivision, such as garages, backyards, and streets, could be considered resources for the neighbourhood to utilise in new ways towards the creation of a more effective and productive local environment. An examination of the opportunities created by these neighbourhood attributes has been provided in Chapter 4.

Table 5.2 Design Strategies and Compatibility with Suburban Form

Strategy	Compatible	Challenge	Incompatible	Rationale
Highly efficient buildings or building retrofits				
Upgraded major appliances	●			No change to form
Upgraded lighting	●			No change to form
Increased insulation values	●			No change to form
Upgraded doors and windows	●			No change to form
Reduced air infiltration	●			No change to form
Upgraded heating system	●			No change to form
Solar orientation				
Buildings oriented to south			●	Buildings previously sited
Street and parcel arrangement maximises solar access			●	Streets and parcels previously developed
Increased glazing on southern facades	●			Potential to be incorporated in retrofit process
District energy systems				
Underground heat piping through dense development		●		Densities currently too low
Renewable on site energy generation				
Photovoltaics	●			Potential to be integrated with roof
Geo-exchange systems	●			Underground, no change to form
Combined heat and power systems		●		Densities currently too low
Wind turbines			●	Not feasible for site
Micro-hydroelectricity			●	No water available on site
Higher densities				
Stacked residential		●		Not consistent with current ownership, building and lot patterns
Attached residential		●		Not consistent with current ownership, building and lot patterns
Secondary suites, basement	●			No change to form
Secondary suites, garage		●		Requires change in building use

Strategy	Compatible	Challenge	Incompatible	Rationale
A diverse mix of land uses				
Town center or main street commercial district			●	Limited by existing neighbourhood layout
Mixed use, residential stacked above commercial		●		Not consistent with current ownership, building and lot patterns
Home based businesses	●			No change to form
Increased on site vegetation				
Tree planting	●			Some planting currently existing
Substantial landscaping and productive gardens	●			Some planting currently existing
A finer grained street and path system				
Standard street grid			●	Streets previously developed
Modified street grid			●	Streets previously developed
Lanes or alleys			●	Streets previously developed
Cycling lanes and sidewalks	●			Existing sidewalks, cycling lanes do not change form of street
Pedestrian and cycling amenities				
Pedestrian and cycling paths and connections to larger networks		●		Most property privately owned, connections currently difficult
Bicycle storage and showers at appropriate destinations		●		Currently no major neighbourhood destinations
Traffic calming measures	●			Some measures already in place
Access to public transit				
Transit stops within neighbourhood		●		Density currently too low
Frequent transit service		●		Density currently too low

Strategy	Compatible	Challenge	Incompatible	Rationale
Alternative transportation options				
Carpooling and car-sharing programs	●			No change to form
Community shuttle service	●			No change to form
Charging stations for electric and fuel cell vehicles		●		Not consistent with current building patterns
Telecommuting options	●			No change to form
Goods delivery services	●			No change to form

5.2.2 Working Across Scales

Like the attachment to suburban forms, the values of private ownership and personal autonomy, often intrinsic to the suburban lifestyle, currently limit the ability to enact certain design strategies. Shared investment and cooperative projects among neighbours are typically the exception to the rule in average suburban developments. However, achieving the efficiencies, cost sharing opportunities, and synergies often provided by broader scale strategies utilised among groups of neighbours or the community at large can mean substantially greater success in reducing the energy use and emissions for the neighbourhood. Working across scales does not necessarily imply making substantial changes to the suburban form. Certain strategies, such as a shared ground source heat pump installed underground between a cluster of four houses, achieves significant efficiency, cost savings, and energy reductions without altering the single family pattern or the lifestyles of local residents. A list of strategies, associated scales and their benefits are summarised in Table 5.3.

For the purpose of the thesis, parcel scale strategies are defined as those measures which can be implemented entirely within the boundaries of a privately owned piece of property. Block and cluster scale strategies are defined as those which extend between two or more houses, but not to the entire neighbourhood. Neighbourhood scale strategies are defined as measures which necessarily include the entire community in their implementation.

Table 5.3 Design Strategies and Scale of Implementation

Strategy	Parcel	Block/Cluster	Neighbourhood	Rationale
Highly efficient buildings or building retrofits				
Upgraded major appliances	●			House by house upgrade
Upgraded lighting	●			House by house upgrade
Increased insulation values	●			House by house upgrade
Upgraded doors and windows	●			House by house upgrade
Reduced air infiltration	●			House by house upgrade
Upgraded heating system	●	●	●	Scale depends on system; potential to share capital costs at larger scales
Solar orientation				
Buildings oriented to south	●			Dependent on building and site design
Street and parcel arrangement maximises solar access		●	●	Dependent of street and block layout
Increased glazing on southern facades	●			Dependent on building orientation and design
District energy systems				
Underground heat piping through dense development			●	Involves neighbourhood infrastructural changes; potential to share capital costs among residents
Renewable on site energy generation				
Photovoltaics	●	●	●	Potential to be applied at any scale; requires shared investment at larger scales
Geo-exchange systems	●	●		Individual systems or shared among 4-6 homes; potential to share capital costs at larger scales
Combined heat and power systems		●	●	Involves neighbourhood infrastructural changes; potential to share capital costs among residents
Wind turbines	●	●	●	Scale depends on system
Micro-hydroelectricity	●	●	●	Scale depends on system

Strategy	Parcel	Block/Cluster	Neighbourhood	Reason
Higher densities				
Stacked residential	●	●		Requires larger or consolidated lots
Attached residential	●	●		Requires larger or consolidated lots
Secondary suites, basement	●			House by house retrofit
Secondary suites, garage	●			House by house retrofit
A diverse mix of land uses				
Town center or main street commercial district		●		Requires larger or consolidated lots
Mixed use, residential stacked above commercial	●	●		Requires larger or consolidated lots
Home based businesses	●			House by house retrofit
Increased on site vegetation				
Tree planting	●	●	●	Potential to be applied at any scale; individual or community intiatives
Substantial landscaping and productive gardens	●	●	●	Potential to be applied at any scale; individual or community intiatives
A finer grained street and path system				
Standard street grid			●	Involves neighbourhood infrastructural changes
Modified street grid			●	Involves neighbourhood infrastructural changes
Lanes or alleys			●	Involves neighbourhood infrastructural changes
Cycling lanes and sidewalks			●	Involves neighbourhood infrastructural changes
Pedestrian and cycling amenities				
Pedestrian and cycling paths and connections to larger networks		●	●	Involves neighbourhood infrastructural changes; requires some access to private property
Bicycle storage and showers at appropriate destinations	●	●		Requires investment at new destination sites
Traffic calming measures		●	●	Involves neighbourhood infrastructural changes

Strategy	Parcel	Block/Cluster	Neighbourhood	Reason
Access to public transit				
Transit stops within neighbourhood		●	●	Involves neighbourhood infrastructural changes
Frequent transit service			●	Requires density increases throughout neighbourhood
Alternative transportation options				
Carpooling and car-sharing programs		●	●	Requires sufficient resident participation and organisation
Community shuttle service			●	Requires sufficient resident participation and neighbourhood density
Charging stations for electric and fuel cell vehicles	●	●	●	Scale depends on system; potential to share capital costs at larger scales
Telecommuting options	●	●	●	Potential to be applied at any scale; individual or community initiatives
Goods delivery services	●	●	●	Potential to be applied at any scale; individual or community initiatives

5.2.3 Scenario Map

By considering the possible relationships between the ability to utilise design strategies that challenge existing suburban form and design strategies that function at scales beyond the parcel, four broadly based scenarios are formulated, representing a range of possible retrofit futures for the study area. Analysed within a two-dimensional matrix (Figure 5.3), these scenarios are driven by the limitations discussed in previous sections: the level of challenge to suburban form, and the scales at which retrofit strategies take place[276].

[276] A similar use of the scenario mapping technique in a sustainability context can be found in Cohen, et al.

The lower, left corner represents a scenario in which there is no challenge to form, and only parcel scale interventions. While emission reductions are still achieved, it is the lowest level of improvement for the neighbourhood. Alternatively, the upper, right corner represents a scenario in which strategies are allowed to both challenge the standard suburban form and expand to block or neighbourhood level interventions, maximising emissions reductions and offering the greatest opportunity for achieving carbon neutrality. Strategies such as a combined heat and power system, which requires adding density to the existing neighbourhood form while implementing a community scale distribution system, would be an alternative achievable under this scenario.

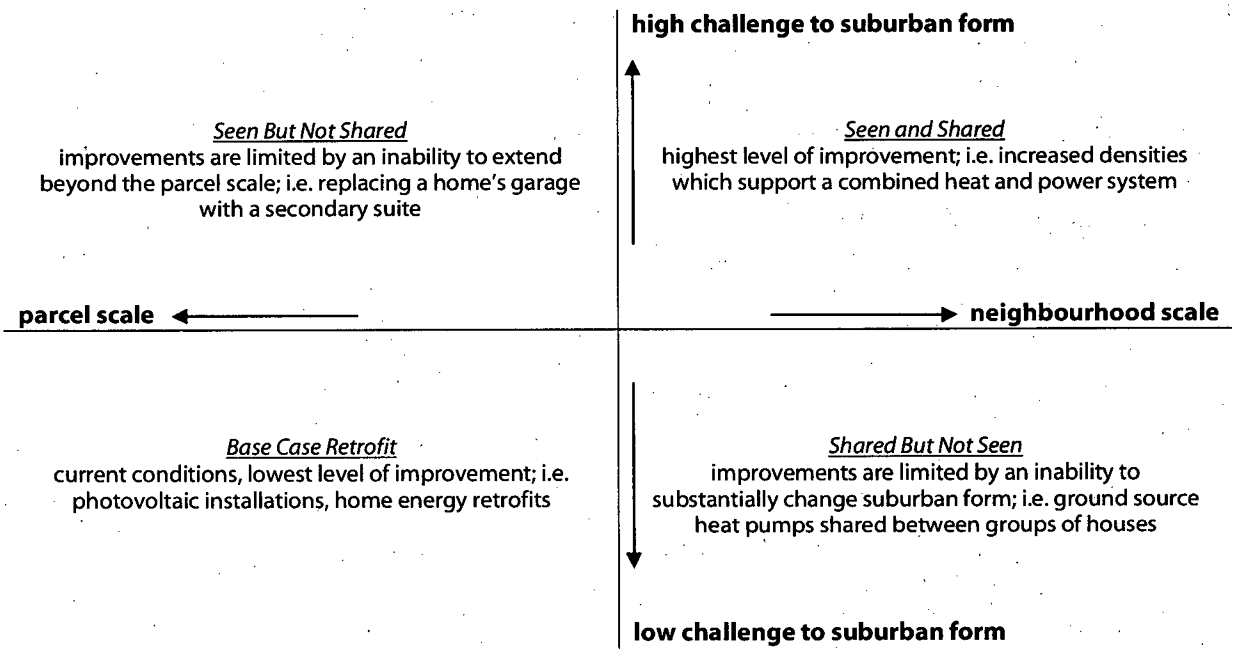


Figure 5.3 Scenario Map, Form and Scale

The other two quadrants represent scenarios in which one limitation is lifted, but not the other. For example, "seen but not shared" improvements may be able to challenge the visible suburban form within individual parcels, but not beyond the parcel scale, limiting emission reduction potential. Similarly, a "shared but not seen" scenario indicates that while larger scale interventions are achievable, only those which are invisible in the outward form of the neighbourhood are suitable. Again, emission reduction potential is limited. This scenario map will be used as the guidelines for the development of four neighbourhood retrofit scenarios, described in the following sections.

5.3 Four Neighbourhood Retrofit Scenarios

The assessment and analysis of the study area and related contextual issues enables the development of emissions mitigation scenarios which illustrate the wide range of design possibilities for the Fleetwood study area. While the thesis promotes foremost those design strategies that achieve the highest neighbourhood per capita reductions, the scenarios described in this section represent each of the four quadrants of the scenario map developed in section 5.2.3: Base Case Retrofit, Seen but Not Shared, Shared but Not Seen, and Seen and Shared. These scenarios utilise many of the design principles discovered in Chapter 3, but translate them as manifestations more appropriate for the specific challenges of suburbia.

5.3.1 Scenario Development

Four retrofit scenarios have been developed utilising the analysis presented in the previous sections. As these scenarios represent each of the four contextual neighbourhood futures described by the scenario map, the general characteristics of these futures are used to define the parameters for potential design strategies in each scenario, i.e. the Seen But Not Shared quadrant is defined by strategies which challenge suburban form but do not extend beyond the parcel scale. A list of design strategies meeting these qualifications can then be developed and assessed for expected levels emissions reductions (Table 5.4) so that realistic targets can be set based on solution spaces and the research on design strategies presented in Chapter 3. For example, if photovoltaics are the only energy generation source available to a scenario and their capacity is limited to 30 percent of current housing energy requirements (Table 5.4), then a target for energy generation cannot exceed 30 percent.

