GETTING TO CARBON NEUTRAL:
a Guide for Canadian Municipalities

Toronto and Region Conservation for The Living City

Getting to Carbon Neutral:

A Guide for Canadian Municipalities

Produced for

Toronto and Region Conservation

by

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Summary

CONTEXT

Climate change is emerging as the defining challenge of a generation. The scientific evidence that some measure of climate change is anthropogenically induced is overwhelming; greenhouse gas emissions from human activities have risen sharply as population expands and people become increasingly wealthy, and therefore able to consume resources at a faster rate. It is a global issue, both severe and indiscriminate in its impacts, but as daunting a challenge as it may be, addressing climate change offers a focal point for global collaboration and innovation. Furthermore, a significant proportion of the scientific community posits that with decisive action, mitigation is still a viable component of a global response to the threats posed by climate change.

The window of opportunity to take action against rising emissions is shrinking. Achieving carbon reduction targets within the necessary timeframe will require coordinated efforts from all levels of government, corporations and individuals. With more than half of the world's human population living in urban areas, the concentration of financial and human capital positions municipalities particularly well to be successful at contributing significantly to global emission reductions.

This report strives to provide Canadian municipalities with a menu of options for greenhouse gas emission reductions, allowing a city to choose the combination of actions that are both feasible and most strategic for their specific circumstances.

CARBON NEUTRAL

The concept of 'carbon neutral' is a useful benchmark to gauge progress toward overall sustainability. Within the context of this report, carbon neutral is defined as: *the total greenhouse gas (GHG) emissions generated by a city, directly or indirectly, less the emissions sequestered and offset summing to zero.* Achieving carbon neutrality is an indicator of living within our ecological means and consuming resources at a rate that does not impede future generations' ability to enjoy them. Without balancing the rate of emission generation with the rate of sequestration, climate change is inevitable. For an individual municipality, establishing a carbon neutral target makes a statement about the priority level of sustainability and provides a framework to guide a wide range of programs and regulation; collectively working toward carbon neutrality, municipalities could significantly lessen the impact of climate change.

REPORT METHODOLOGY AND STRUCTURE

Many Canadian municipalities have already taken the first step toward reducing carbon emissions: conducting an inventory of emissions. Data collection is critical to design and implement effective strategies for reducing emissions, but many cities are finding it difficult to translate this information into actual programs and projects with impact. The analysis conducted for this report aims to facilitate the transition from data collection to strategic action.

Carbon dioxide has great utility as a standard unit of measurement, and permits the extensive quantitative modeling contained in this guide. Part I reiterates the value and process of carbon inventorying and identifies the categories of significant sources of GHG emissions from a city. Part II offers best practice strategies for GHG reductions in these categories and provides Estimation Guidelines—equations that quantify the approximate emission reductions that could be achieved from implementing these activities.

The suggested activities in Part II are derived from the actual experiences of cities across Canada and worldwide that are experimenting with an array of actions to reduce emissions. Over 70 case studies substantiate the suggested actions and the associated Estimation Guidelines. The variety in the scale and nature of the projects explored through the case studies indicates that participation in climate change mitigation activity need not be restricted by the size, location or other characteristics of the municipality. There are opportunities to tailor strategies to fit the unique conditions of each individual municipality. Part III compares different strategies, considering both the costs and the GHG abatement potential. It also offers a "Top Ten" list of specific actions a city could take with the greatest impact on GHG emissions.

FINDINGS

The areas identified in the report as having the greatest mitigation potential in the municipal context are familiar to the environmental policy and planning community. They are consistent with previous knowledge of the key drivers of GHG emission reduction, as are the actions highlighted as "best practices" in the report. However, maximizing the GHG abatement potential may require a collaborative effort between municipal, provincial and/or federal governments. The areas recommended for strategic action are:

1. **Buildings**
    a. Retrofits of existing buildings for greater efficiency.
    b. Stricter regulation for resource consumption in new buildings.
2. **Land use and urban planning**
    a. Increased density.
    b. Increased urban green spaces (parkland, urban tree canopy, green roofs).
    c. Neighbourhood design that encourages active transportation (cycling and walking)
3. **Transportation**
    a. Improve coverage of public transit infrastructure.
    b. Inhibit personal automobile use in urban areas (tolls, restricted parking, traffic calming mechanisms).
    c. Encourage adoption of electric or low-emission vehicles.

4. **Energy Supply**
    a. Integrated community energy planning.
    b. Harvest energy from municipal waste stream.
    c. Increase renewable energy supply.
5. **Efficiency and demand management**
    a. Increase efficiency of municipal services and buildings.

The Estimation Guidelines and the case studies revealed that more expensive projects resulted in greater GHG savings. The trend of projects requiring greater investment yielding greater GHG abatement was generally consistent across categories. The guide highlights several especially noteworthy cases, in which the ratio of GHG emissions saved per investment was substantially higher, such as a congestion pricing scheme for central London and Calgary's light rail system, the C-train.