Targets for housing and transportation emission reductions and energy generation offsets can also be compared to the "solution spaces" developed for the project, as the space where the targets intersect indicates the general level of emissions mitigation (100, 75, 50, or 25 percent) which can be achieved. As discussed in Section 5.2, many combinations of targets included within the solution spaces are not achievable under the conditions which limit scenarios for the thesis; however, how the higher targets suggested by the solution spaces might be met in the future through technology, policy, or changing community values should be a topic of further research. The scenario development process is described in Figure 5.4.

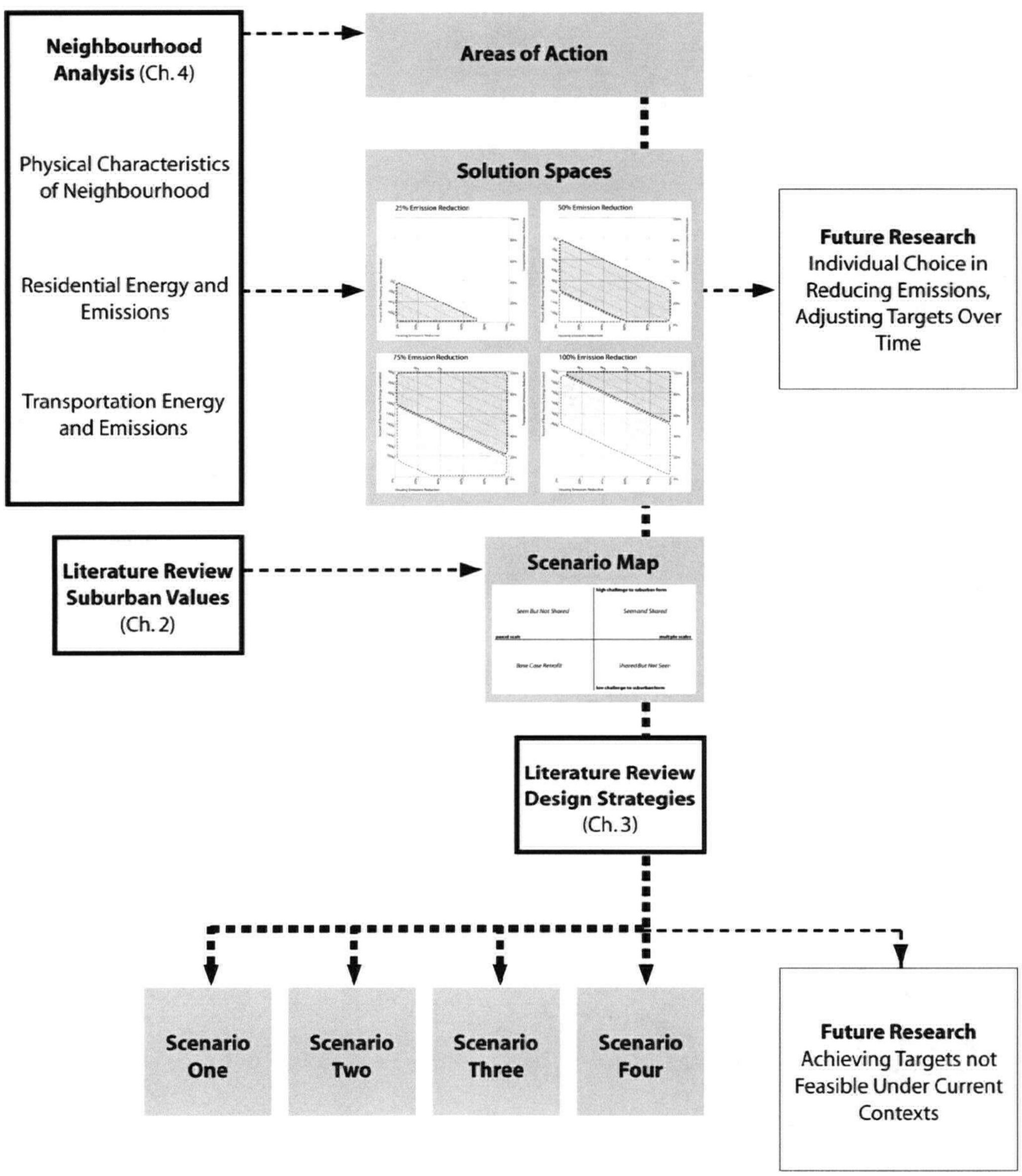


Figure 5.4, Scenario Development Process

5.3.2 Strategy Assessment for Suburban Retrofits

To provide a basis for scenario development, potential design strategies must be evaluated for their relationships to suburban form and scale and their capacity for emissions reductions. Form and scale assessments of common energy related design strategies have been summarised in Table 5.4, based on information provided in sections 5.2.1 and 5.2.2, while the review of design strategies and related research found in Chapter 3 has formed the basis for estimating emissions reductions. While the list of design strategies in Table 5.4 is not exhaustive, it does represent many of the most prevalent and studied strategies available at the time of the thesis. By following a similar process of assessment, additional strategies can be added to the list according to the needs of a study area. Also, parallel methods of analysis and comparison may be used within a community scenario development process to analyse other factors involved in sustainability neighbourhood retrofits, such as social and economic considerations, time, resource availability, and policy decisions.

The level of certainty regarding the emission reduction capacity for each design strategy varies significantly. In particular, design strategies intended to reduce vehicle travel and consequent transportation emissions are not only highly interrelated, but also heavily impacted by human choice and behaviour[277]. To ensure greater certainty within the thesis, developed scenarios tend to maximise the impacts of those strategies, particularly housing emission and energy generation strategies, which find greater agreement concerning emission reduction capabilities.

277 Handy, *Driving by Choice or Necessity* p. vii; Handy, *Regional versus Local Accessibility* p. 13

Table 5.4 Strategy Assessment: Form, Scale and Emission Reductions

	Suburban Form		Scale		Reduction
Strategy	Compatible with Form	Challenge to Form	Parcel	Block or Larger	Estimated Emission Reduction [a]
Highly efficient buildings or building retrofits					
Upgraded major appliances	●		●		Studies find that a total home retrofit can yield energy and emissions reductions of 25-40%
Upgraded lighting	●		●		
Increased insulation values	●		●		
Upgraded doors and windows	●		●		
Reduced air infiltration	●		●		
Upgraded heating system	●		●	●	Ground source heat pumps can reduce heating energy and emissions 40-60% Switching from natural gas to an efficient electric heat pump can reduce heating emissions 75% based on relative emission factors
Solar orientation					
Increased glazing on southern facades	●		●		Nominal; most study area homes are not oriented for solar access
District energy systems					
Underground heat piping through dense development		●		●	Heat/waste heat from a zero emission source like biomass can reduce heating emissions 100%
Renewable on site energy generation					
Photovoltaics	●		●	●	Based on available roof area and technology, max. housing emission offset is 30%
Geo-exchange systems	●		●	●	Ground source heat pumps can reduce heating energy and emissions 40-60%
Combined heat and power systems		●		●	Electricity and waste heat from a zero emission source such as biomass can eliminate most housing emissions.

Strategy	Suburban Form: Compatible with Form	Suburban Form: Challenge to Form	Scale: Parcel	Scale: Block or Larger	Reduction: Estimated Emission Reduction [a]
Higher densities					
Stacked residential		●	●	●	Higher densities do not have a direct affect on transportation emissions but have been shown to support public transportation and reduce daily vehicle travel
Attached residential		●	●	●	
Secondary suites, basement	●		●		
Secondary suites, garage		●	●		
A diverse mix of land uses					
Mixed use, residential stacked above commercial		●		●	Diverse land uses providing a range of services, when paired with pedestrian amenities and higher densities have been shown to reduce daily vehicle travel. Reports on driving reductions range from 10-60%, but are more commonly estimated between 20-30%.
Home based businesses	●		●		
Increased on site vegetation					
Tree planting	●		●	●	For each medium to large tree planted per capita, 1.7% of total per capita emissions will be sequestered annually
Substantial landscaping and productive gardens	●		●	●	Nominal
A finer grained street and path system					
Cycling lanes and sidewalks	●			●	Supports higher densities and diverse land uses to reduce vehicle travel and transportation emissions
Pedestrian and cycling amenities					
Pedestrian and cycling paths and connections to larger networks		●		●	Supports higher densities and diverse land uses to reduce vehicle travel and transportation emissions
Bicycle storage and showers at appropriate destinations		●	●		
Traffic calming measures	●			●	

Strategy	Suburban Form: Compatible with Form	Suburban Form: Challenge to Form	Scale: Parcel	Scale: Block or Larger	Reduction: Estimated Emission Reduction [a]
Access to public transit					
Transit stops within neighbourhood		●		●	Supports higher densities and diverse land uses to reduce vehicle travel and transportation emissions
Frequent transit service		●		●	
Alternative transportation options					
Carpooling and car-sharing programs	●			●	Supports reduced vehicle travel by reducing single occupancy vehicles
Community shuttle service	●			●	Supports reduced vehicle travel
Charging stations for electric and fuel cell vehicles		●	●	●	Each 100 kWh of electricity contributed to vehicle travel provides 320 km of travel for an electric vehicle and 190 km for a hydrogen fuel cell vehicle, reducing transportation emissions 2.8% and 1.7% respectively
Telecommuting options	●		●	●	Supports reduced vehicle travel by eliminating trips
Goods delivery services	●		●	●	Supports reduced vehicle travel by eliminating trips

[a] See related sections of thesis for references on emissions reductions.

5.3.3 Scenario One: Base Case Retrofit

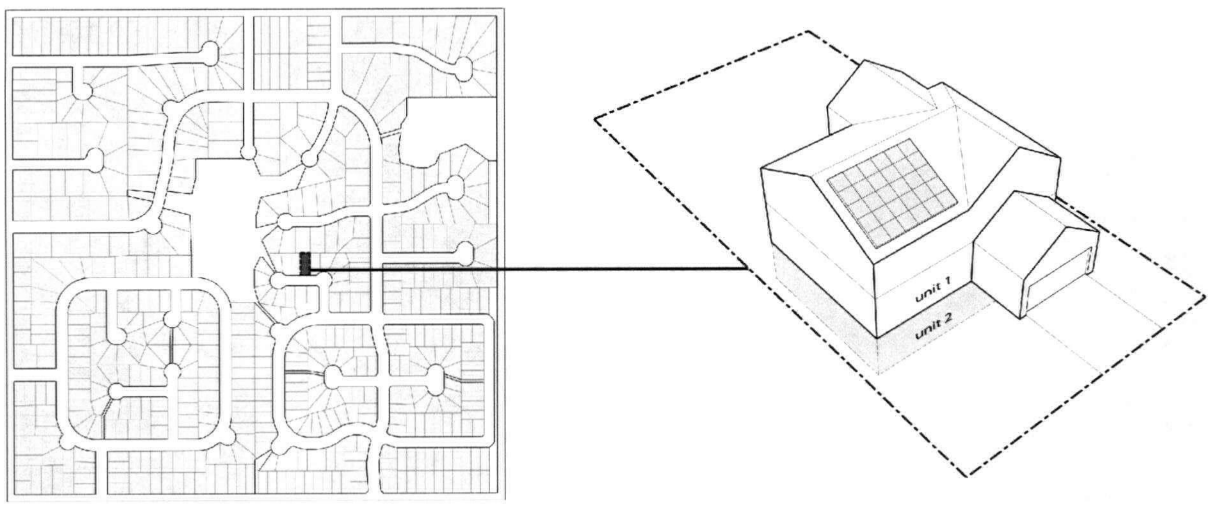


Figure 5.5 Scenario One, Base Case Retrofit

The Base Case Retrofit scenario is characterised by strategies that do not significantly alter the existing form of the development, and which do not extend beyond the parcel scale. The design strategies which conform to the characteristics required for this scenario are summarised in Table 5.5.

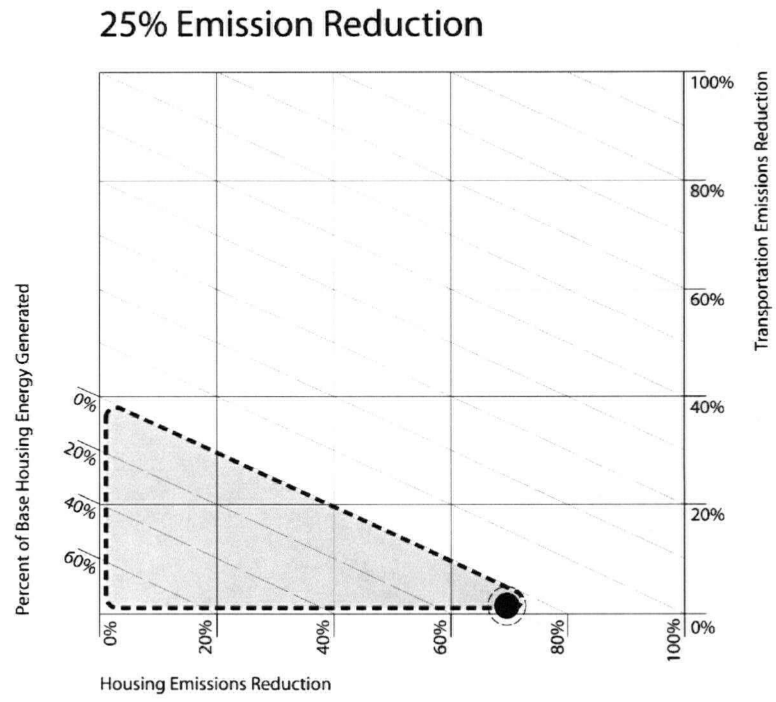
Table 5.5 Design Strategies, Base Case Retrofit

Highly efficient buildings or building retrofits	**Renewable on site energy generation**	**Increased on site vegetation**
Upgraded major appliances	Photovoltaics	Tree planting
Upgraded lighting	Geo-exchange systems	Substantial landscaping and productive gardens
Increased insulation values		
Upgraded doors and windows		
Reduced air infiltration		
Upgraded heating system	**Higher densities**	**Alternative transportation Options**
	Secondary suites, basement	Telecommuting options
		Goods delivery services
Solar orientation	**A diverse mix of land uses**	
Increased glazing on southern facades	Home based businesses	

Based on the design strategies available for the first scenario, the emission reduction targets set for the three major areas of action are listed in Table 5.6, yielding an estimated 25 percent total emission reduction for the study area. Emissions from housing energy consumption can be expected to reach a target of 70 percent reductions by replacing natural gas with hydroelectricity as an energy source for space heating and hot water, as well as reducing overall energy needs by 25 to 30 percent through home retrofits. Targets for transportation emission reductions cannot be reasonably set at more than 5 percent, as many of the strategies which support reduced vehicle travel, such as mixed land uses, are not options within the given scenario context. Energy generation for this scenario is limited to roof-installed photovoltaics and geothermal-exchange systems; however, because these systems cannot extend outside the parcel scale per the scenario, those parcels with more energy generation capacity are not assumed to share energy and offsets with those parcels with less generation capacity, so offset benefits will not be maximised. For this reason, an emissions offset target of 10 percent for energy generation has been set for the study area.

Table 5.6 Base Case Retrofit Scenario Targets

Housing Reduction	70%
Transportation Reduction	<5%
Energy Generation	10%



5.3.3.1 Seventy Percent Housing Emission Reduction

At the housing level, the Base Case Retrofit scenario reduces energy consumption through substantial home energy retrofits including the building envelope, lighting and appliances, and upgrades to the heating and hot water systems, yielding energy and emissions savings of 25 to 30 percent per household. The balance of the target is met by the conversion from natural gas to hydroelectricity for space heating and hot water, which reduces emissions from heating by 75 percent; a comparison of local carbon emission factors illustrates that a unit of natural gas emits over four times that of an equivalent unit of hydroelectricity. New construction on undeveloped areas of the site is limited by the scenario to continued detached, single family housing, but will be held to energy and emission performance standards equivalent to or better than existing, retrofitted homes. This new development, along with aggressive home retrofits, maintains the formal qualities of the residential neighbourhood while maximising housing energy benefits.

5.3.3.2 Five Percent Transportation Emission Reduction

The Base Case Retrofit scenario greatly restricts neighbourhood potentials for reduced vehicle travel and associated emissions by limiting many transportation related design strategies, such as mixed land uses and pedestrian and cycling paths, which serve to provide alternatives to automobile use. However, travel still has the potential to be slightly affected by providing secondary suites in study area homes, increasing residential and population density, which encourages increased public transit service. Already an established densification pattern in the Greater Vancouver Regional District, the insertion of one secondary suite in the basement of each new and existing household in the study area will double overall gross residential densities to nearly ten units per acre (25 units per hectare), a density supportive of increased public transit. Transportation reductions will be further influenced within the existing suburban form through the encouragement of home based businesses, alternative work options such as telecommuting, and goods delivery services, each of which in some measure increase the amount of daily needs that can be met within the neighbourhood.

5.3.3.3 Ten Percent Energy Generation

For the Base Case Retrofit scenario, renewable on site energy generation is limited to photovoltaic roof installations, as well as supplemental energy contributions from ground source heat pumps. While maximising roof surface photovoltaic coverage could serve to produce nearly 30 percent of household energy requirements, south-facing roof surface is not distributed evenly among households. Limiting strategies to the parcel scale and assuming that households will not invest in systems larger than necessary means that, on average, closer to 10 percent of housing energy needs per capita might be generated through solar technology. The electricity generated from photovoltaics, roughly 1,370 kWh per capita annually, can serve to supplement household hydroelectricity loads, offsetting an equivalent 10 percent of housing emissions from energy consumption. Rather than battery storage, generated electricity is contributed to the municipal grid through a net metering program, ensuring that generation is not limited by storage capacity.

5.3.3.4 Additional Reductions and Offsets

Although not included in initial emission reduction estimates, a small portion of the emissions still generated on site has the potential to be sequestered through the addition of trees and substantial plantings on each parcel. One large or medium deciduous or evergreen tree sequesters between 0.0495 tonnes of CO_2 and 0.1324 tonnes of CO_2 per year[278]. For this scenario one tree is planted per capita, sequestering an average of 92 kilograms of carbon annually[279], or an additional 1.7 percent of total per capita emissions.

Additionally, the ways in which the energy generated on site is used within the study area can greatly affect total emission reductions. While the Base Case Retrofit scenario assumes that electricity from photovoltaics is applied to household energy uses, much greater emissions reductions could be achieved by supplying the power to alternative vehicles. For example, if this energy was used to generate hydrogen for a fuel cell vehicle, 2,600 kilometers per capita could be traveled emissions-free annually according to the

[278] McPherson and Simpson Appendix A, Pacific Northwest Climate Region

[279] Sequestration rate based on the average of sequestration rates of large and medium deciduous and evergreen trees in the Pacific Northwest climate. McPherson and Simpson p. 113

conversion factors provided in Chapter 3, a transportation emission reduction of 23 percent. If the same amount of energy was used to power an electric vehicle, a study area resident could drive 4,400 kilometers, reducing transportation emissions by nearly 40 percent according to conversion factors. These additional reductions result in total per capita emissions mitigation of 40 and 51 percent respectively, substantially higher than the projected 25 percent reduction.

5.3.3.5 Lessons from the Base Case Retrofit Scenario

The examination of the Base Case Retrofit scenario enables the thesis to consider the potentials for emissions mitigation without significant changes to the common suburban form and without implementing strategies that extend beyond the private parcel. The development of the scenario suggests that even with current limitations, substantial improvements can be made to energy and emissions performance within the study area. A map of per capita carbon emissions for Scenario One is illustrated in Figure 5.6.

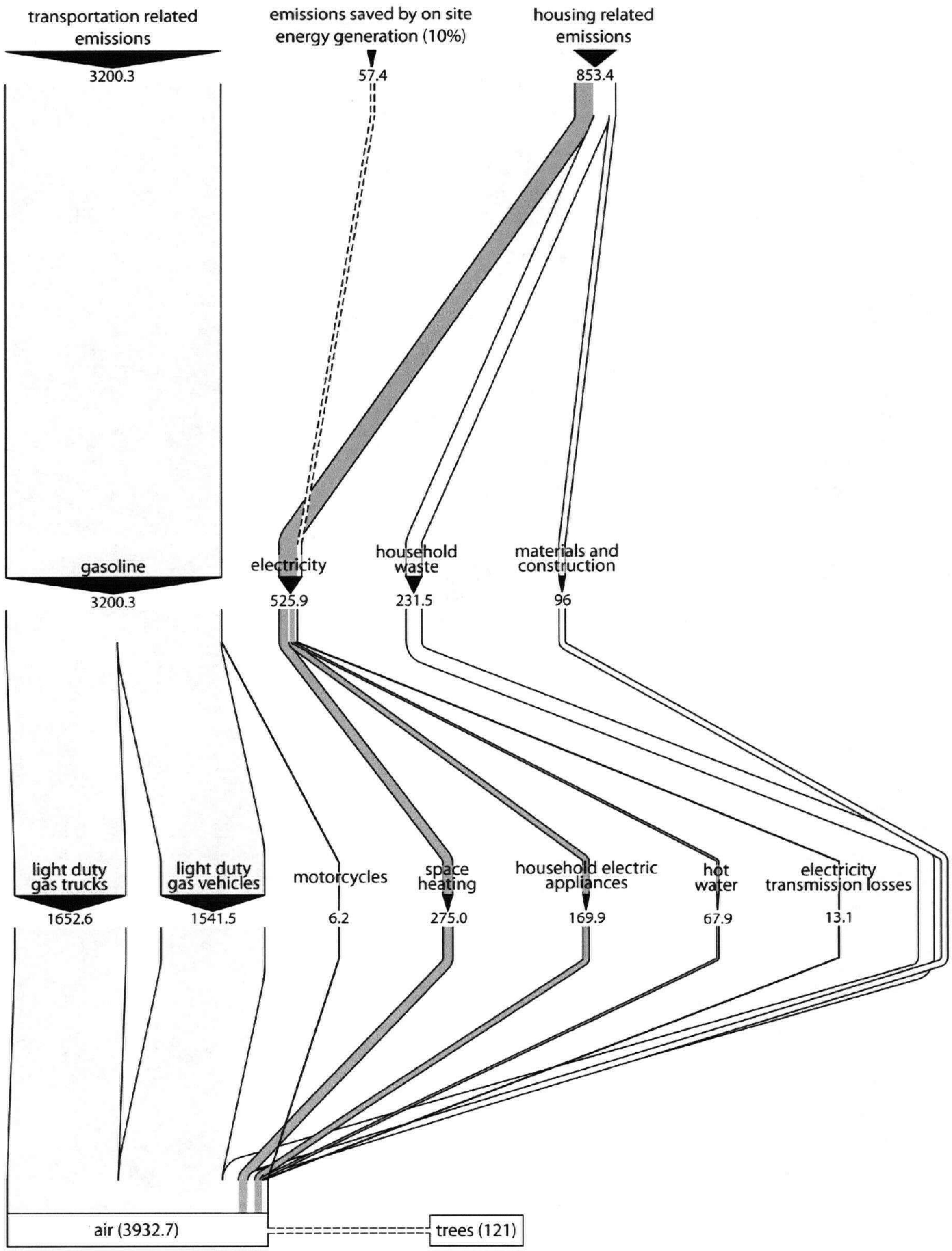


Figure 5.6 Map of Scenario One Carbon Emissions, kg CO_2E per capita

5.3.4 Scenario Two: Seen But Not Shared

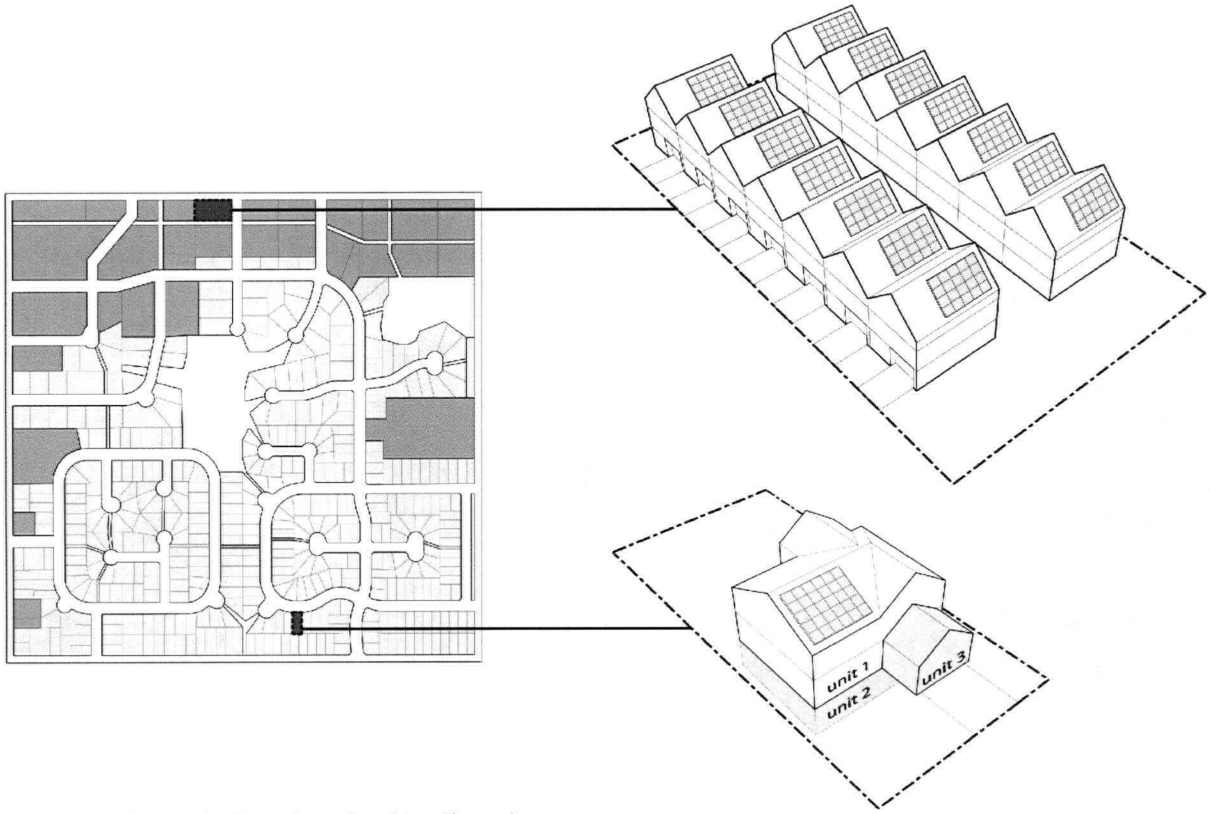


Figure 5.7 Scenario Two, Seen But Not Shared

The Seen But Not Shared Scenario is characterised by strategies that do not extend beyond the parcel scale, but that can challenge the accepted suburban form. The design strategies appropriate for this scenario are summarised in Table 5.7. Strategies which have been added to the base list provided in Scenario One due to the ability of this scenario to challenge form have been highlighted in italics.