The guide concludes that there are indeed opportunities for municipalities to reduce their emissions dramatically, and that achieving carbon neutrality is possible in the Canadian municipal context. The report also notes that there are social, economic and environmental benefits to many of these projects beyond their climate change mitigation potential, further enhancing their value.

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Part 1. *Understanding Municipal GHG Emissions*

CHAPTER 1: INTRODUCTION

(C. Kennedy and E. Mohareb)

Today, more than half the world's human inhabitants live in urban areas. This means that cities have become a major driver of global greenhouse gas (GHG) emissions. Moreover, as centres of wealth and creativity, afforded high population densities and favourable economies of scale, cities have a duty to play a significant role in tackling the causes of global climate change. This is particularly vital in a political context, where the potential influence and cumulative actions of groups, such as the C40 mayors, exceed those of many national governments.

As a first step to addressing climate change, many cities have undertaken inventories of their GHG emissions, often using the simple pragmatic approach of the International Council for Local Environmental Initiatives (ICLEI, 2009). Close to 200 Canadian municipalities are participating in the Partners for Climate Protection (PCP) program (FCM, 2009), the Canadian component of ICLEI's Cities for Climate Protection (CCP) network. While most of these municipalities have completed inventories of urban GHG emissions, many are struggling to develop and implement effective strategies for substantially reducing those GHGs.

There are many examples of sustainable design practices, adopted in Canada or elsewhere, that have lowered GHG emissions from various urban neighbourhoods or infrastructure systems. Canadian examples include: Calgary's wind-powered C-train, Toronto's deep lake water cooling project, and sustainable neighbourhood developments at Dockside Green and Southeast False Creek (both in BC), and Okotoks (Alberta). To these we can add international examples, such as Malmö's port, Hammarby (Stockholm) and Kronsberg (Hannover). A few western cities, such as London (UK) and Freiburg (Germany), have reduced per capita automobile use and associated emissions.

Many of the strategies employed in these examples are substantial, long term endeavours requiring serious investment and significant societal change. If Canadian municipalities were to aggressively pursue a wide range of such strategies, subject to their own unique conditions, then it is technically feasible for many to become carbon neutral.

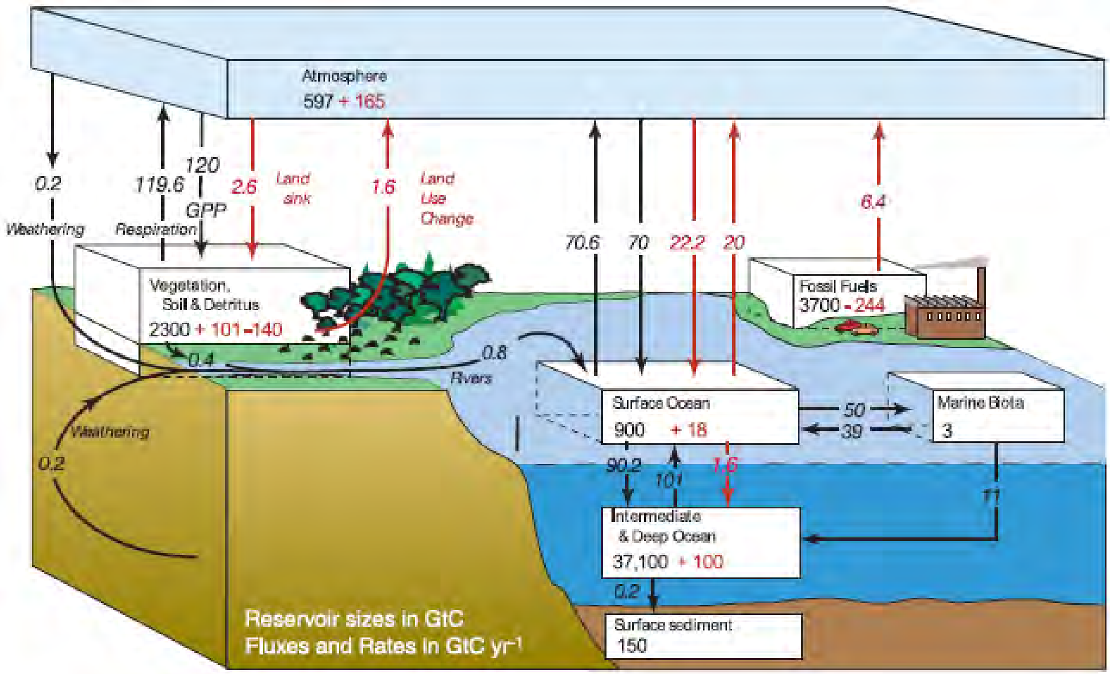

Figure 1.1 The Global Carbon Cycle

Source: IPCC, 2007b

1.1 CLIMATE CHANGE AND THE GLOBAL CARBON CYCLE

Anthropogenically-induced climate change caused by the direct and indirect increase of GHGs in the atmosphere (e.g., due to fossil fuel combustion and land use change) is an urgent global environmental concern. Given a global average increase in temperature of 2 to 3°C from pre-industrial conditions, anticipated environmental impacts would include (IPCC, 2007a):

- extinction of 20 to 30 per cent of all species
- major loss of rainforests
- substantial structural / functional shifts in terrestrial and marine ecosystems
- high risk of breakdown of the Greenland ice sheet causing sea level rise
- worsening degree of water stress
- increased flood / storm damage

These anticipated impacts are due, in part, to an imbalance in the global carbon cycle. As a consequence of fossil fuel combustion and land use change, the atmospheric concentration of carbon, expressed in gigatonnes of carbon (GtC), has increased relative to pre-industrial levels. The higher concentration of carbon-based molecules (such as carbon dioxide and methane) in the atmosphere is believed to be causing global climate change, through the aptly-named greenhouse effect.