Based on the design strategies available for the second scenario, the emission reduction targets set for the three major areas of action are listed in Table 5.8, yielding an estimated 50 percent total emission reduction for the study area. Maximising home energy retrofits within the study area, emissions from housing energy consumption are expected decrease by a targeted 80 percent by reducing total home energy demand by 40 percent, and replacing natural gas with hydroelectricity as an energy source for space heating and hot water. Targets for transportation emission reductions are set at 30 percent, based on the increased ability to densify the site through new housing typologies, which encourages public transportation, and the opportunity to insert new land uses and services into the study area, increasing walkability. Similar to Scenario One, energy generation for this scenario is limited to roof-installed photovoltaics and geothermal-exchange systems; also like Scenario One, design strategies limited to the parcel scale prevent photovoltaic energy generation from reaching its maximum potential. For this scenario, an emissions offset target of 20 percent for energy generation has been set for the study area.

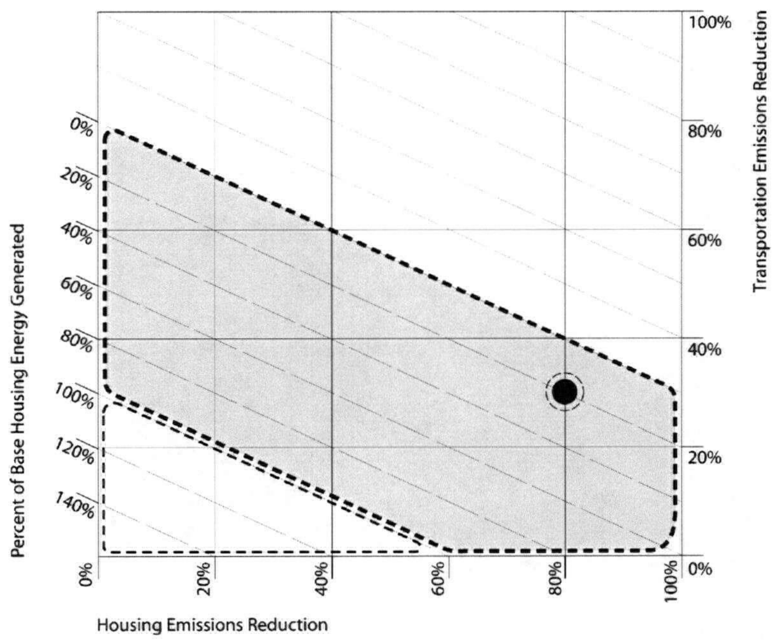
Table 5.7 Design Strategies, Seen But Not Shared

Highly efficient buildings or building retrofits	Renewable on site energy generation	Increased on site vegetation
Upgraded major appliances Upgraded lighting Increased insulation values Upgraded doors and windows Reduced air infiltration Upgraded heating system	Photovoltaics Geo-exchange systems	Tree planting Substantial landscaping and productive gardens
	Higher densities	**Alternative transportation Options**
	Stacked residential ***Attached residential*** Secondary suites, basement ***Secondary suites, garage***	Telecommuting options Goods delivery services
Solar orientation	**A diverse mix of land uses**	
Increased glazing on southern facades	Home based businesses ***Mixed use, residential stacked above commercial***	

Table 5.8 Seen But Not Shared Scenario Targets

Housing Reduction	80%
Transportation Reduction	30%
Energy Generation	20%

50% Emission Reduction



5.3.4.1 Eighty Percent Housing Emission Reduction

To achieve the targeted 80 percent housing emission reduction, the Seen But Not Shared scenario continues to emphasise significant home energy retrofits, reducing overall home energy consumption by 40 percent through improvements to the building envelope, lighting and appliances, and upgrades to the space heating and hot water systems. Space heating and hot water systems are converted from natural gas to hydroelectricity, achieving an additional 75 percent reduction in heating related emissions based on the emissions factors discussed in Scenario One. As the typical suburban form is able to be challenged within this scenario, the maintenance of the detached, single family housing pattern is no longer mandatory. New construction on undeveloped areas of the site, a mix of housing types including attached and stacked dwelling units and mixed use projects, is also required to meet or exceed the performance standards of retrofitted study area buildings, and offer new opportunities for energy efficiencies related to denser housing typologies, as discussed in Chapter 4.

5.3.4.2 Thirty Percent Transportation Emission Reduction

The Seen But Not Shared scenario, by allowing design strategies that challenge common suburban forms, greatly increases opportunities to reduce transportation related emissions within the study area. Within this scenario, residential densities can be increased to at least 15 units per acre (37.5 units per hectare) through the development of secondary suites in existing homes, as well as through new medium to high density construction on undeveloped areas of the site. The conversion of garages into small apartments, in addition to basement secondary suites, can serve to triple the residential density per developed parcel, while moving automobiles to the ample parking afforded by wide neighbourhood streets. The intensification of residential density increases the possibilities for enhanced public transportation service, including closer routes and transit stops. New development will also include a range of retail and services, enabling more daily needs to be met within walking distance in the neighbourhood. Alternative transportation options, limited to telecommuting and goods delivery services for this scenario as strategies that do not extend beyond the private parcel, also provide opportunities to accomplish tasks without the use of an automobile. While none of these strategies can guarantee a specific reduction in vehicle travel and consequent emissions, many reports, such as those cited in Chapter 4, offer strong evidence for their contributions to decreasing automobile travel.

5.3.4.3 Twenty Percent Energy Generation

For this scenario, renewable on site energy generation is limited to photovoltaic roof installations, as well as energy contributions from ground source heat pumps. As mentioned in Scenario One, south facing roof surface is not distributed evenly among households, which means that not all homes have the ability to meet this target through photovoltaic roof installations alone. In these cases, the balance of energy required for a 20 percent generation target can be met through investment in ground source heat pumps, which pull heat energy from the ground for use in space and water heating. The electricity generated from photovoltaics, approximately 2,700 kWh per capita annually for a 20 percent generation target, can serve to supplement household hydroelectricity loads, offsetting an equivalent 20 percent of housing emissions from energy consumption. Rather than battery storage, generated electricity is contributed to the municipal grid through a net metering program, ensuring that generation is not limited by storage capacity.

5.3.4.4 Additional Reductions and Offsets

While carbon sequestration has not been included in initial emission reduction estimates, a small portion of the emissions still generated on site will be sequestered through the addition of trees and substantial plantings on each parcel. As discussed in Scenario One, one medium or large tree sequesters an average of 92 kilograms of carbon annually. By planting one tree per capita on site, 1.7 percent of total per capita emissions is mitigated annually.

As suggested in Scenario One, additional emissions reductions could be achieved within the study area by using the electricity generated on site to power alternative vehicles. If this energy from photovoltaics (2,700 kWh per capita annually for this scenario) was used to generate hydrogen for a fuel cell vehicle, 5,100 kilometers per capita could be traveled emissions-free annually according to the energy conversion factors provided in Chapter 3, a transportation emission reduction of 45 percent. If the same amount of energy was used to power an electric vehicle, a study area resident could drive 8,700 kilometers, more than the reduced annual distance already targeted for the scenario. If the remaining generated energy (approximately 260 kWh) is applied to household uses, these additional reductions for hydrogen and electric vehicles result in total per capita emissions mitigation of 77 and 97 percent respectively, substantially higher than the projected 50 percent reduction, and nearly reaching carbon neutrality.

5.3.4.5 Lessons from the Seen But Not Shared Scenario

The Seen But Not Shared Scenario illustrates that significantly greater emissions reductions might be achieved if certain aspects of the suburban form, especially housing density, housing typology and land use mix, are able to be challenged for the purpose of emissions mitigation. This scenario also indicates that the use of energy generated on site to power alternative vehicles may bring overall emission reductions very close achieving full emissions mitigation, even in the absence of the larger scale design strategies prohibited by this scenario. A map of per capita carbon emissions for Scenario Two is illustrated in Figure 5.8.

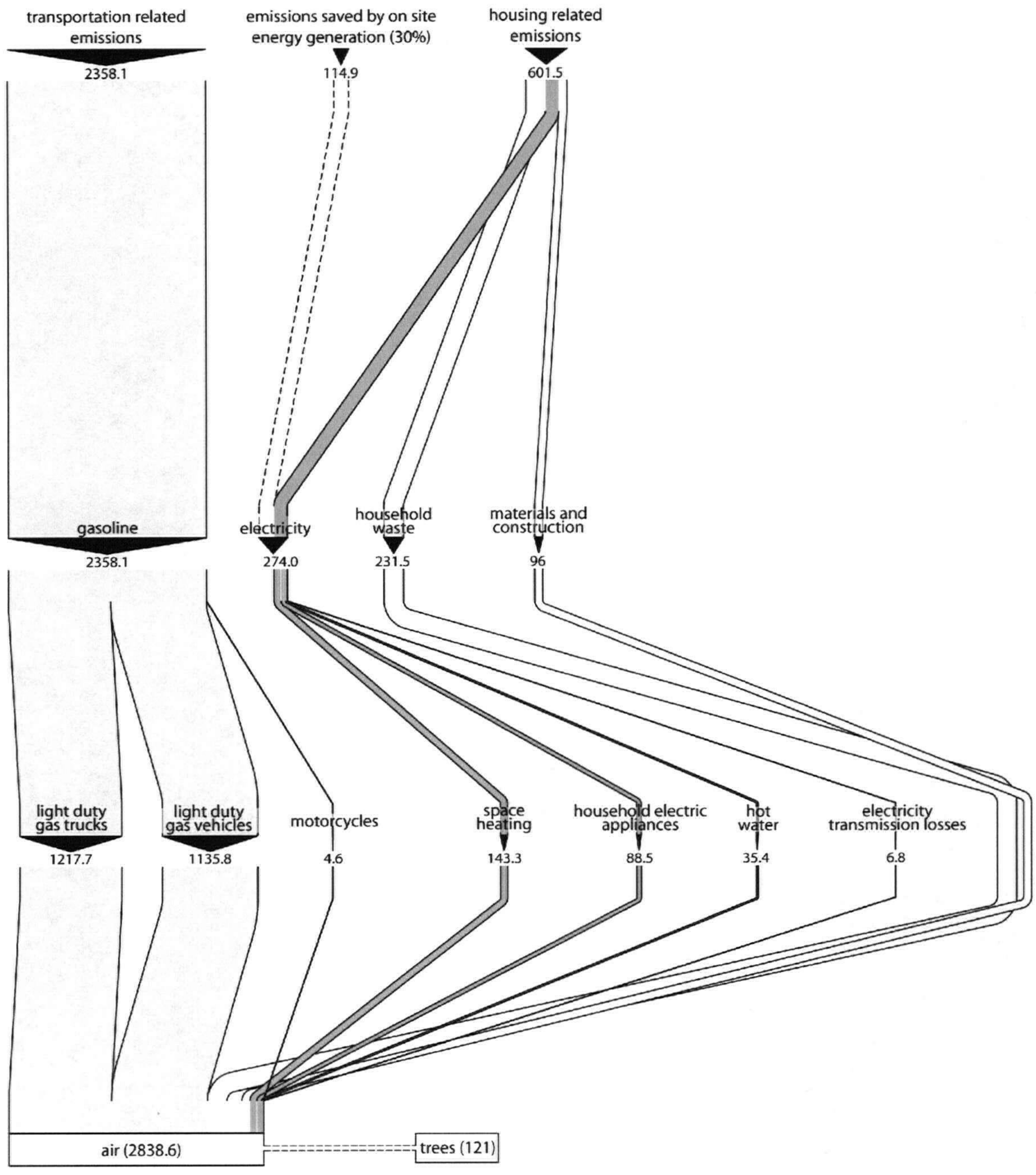


Figure 5.8 Map of Scenario Two Carbon Emissions, kg CO_2E per capita

5.3.5 Scenario Three: Shared but Not Seen

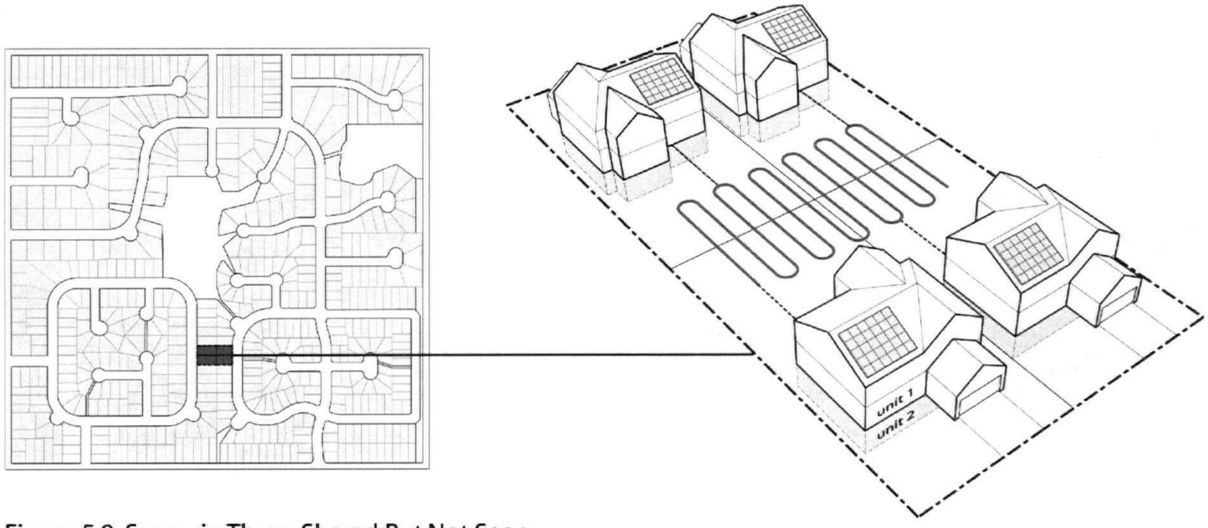


Figure 5.9 Scenario Three, Shared But Not Seen

Strategies for the Shared But Not Seen scenario are limited to those which do not significantly alter the existing form of the development, but that can extend beyond the parcel scale to solutions which involve clusters of buildings, blocks or the entire neighbourhood. The design strategies appropriate for this scenario are summarised in Table 5.9. Strategies which have been added to the base list provided in Scenario One due to the ability of this scenario to extend beyond the parcel scale have been highlighted in italics.

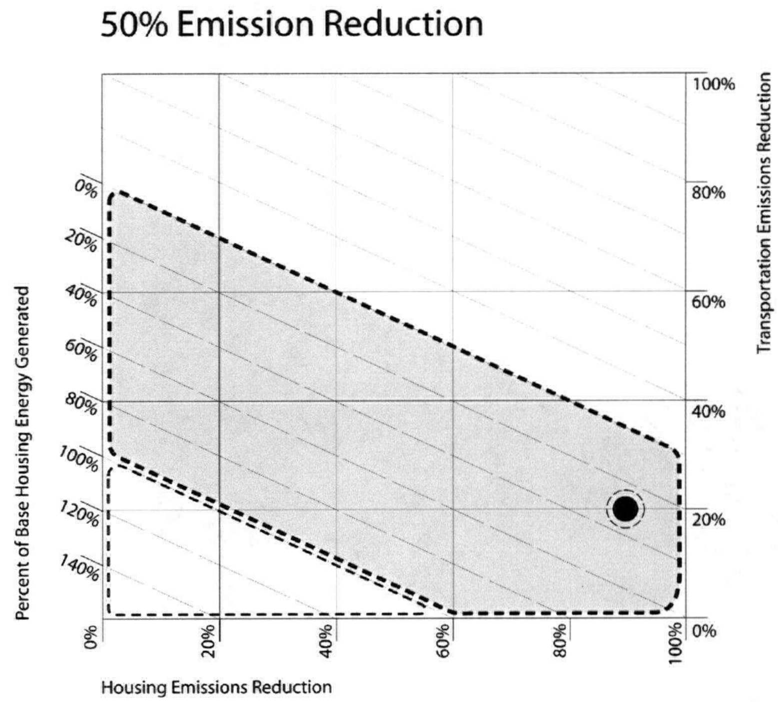
Based on the design strategies available for the third scenario, the emission reduction targets set for the three major areas of action are listed in Table 5.10, yielding an estimated 50 percent total emission reduction for the study area, similar to Scenario Two. A target of 90 percent reductions is set for housing emissions, based on maximised home energy retrofits paired with the installation of ground source heat pumps throughout the neighbourhood for space heating and hot water needs, which utilises heat energy available on site and eliminates the use of natural gas. Targets for transportation emission reductions are set at 20 percent, based on the available opportunities for community car pooling and car sharing programs, which combine trips and reduce per capita vehicle mileage. Energy generation in this scenario is still limited to roof-installed photovoltaics and geothermal-exchange systems, although photovoltaic generation capacity can now be maximised, as the scenario allows for neighbourhood scale design strategies including community energy systems. For this scenario, an emissions offset target of 30 percent for energy generation has been set for the study area.

Table 5.9 Design Strategies, Shared But Not Seen

Highly efficient buildings or building retrofits	**Higher densities**	**A finer grained street and path system**
Upgraded major appliances	Secondary suites, basement	***Cycling lanes and sidewalks***
Upgraded lighting		
Increased insulation values		
Upgraded doors and windows	**A diverse mix of land uses**	**Pedestrian and cycling amenities**
Reduced air infiltration	Home based businesses	***Traffic calming measures***
Upgraded heating system		
Solar orientation	**Increased on site vegetation**	**Alternative transportation Options**
Increased glazing on southern facades	Tree planting	***Carpooling and car-sharing programs***
	Substantial landscaping and productive gardens	***Community shuttle service***
		Telecommuting options
Renewable on site energy generation		Goods delivery services
Photovoltaics		
Geo-exchange systems		

Table 5.10 Shared But Not Seen Scenario Targets

Housing Reduction	90%
Transportation Reduction	20%
Energy Generation	30%



5.3.5.1 Ninety Percent Housing Emission Reduction

To achieve the 90 percent housing emission reduction target, the Shared But Not Seen scenario first continues the strategy of maximised home energy retrofits, including building envelope, lighting, and appliances, achieving 40 percent energy reductions. Housing energy and related emissions are further reduced by the installation of ground source heat pumps, which use the constant heat of the earth and small amounts of electricity for space heating and hot water. Although it may not be practical for each household in the study area to invest in individual ground source heating systems, the ability to extend solutions beyond the parcel scale enables the installation of "group" ground source systems, in which clusters of four to six detached homes might share in both the investment and benefits of this technology through underground connections which do not affect the existing low density suburban form. Ground source heat pumps also eliminate the use of natural gas for space heating and hot water, achieving an additional 75 percent reduction in heating related emissions as discussed in the previous scenarios. The collective amount of yard space available between homes means that more cost-effective horizontal loop systems[280] will be viable with adequate land area. New construction on undeveloped areas of the site will maintain the single family character of the neighbourhood as required by the scenario, but will be built to high performance standards, and utilise similar, clustered ground source heating system technology.

5.3.5.2 Twenty Percent Transportation Emission Reduction

To achieve the targeted 20 percent transportation emission reduction, the Shared But Not Seen scenario first increases residential densities to encourage enhanced public transportation, such as improved service hours and closer transit stops. Because the scenario does not permit changes to the suburban form, residential densification is limited to secondary basement suites; the insertion of one suite per household serves to double residential densities to 10 units per acre (25 units per hectare). Homogenous residential land uses are maintained within the study area, causing most daily needs, such as shopping and services, to be met off site and often by private automobile; however, new neighbourhood programs for car pooling, car sharing or shuttle service enabled by this scenario allow fewer trips to get more residents to their destinations. Likewise, access to larger vehicles such as trucks and vans, owned by a few residents but available to the community for use, means that most residents can purchase smaller cars, and use large vehicles only when necessary. The Shared But Not Seen scenario also establishes a greater willingness to provide private property access for the insertion of a finer grained system of pedestrian and cycling paths between houses to connect various cul-de-sacs and disconnected streets, providing more direct travel routes to locations both within and adjacent to the study area. Further alternative transportation options, especially telecommuting and goods delivery services, provide opportunities to accomplish tasks without the use of an automobile.

5.3.5.3 Thirty Percent Energy Generation

Like Scenarios One and Two, the Shared But Not Seen scenario generates energy on site through photovoltaic roof installations and energy contributions from ground source heat pumps. Because this scenario concentrates on larger scale design strategies and cooperative solutions, the total area of south facing roof surfaces located within the study

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280 Compass Resource Management, *Sustainable Energy Technology* p. 15

area can now be considered as a neighbourhood amenity, so that photovoltaic installations can be maximised as a community energy system where neighbourhood households share equally in installation costs and energy benefits, generating a maximum 30 percent of current housing energy requirements. The electricity generated from photovoltaics in this scenario, a maximum 3,773 kWh per capita annually, can serve to supplement household energy loads, offsetting an equivalent 30 percent of housing emissions from energy consumption. Rather than battery storage, generated electricity is contributed to the municipal grid through a net metering program, ensuring that generation is not limited by storage capacity.

5.3.5.4 Additional Reductions and Offsets

As in previous scenarios, a small portion of the emissions still generated on site will be sequestered through the addition of trees and substantial plantings on each parcel. The ability to extend design strategies beyond the parcel scale enables the enactment of a neighbourhood street tree initiative, incorporating the planting of trees into the street right of way, improving pedestrian conditions and further increasing the total number of trees per capita on site for carbon sequestration. With this added opportunity, an estimated 1.5 trees per capita will be added within the study area. At an average annual sequestration rate of 92 kilograms of carbon per medium or large tree planted, 2.6 percent of per capita emissions will be mitigated.

Additional emissions reductions could be achieved within the study area by using the electricity generated from photovoltaics to power alternative vehicles. If the 3,773 kWh generated per capita annually in this scenario were used to generate hydrogen for a fuel cell vehicle, 7,200 kilometers per capita could be traveled emissions-free annually according to the energy conversion factors provided in Chapter 3, a transportation emission reduction of 64 percent. If the same amount of energy was used to power an electric vehicle, a study area resident could drive 12,000 kilometers, well over the reduced per capita annual distances driven under this scenario. If the remaining generated energy (approximately 980 kWh) is applied to household uses, these additional reductions for hydrogen and electric vehicles result in total per capita emissions mitigation of 86 and 99 percent respectively, substantially higher than the projected 50 percent reduction and, like Scenario Two, nearly reaching carbon neutrality.

5.3.5.5 Lessons Learned from the Shared But Not Seen Scenario

The Shared But Not Seen Scenario illustrates that significantly greater emissions reductions can be achieved when design strategies that extend beyond the private parcel are utilised within a suburban study area for the purpose of emissions mitigation. This scenario also indicates that the use of energy generated on site to power alternative vehicles brings overall emission reductions very close to complete emissions mitigation, even in the absence of design strategies which challenge the typical characteristics of suburban form. A map of per capita carbon emissions for Scenario Three is illustrated in Figure 5.10.

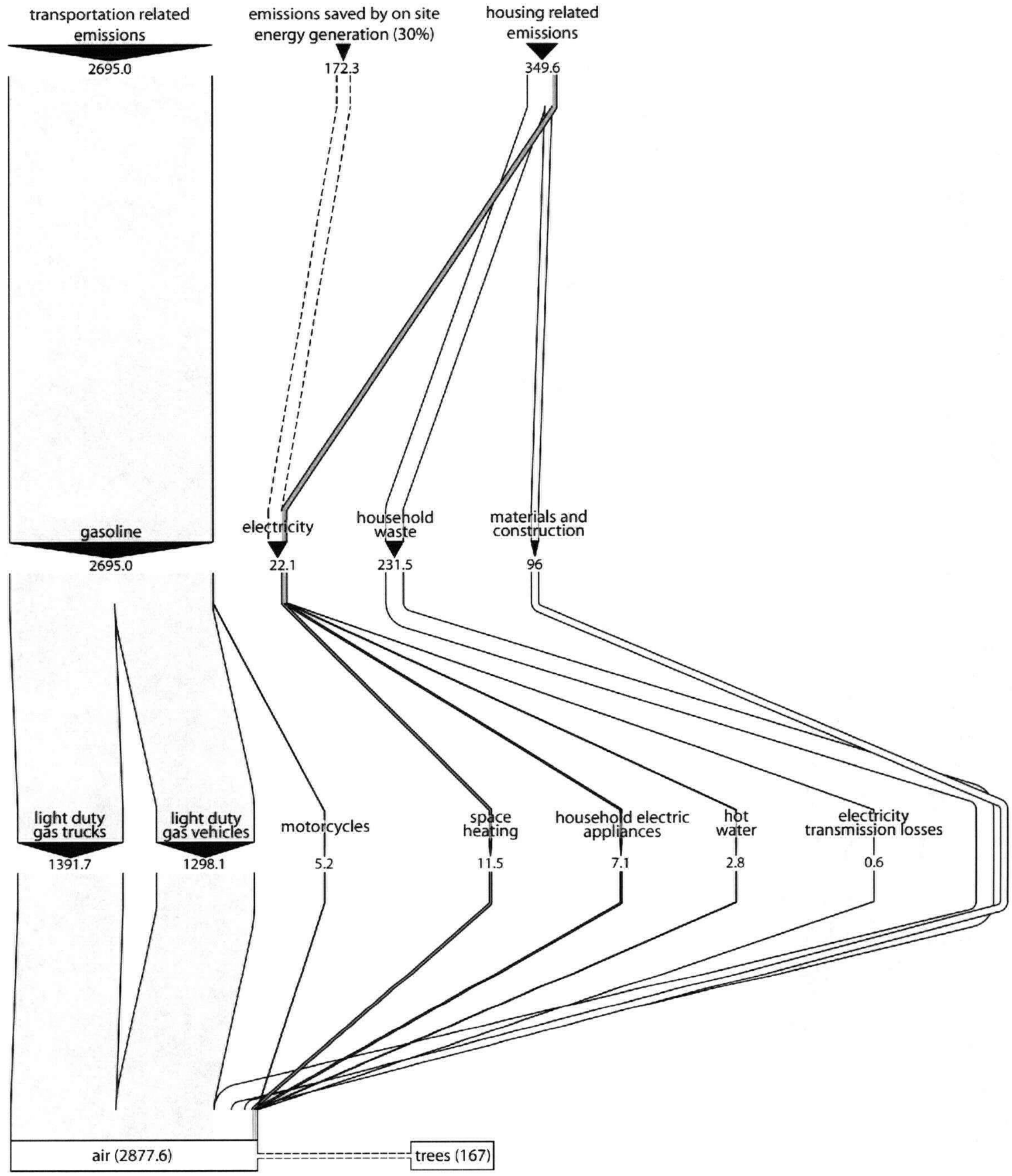


Figure 5.10 Map of Scenario Three Carbon Emissions, kg CO_2E per capita

5.3.6 Scenario Four: Seen and Shared

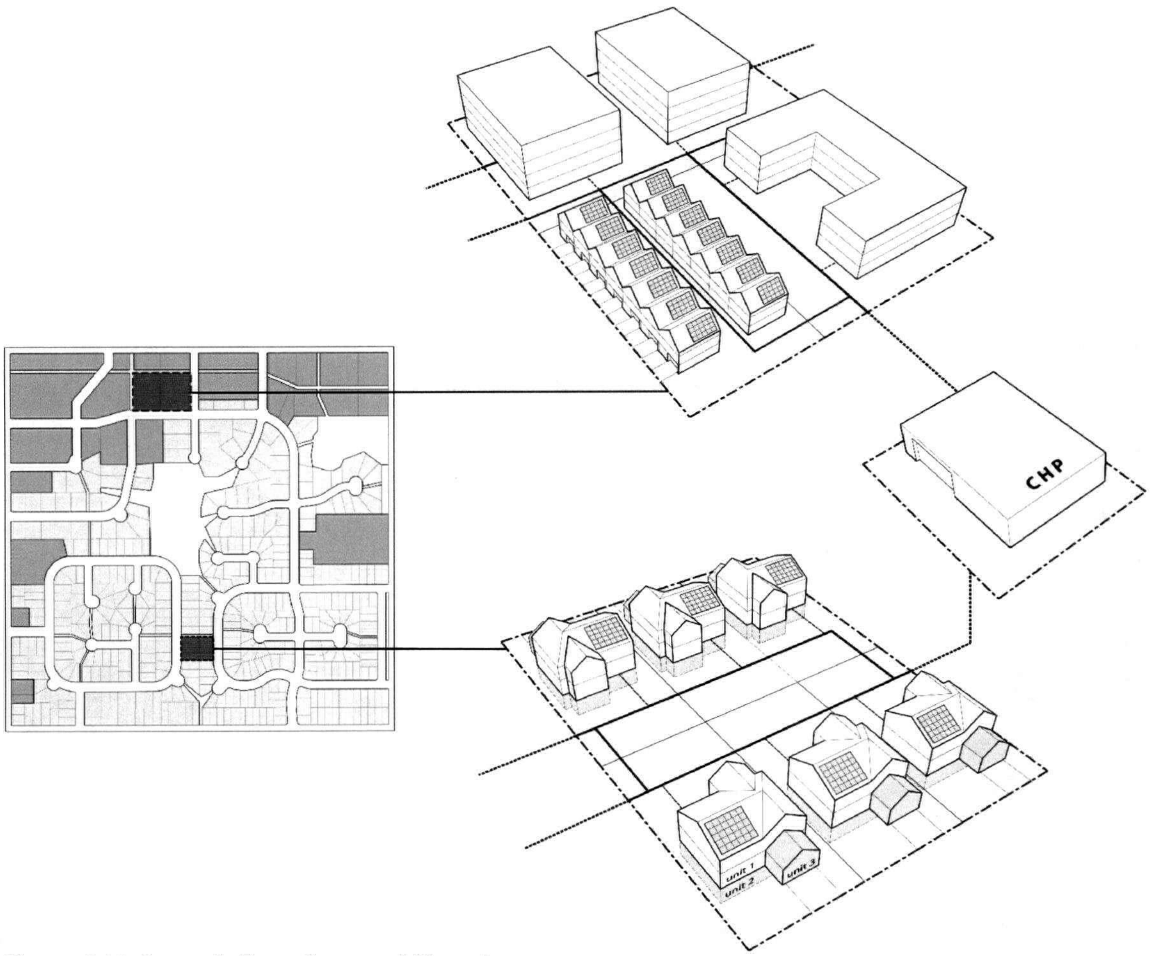


Figure 5.11 Scenario Four, Seen and Shared

Strategies for the Seen and Shared scenario do not face the design limitations imposed by other retrofit scenarios. By permitting strategies that both densify and diversify the existing suburban form, and strategies which promote neighbourhood cooperation and transcend typical property boundaries, the highest levels of carbon emission reductions can be achieved. Design strategies appropriate for this scenario are summarised in Table 5.11. Strategies which are unique to this scenario due to its ability to both challenge form and extend beyond the parcel scale have been highlighted in italics.

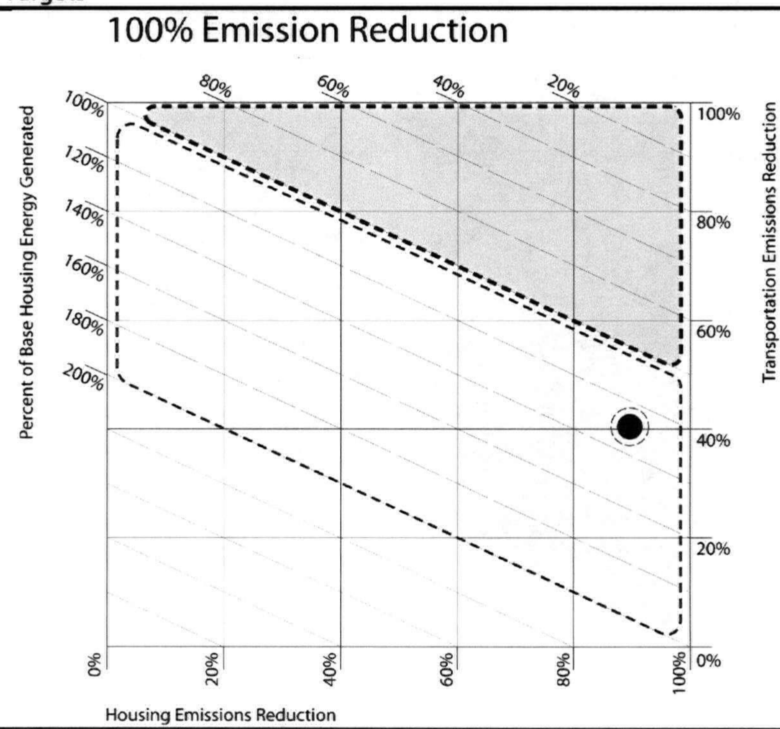
Table 5.11 Design Strategies, Seen and Shared

Highly efficient buildings or building retrofits Upgraded major appliances Upgraded lighting Increased insulation values Upgraded doors and windows Reduced air infiltration Upgraded heating system	**Higher densities** Stacked residential Attached residential Secondary suites, basement Secondary suites, garage	**Pedestrian and cycling amenities** ***Pedestrian and cycling paths and connections to larger networks*** ***Bicycle storage and showers at appropriate destinations*** Traffic calming measures
Solar orientation Increased glazing on southern facades	**A diverse mix of land uses** Mixed use, residential stacked above commercial Home based businesses	**Access to Public Transit** ***Transit stops within neighbourhood*** ***Frequent transit service***
District energy systems ***Underground heat piping through dense development***	**Increased on site vegetation** Tree planting Substantial landscaping and productive gardens	**Alternative transportation Options** Carpooling and car-sharing programs Community shuttle service ***Charging stations for electric and fuel cell vehicles*** Telecommuting options Goods delivery services
Renewable on site energy generation Photovoltaics Geo-exchange systems ***Combined heat and power systems***	**A finer grained street and path system** Cycling lanes and sidewalks	

Based on the design strategies available for the fourth scenario, the emission reduction targets set for the three major areas of action are listed in Table 5.12, potentially achieving 100 percent emission reductions for the study area. Similar to Scenario Three, a target of 90 percent reductions is set for housing emissions, based on maximised home energy retrofits paired with the replacement of home-scaled space heating and hot water systems with neighbourhood-scaled combined heat and power (CHP). Targets for transportation emission reductions are set at a relatively high 40 percent, but are considered appropriate for the number of design strategies available, in conjunction with an assumed willing attitude among residents to reduce vehicle travel within this particular future context. Increased densities and the opportunity to apply neighbourhood scale strategies enable new forms of energy generation, particularly combined heat and power, in addition to photovoltaics. For the Seen and Shared scenario, an emissions offset target of 130 percent for energy generation, including both electricity and waste heat, has been set based on the increased generation capacity enabled by the assigned scenario context.

Table 5.12 Seen and Shared Scenario Targets

Housing Reduction	90%
Transportation Reduction	40%
Energy Generation	130%



5.3.6.1 Ninety Percent Housing Emission Reduction

Similar to Scenario Three, the Seen and Shared scenario also achieves a 90 percent housing emission reductions target. As in preceding scenarios, this target accomplished in part through substantial home energy retrofits, which reduce overall home energy consumption and emissions by 40 percent. Greater reductions in energy use are achieved through the incorporation of a district heating system, which provides heat and hot water needs to each household through an underground pipe network. Generated as waste during zero net emission electricity production from biomass at a small cogeneration plant on site, this recovered heat eliminates the need for individual heating systems, resulting in a 90 percent total housing energy reduction in terms of electricity and natural gas. The combined heat and power system is made possible in this scenario due to the ability to combine strategies which challenge the suburban form by increasing residential densities with strategies that extend beyond the parcel scale to shared community systems, such as neighbourhood heat distribution. As discussed in Chapter 3, densities of over 12 units per acre (30 units per hectare) are necessary for effective district heating. Viable densities within the study area are achieved through secondary basement suites as well as garage suites and new attached and stacked dwelling development. New construction on undeveloped land will utilise high performance standards and connect to the district energy and heating system.

5.3.6.2 Forty Percent Transportation Emission Reduction

The ability to utilise design strategies which both challenge the suburban form and extend beyond the parcel scale provides the opportunity to utilise a wide range of travel reduction measures, which if used in combination, serve to achieve the scenario's 40 percent transportation emission reduction target. Challenging the suburban form enables residential density increases not only through secondary basement suites but through garage conversions and medium to high density construction on undeveloped areas of the site. The tripling of residential densities to 15 units per acre (37.5 units per hectare), as enabled by the scenario, increases possibilities for enhanced public transportation service, including closer routes and transit stops within the study area, particularly when paired with the development of new mixed use and commercial projects on undeveloped areas of the site. Neighbourhood destinations, such as those provided by new mixed use development, increase the number of daily needs which can be met within the neighbourhood and enhance neighbourhood walkability. These destinations are made more accessible with neighbourhood scale strategies such as the incorporation of pedestrian and cycling shortcuts providing more direct access to destinations, and additional paths linking to nearby city trails and the developing shopping district one kilometer away. Community organised transportation options, such as car pooling, car sharing and shuttle services as described in Scenario Three, along with alternatives to travel such as telecommuting and delivery services, contribute to trip reduction and consequent emissions mitigation. While achieving a 40 percent reduction in transportation emissions through design strategies is a challenging target, it is considered appropriate and attainable within this scenario, as it is assumed that a resident population accepting of substantial change within their community will be more willing to participate in travel reduction measures.

5.3.6.3 One Hundred Thirty Percent Energy Generation

A combination of increased density and neighbourhood scale design strategies enables the Seen and Shared scenario to generate substantially more energy than previous scenarios due to the opportunity to implement a small combined heat and power facility on undeveloped land within the study area. A target of 130 percent energy generation is achieved through this facility with a combination of electricity and waste heat generated by biomass fuels such as wood pellets. Within the system, the heat created through electricity generation provides the energy necessary for space heating and hot water, while the electricity generated more than meets reduced home energy needs. Excess electricity can be supplied to the grid for surrounding areas to use, or be put to use for transportation through electric vehicles or the generation of hydrogen fuel, if appropriate technology is available. The combined heat and power plant also has the potential to be fuelled in part through local biomass in the form of yard waste or cultivated fuel crops, such as quick growing trees, due to the proliferation of open space and landscaping within the study area. The electricity generated in this scenario, 50 percent of total energy generated or approximately 8,900 kWh per capita annually[281], serves to fully supply remaining household energy loads, eliminating energy related household emissions while leaving 8,533 kWh for other applications.

5.3.6.5 Additional Reductions and Offsets

Scenario Four is unique as the only scenario to generate a surplus of energy, beyond what can be consumed for housing energy requirements. If this energy (8,533 kWh) is supplied to the municipal hydroelectricity grid, it will offset just 358 kilograms of carbon, for a total per capita emissions reduction of 67 percent. Although targets for this scenario were

[281] Based on information from the International District Energy Association, a combined heat and power plant produces equal parts of useful waste heat and electricity during generation.

chosen to achieve a 100 percent reduction, by applying energy generated on site to the least emissions intensive use, hydroelectricity, total reduction goals are not achieved. Additional emissions reductions could be achieved within the study area by using the electricity generated from biomass to power alternative vehicles, assuming appropriate technology is available. If the 8,533 kWh generated per capita annually in this scenario were used to generate hydrogen for a fuel cell vehicle or to charge electric vehicles, between 16,000 and 27,000 kilometers per capita could be traveled emissions-free annually. If only half of this energy was applied to transportation, per capita travel needs could still be met, while additional energy could be supplied to neighbouring communities, yielding full emissions mitigation for the study area.

Like Scenario Three, the ability to extend design strategies beyond the parcel scale enables additional carbon sequestration opportunities through the enactment of a neighbourhood street tree initiative, incorporating the planting of trees into the street right of way. For the Seen and Shared scenario, an estimated 1.5 trees per capita will be added within the study area. At an average annual sequestration rate of 92 kilograms of carbon per medium or large tree planted, 2.6 percent of per capita emissions will be mitigated. Available open space is additionally planted with fast growing trees and gardens for further sequestration benefits, while providing additional biomass that may be incorporated into the fuel supply for renewable energy generation on site.

5.3.6.6 Lessons Learned from the Seen and Shared Scenario

The Seen and Shared scenario illustrates that the largest emissions reductions can be achieved within the study area when design strategies that allow both challenge to the suburban form and extensions beyond the private parcel are permitted. However, reducing net carbon emissions to zero within this scenario is dependent on the adoption of new transportation technologies rather than on design solutions alone. Without adopting such technologies within the study area, or alternatively, without decreasing vehicle travel substantially more than the reductions generally indicated by transportation research, 100 percent emission reduction goals will not be achieved; however, smaller but substantial reductions are entirely feasible. A map of per capita carbon emissions for Scenario Four is illustrated in Figure 5.12.

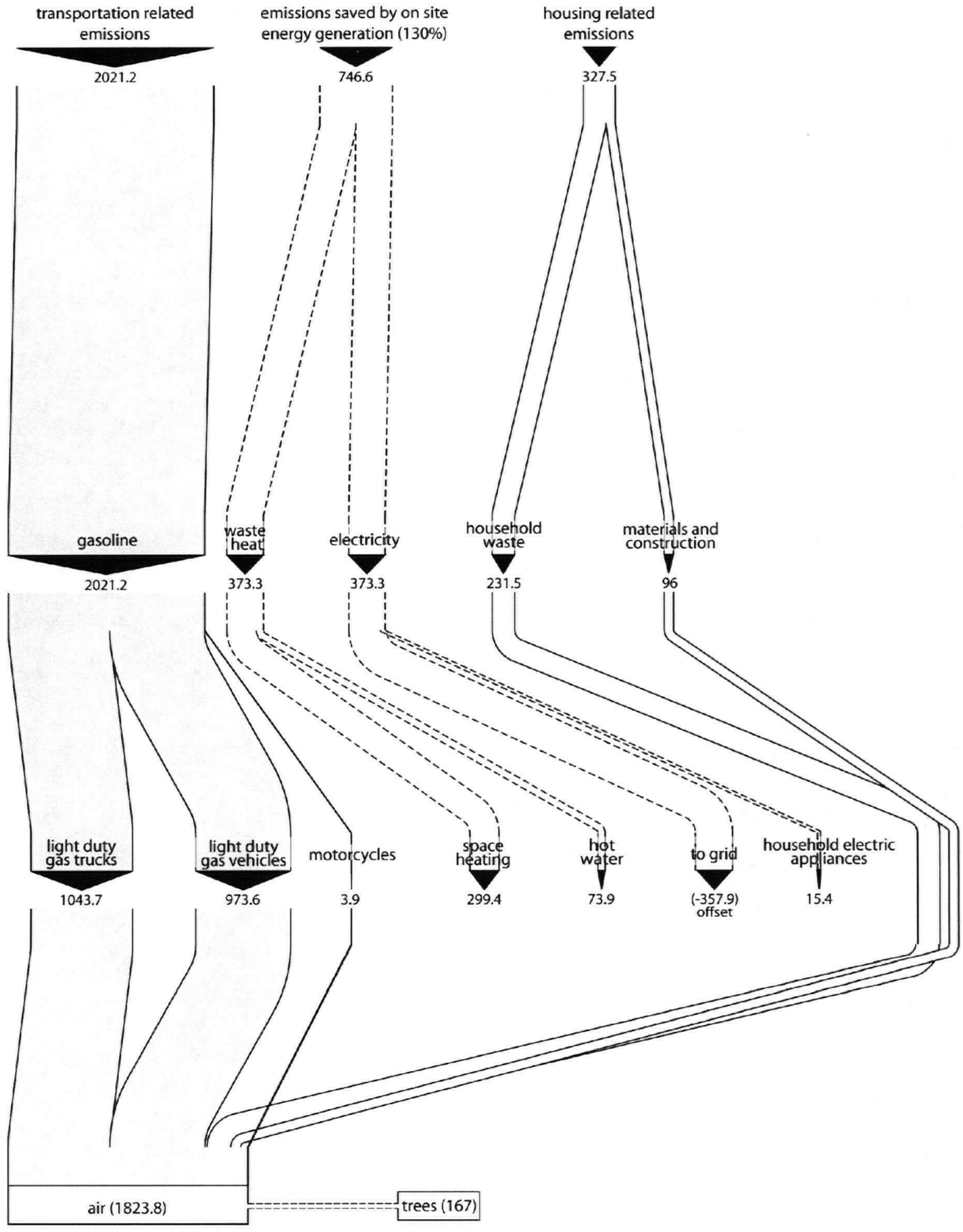


Figure 5.12 Map of Scenario Four Carbon Emissions, kg CO_2E per capita

CHAPTER 6:
DISCUSSION

6.1 Conclusions

6.1.1 General Discussion

The development of the four scenarios established in Chapter 5 suggests that the study area, and developments like it, have the capacity to mitigate a substantial portion of their per capita greenhouse gas emissions through neighbourhood retrofits under a variety of contextual conditions. Scenario One, Base Case Retrofit, illustrates the ability to reduce carbon emissions by at least 25 percent while working within the existing limitations of the study area. Through this scenario, the existing form of the development, along with the issues of private ownership and resistance to change, are discovered not to be definitive barriers to neighbourhood improvement, although they do affect the form and approaches of implemented energy and emission reduction strategies.

Scenarios Two and Three (Seen But Not Shared and Shared But Not Seen), each of which achieve twice the emission reductions of Scenario One, at 49 and 48 percent respectively, suggest that both challenging the existing suburban form and extending design strategies beyond the scale of the private parcel achieve greater results towards the goal of carbon mitigation within the study area. Scenario Four, Seen and Shared, achieves the greatest emission reductions, mitigating two-thirds of per capita emissions, and illustrates that the combination of challenging forms and expanding scales allows for the widest variety of design strategies and emissions mitigation potential. This is most clearly illustrated in the scenario's capacity for energy generation, which far surpasses previous scenarios with its ability to utilise district heating and energy systems. A summary of the four scenarios and their respective emission reductions is provided in Figure 6.1.

In addition, the thesis illustrates through the development of "solution spaces" that there is no singular solution for achieving emissions reduction targets in a suburban residential development. Rather, a wide variety of combinations for housing emission reductions, transportation emission reductions and carbon offsets from on site energy generation may serve to achieve similar goals. These reductions may be met through design interventions, as presented in the thesis, but also through technological advances and through changes in resident behaviour.

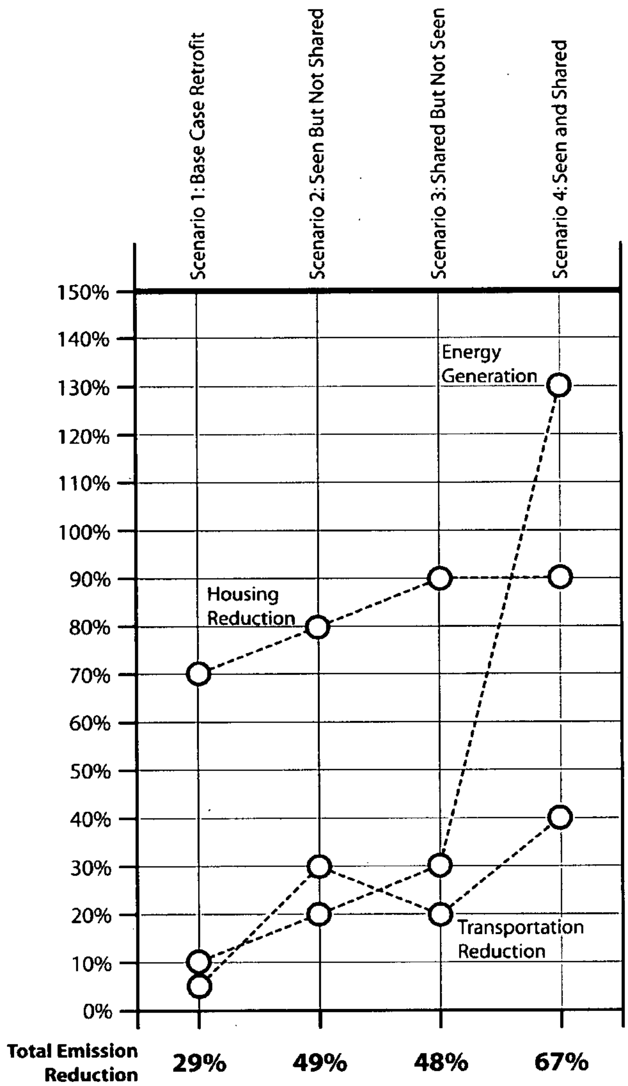


Figure 6.1, Scenario Summary and Comparison

6.1.2 Challenges for Achieving Carbon Neutrality

It is important to note that, despite substantial reductions, none of the scenarios presented in Chapter 5 achieve 100 percent emissions mitigation through design strategies alone. Even Scenario Four (Seen and Shared), which is based on targets chosen to achieve 100 percent emissions reductions, misses the goal by more than 30 percent in the absence of alternative vehicle technologies such as fuel cells.

The difficulties surrounding the achievement of carbon neutrality within the study area can be linked to several important issues. First, how the energy generated on site is used within the study area has a profound affect on the level of emission reductions attained. Simply contributing the surplus 8,533 kWh generated on site in Scenario Four to the municipal grid in order to replace hydroelectricity does not offset adequate emissions due to hydroelectricity's extremely low carbon emission factor; total emissions reductions under this application reach 67 percent. In order to offset enough emissions to reach carbon neutrality by grid contributions alone, the study area would have to generate over 350 percent of per capita energy requirements, rather than the 130 percent targeted by the scenario. Instead, generated electricity must be applied to more emissions intensive uses such as space heating or transportation, should appropriate technology become readily available. The immense impact of utilising electricity from photovoltaics or biomass for electric and fuel cell vehicles has already been suggested in Chapter 5, in each of the four scenarios.

A second issue linked to the realisation of carbon neutrality within the study area is the difficulty of mitigating transportation emissions through design. As the four scenarios and research in Chapter 3 indicate, design strategies can reduce housing emissions by 90 percent with relative certainty and ease in a region supplied with hydroelectricity, while design strategies cannot be expected to decrease transportation related emissions more than 40 percent according to current research. Due to this limitation, carbon neutrality in the study area will likely have to depend on new transportation technologies which are either substantially more efficient, or that are able to utilise renewable energy or hydroelectricity from the municipal grid. In the absence of technological advances, behavioural changes among study area residents, possibly brought about by future economic, environmental or policy changes, may also serve to increase transportation emission reductions.

A third and closely related issue in the realisation of carbon neutrality within the study area is the issue of time, particularly in regards to design strategy availability and implementation. As indicated in the discussion on transportation above, complete emissions mitigation within the study area likely depends on transportation technology which is not yet readily available. In this situation, design strategies must be implemented in such a way that they provide a foundation for future technology, such as planning for additional energy generation capacity as new electric vehicle types develop.

The issue of time and implementation also affects those strategies which are currently available. Within the range of strategies described by the four scenarios in Chapter 5, many involve substantial construction, substantial financial investment, or both. Although presented as singular events in the thesis, the four scenarios and their respective design strategies will likely be implemented over time, as funding and resources become available. Retrofits that occur incrementally have the added benefit of being able to evolve with changing contexts, technologies, or levels of acceptance.

In recognising these issues and their importance to the realisation of carbon neutrality within the study area, a new version of Scenario Four can be developed in which carbon neutrality is achieved. A new Scenario Four, Seen and Shared, recognises the need to implement appropriate strategies over time, plan for the incorporation of future technologies, and participate in regional sustainable strategies as they develop. Under this scenario, renewable energy surpluses are first contributed to the municipal hydroelectric grid, but later to a vehicle charging station within the study area for neighbourhood electric vehicles purchased cooperatively by residents. As technology and regional markets expand, personal electric vehicles, along with fuel cell vehicles, are incorporated. A few gasoline powered vehicles are maintained for longer trips to locations where alternative fuels are not available, although as regional transportation networks increase support for new sustainable transportation technologies, gasoline may be phased out entirely. For the new scenario, 10 percent of annual driving distance is attributed to existing internal combustion engine vehicles, while 1,590 kWh per capita generates hydrogen for 45 percent of annual driving distance by fuel cell vehicle and 943 kWh per capita powers electric vehicles for remaining distances. This leaves approximately 6,000 kWh for contribution to the grid, offsetting the emissions generated from travel by traditional automobile. A map of carbon emissions for this scenario is illustrated in Figure 6.2.

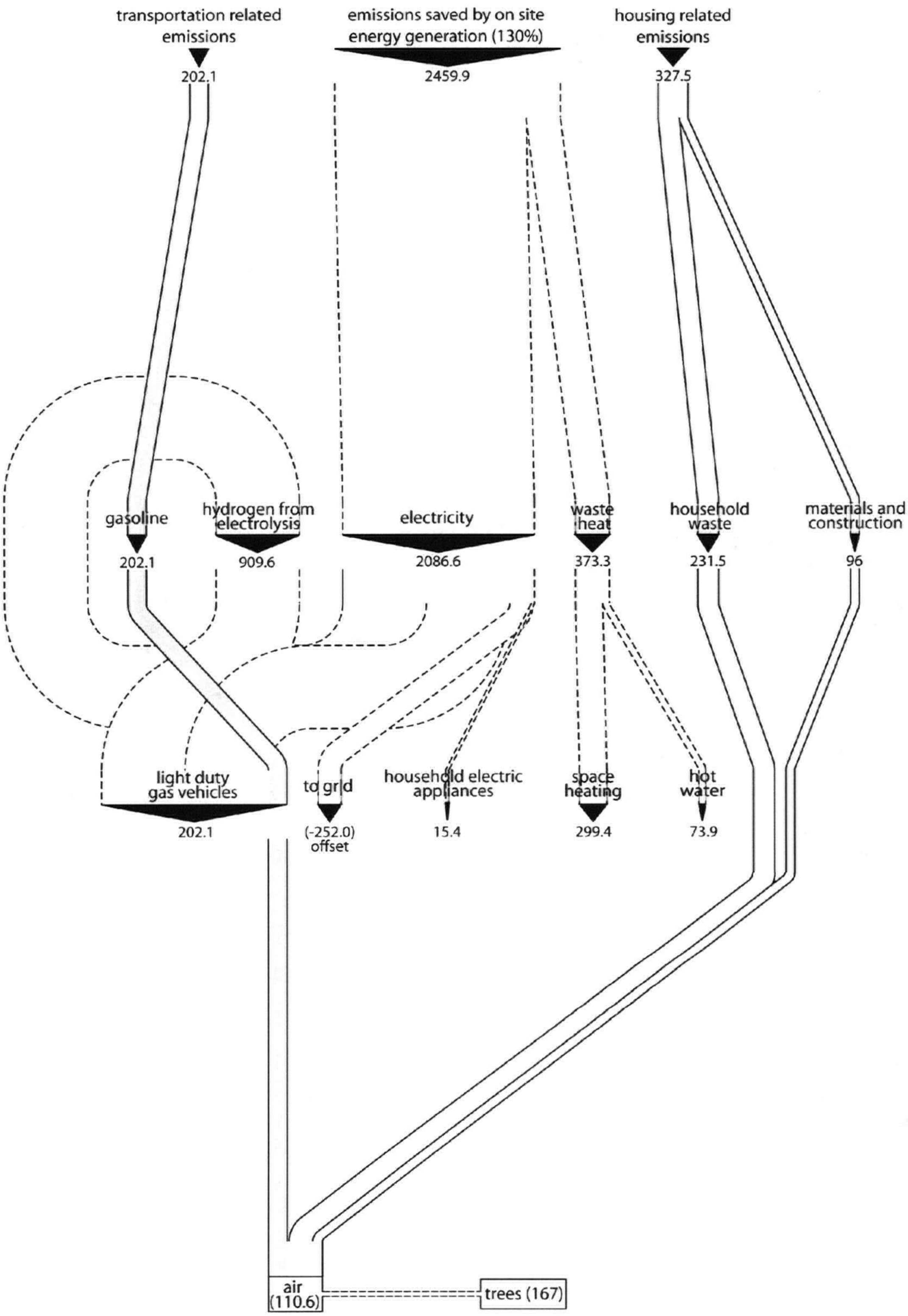


Figure 6.2 Map of Carbon Emissions, Carbon Neutral Scenario, kg CO_2E per capita

6.2 Research Applications

6.2.1 Design

From a design perspective, the commonalities in pattern and form among many suburban residential communities signify that the lessons uncovered through the research are applicable to numerous residential subdivisions found throughout North America. As the thesis shows, each of these neighbourhoods has the potential to achieve significant energy and emissions reductions through design and technology interventions, and even to achieve carbon neutrality over time and under the right set of circumstances. The thesis has the potential to be used as a point of departure for pilot projects in various locations and climates across the continent; such projects will add depth to the findings of the thesis as well as investigate how results may change in different geographical and cultural contexts. Naturally, modifications to targets and prioritised strategies are necessary in each new location based on issues such as climate, source of electricity generation and means of space heating; however, general thesis conclusions about the potential of these developments remain constant.

Moreover, as the thesis illustrates that suburban residential neighbourhoods have the potential to mitigate carbon emissions, lessons regarding the design potentials of suburban retrofits might also extend to other indicators of sustainability. The range of issues addressed in the effort to create more sustainable communities, such as preservation of natural habitat, stormwater management, biodiversity, affordable housing, and healthy living environments, all face similar challenges of form and scale when attempts are made to integrate these ideas into existing suburban conditions. Therefore, as the thesis has shown the potential of a suburban residential community to reach one sustainability target, it is proposed that many other indicators of sustainability have the potential to be met as well.

6.2.2 Decision Making and Scenario Development

From the perspective of decision making within the context of sustainable suburban retrofits, the thesis offers a process of strategy analysis and futures visualisation including solution spaces, assessment tables, and scenario mapping which is a useful and replicable strategy for target setting and sustainability planning in a community context.

As recognised in Chapter 2, the suburban form is influenced by many players operating under different sets of priorities, aspirations, and interests. For suburban retrofits, these same players will play a significant role in what is achievable. For example, while a municipality might be interested in providing affordable housing and conserving energy, a developer may investigate investment payback periods on various housing typologies and energy generation technologies. Community members may focus on quality of life and local amenity provisions.

Outside of design strategy analysis, the solution spaces, scenario maps and assessment tables derived in Chapter 5 can be redeveloped for other research domains of sustainability including time considerations, technology, demographics, or equity, each of which will interest different decision makers to various degrees. By avoiding deterministic and singular solutions to sustainability questions, a range of potential solutions all working towards the same target can be generated. The method of analysis and scenario development described by the thesis enables various stakeholders in the sustainable development process to consider a range of solutions and their consequences quickly, while developing a basic understanding of the tradeoffs that occur under selected scenarios. In addition, this method of analysis, and especially solution spaces, provide a level of individual choice among solutions and enable strategies to be re-evaluated and translated over time to meet changing means or needs.

6.3 Limitations of Thesis

Although intentionally broad in its discussions, the thesis is also limited in part by the generalisations it makes. From the outset, the thesis's assumptions of an "average" household, in which each resident contributes equally to energy consumption and emissions, means that a certain level of sophistication, particularly the ability to interpret the differences in energy consumption patterns and preferences among households, is removed. While calculations and assessments are clarified by these averages, finer grained opportunities for synergies and cooperation among households are certainly lost in the simplification. This loss is compounded by the level of data available for the project, which provides energy use for the average single family home in the Lower Mainland, including homes of a much wider range of sizes, ages, and occupancy types than is represented in the chosen study area. The thesis acknowledges that utilising energy consumption data from the regional energy utilities BCHydro and Terasen Gas, rather than independent sources, may also influence the results of the research. Similarly, transportation patterns were estimated using software which generalises daily mileage based on a set of common development characteristics, which does not fully reflect the diverse transportation habits of actual residents in the study area. Without record of these varied travel patterns, estimations for transportation reductions, which treat all study area households equally, may be oversimplified within the thesis. The issue of reducing travel by private automobile is also affected by the general level of uncertainty surrounding available research on the extent to which design measures affect transportation.

In addition, the thesis recognises that by bounding the issue of sustainability within the exclusive consideration of emissions mitigation, a great deal of information, by way of both added synergies and potential conflicts, is lost to the discussion. For example, the thesis preferences hydroelectricity over natural gas for space heating and hot water needs within study area households for its benefits as a low-emitting energy source; however, this does not mean that large scale hydroelectricity is a sustainable form of energy generation in terms of other sustainability indicators such as watershed health and habitat preservation. While the simplification is necessary for in order to limit the scope thesis, carbon neutrality is not, in reality, an issue to be considered in isolation.

The thesis also notes that larger contextual issues, such as policy, resident participation, and the need for substantial economic investment are issues that will greatly affect the outcome of any retrofit project. These factors, while not explicitly discussed in the thesis, will be enormous players in the realisation of neighbourhood retrofit strategies, and the thesis recognises that, along with design strategies, social, political, and economic changes, incentives and consensus within the study area and regionally, will be both essential and invaluable. The consideration of these issues within a retrofit project will significantly influence which strategies are able to be implemented and which are not, potentially leading to very different design priorities than those discussed in the thesis.

6.4 Further Research

Many of the limitations of the thesis can be mitigated by additional research on the topic of suburban residential development retrofits in the future. First, a revisiting of the Fleetwood study area and similar developments with a more intimate, on the ground approach to data collection, including resident habits and household billing data would enable a finer grained analysis of energy use and potential synergies among households. Likewise, resident inclusion in future research will provide a more grounded view of the desirability and applicability of various design changes, as provided by the community itself. Comparisons of Fleetwood data to similar developments in other provinces, particularly those in varying climates and with different energy resources will provide valuable comparisons and wider applicability of research.

In addition, research into the roles of stakeholders outside of local private residents, such as home builders and developers, local policy makers, neighbourhood organisations, and the larger consumer market, will aid in the comprehension of how design strategies, particularly those which extend beyond the limits of private property ownership, are enacted. These types of investigations demand a consideration of issues from a regional perspective, including the potential for supportive policy changes, incentive programs, regional transportation systems, and new building guidelines or mandates which will further the understanding of how change can be incited over time, and how more progressive strategies might be incorporated into common development and redevelopment practice.

Investigation into how neighbourhood retrofit strategies might be incrementally inserted into a community context will aid in the ability to realise progressive design within existing developments. The funding of retrofit projects might be investigated for the potential subsidise future interventions with the financial savings from previous projects. By staging retrofit development in such a way, major improvements might become realisable to a wider range of communities. Similarly, investigations of design strategies that might build on each other, such as an efficient heating system that might later be connected to a district heating facility, ensure that resource, time, and financial investment is not lost along the way towards greater sustainability goals.

Chapter 5 raises possibilities for a significant body of research investigating the possibilities suggested by the development of emissions mitigation "solution spaces." The solution spaces identified for the thesis present a full range of combinations of strategies for a given carbon reduction goal, including those which are not feasible within current contexts, and also reveal possibilities for strategy variation among households and over time. An exploration of these complexities through more sophisticated scenario development, calculations and modeling may uncover new issues and synergies not discovered within the generalised nature of this thesis. In addition, new solution spaces which investigate other issues of sustainable neighbourhood retrofits such as time, cost, or technology availability should be developed in order to provide a more complete understanding of retrofit challenges and potentials.

Finally, although the thesis considers suburban retrofits largely from the neighbourhood scale, true advances in sustainability will require a substantial body of research at the regional level. Topics of research might first include a regional inventory and assessment of energy resources and potentials including sources of biomass, geothermal sites, waste heat, wind energy, etc., as well as investigations into how these sources will change the carbon content inherent in the regional power supply. The storage of these energy sources will also be a key point of research, in addition to a wider integration of food production with the more widely considered issues of housing and transportation energy. From a residential perspective, the addition of neighbourhood components such as greenhouses and community gardens have the capacity to address many of these issues – from heat storage and food production to reduced transportation as more crops are grown locally.

6.5 Closing Remarks

The preceding investigation is an attempt to assess the potentials of existing North American suburban residential developments to mitigate locally generated carbon emissions and to determine a process by which multiple design solutions towards this goal might be evaluated and compared. While common suburban patterns may not encompass the ideal form for more sustainable community design, it does not mean that these developments must necessarily remain emissions and resource intensive. Ironically, because of many of the very suburban characteristics demonised by critics, such as low densities, large yards, and oversized living spaces, the residential subdivision has significant room for improvement and evolution over time. With further study, the suburban residential development might be made into a productive, rather than consumptive, component of many metropolitan regions.

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