There are additional compounds which also contribute to global climate change. These include nitrous oxide, ozone, chlorofluorocarbons, hydrofluorocarbons, perfluorinated compounds, fluorinated ethers and several others. (Water vapour is also a significant greenhouse gas, although its concentration is not considered to be impacted by humans on a global scale).

The relative impacts of greenhouse gases are typically expressed in terms of their global warming potential. This is a measure of the contribution of a particular greenhouse gas to global warming relative to carbon dioxide (Table 1.1). It is a function of both the chemical species and its residence time in the atmosphere. The units of global warming potential are tonnes of carbon dioxide equivalent (t CO_2e).

TABLE 1.1
GLOBAL WARMING POTENTIAL FOR THREE COMMON GHGS

Common name	Chemical formula	100-year global warming potential
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide	N_2O	310

Notes: For a full list of global warming potentials see Table 2.14 in the 2007 IPCC Fourth Assessment Report.

The current best estimates, as set forth in the IPCC's Fourth Assessment Report (IPCC, 2007b), suggest that 'climate sensitivity' is 3°C. This is the increase in global average temperature that would result from a doubling of atmospheric CO_2e concentrations (to roughly 550 ppmv). In order to achieve a stabilization concentration of 450 ppmv CO_2e, the IPCC has proposed that Annex I countries (including Canada) must achieve an 80 to 95 per cent reduction in GHG emissions by 2050 (IPCC 2007c). At this concentration, the global mean surface temperature would increase by an estimated 2.1°C, which would reduce the likelihood and severity of the anticipated environmental impacts.

1.2 HOW TO USE THIS GUIDE

The purpose of this guide is to assist medium to large Canadian municipalities proceed further down the path to becoming carbon neutral. By carbon neutral we mean that direct and indirect emissions from the municipality minus sequestered carbon and offsets sum to zero. The guide provides:

- a collection of case studies of best practices in sustainable urban design and planning worldwide
- guidelines for estimating the GHG emission reductions from a wide range of

strategies that may be pursued by Canadian municipalities

- examples of how integration of these strategies can be used to reduce a municipality's per capita GHG emissions by over 70 per cent

This book describes a variety of technological and urban planning strategies that can be used to substantially reduce community GHG emissions from a municipality. The guide also provides some information on the costs of implementing strategies and ways in which barriers to implementation have been overcome. These are illustrated through approximately 70 case studies, many of which are included in this guide.

The guide begins with a review of the inventorying of municipal GHG emissions. Although most Canadian municipalities have already completed their inventories, this is an important first step. The inventory is the starting point for a systematic and comprehensive set of calculations for measuring the potential GHG reductions that are discussed through the guide.

Theoretically, all reductions in GHG emissions that are determined according to the Estimation Guidelines provided in this guide can be deducted from the starting inventory. However, the inventory process must be comprehensive. Any measures taken to reduce GHG emissions from sources that were not considered or included in the preparation of the original inventory (e.g., greening supply chains, growing local food, or some aspects of waste management) should not be credited.

Part 2 of the guide (Chapters 3-6) provides best practice strategies for reducing municipal GHG emissions in the categories of buildings, transportation / land use, energy supply, and municipal services (waste management, water and wastewater treatment, and carbon sequestration / offsets). For each strategy, the guide provides simple, generic Estimation Guidelines for quantifying the approximate reductions in GHG emissions that can be achieved. For example, the formulae can be used to estimate the GHG reductions from: installing X kilometres of light rail; constructing a gasification plant to process Y tonnes of solid waste; or servicing Z hectares of a municipality using a district energy scheme. The Estimation Guidelines typically calculate changes to intermediary quantities, such as energy use or vehicle kilometres travelled, from which GHG emissions are subsequently determined. The guide does not seek to be prescriptive in how the GHG reduction strategies are selected; it offers a menu of choices.

The GHG reduction strategies are supported by a selection of case studies, which are included as boxed examples throughout the guide. The case studies provide examples of leading-edge initiatives that municipalities are taking to reduce GHG emissions, both in Canada and worldwide. The case studies provide information on costs, benefits, implementation and GHG savings. They also provide empirical data to support and verify the Estimation Guidelines developed in this guide.

The selection criteria for the case studies were:

- strategies that reduce (orprevent an increase in) GHG emissions
- coverage of both Canadian and non-Canadian best practices
- examples from both medium and large municipalities
- a primary focus on technological and urban design solutions, rather than economic measures
- availability of information.

The information on capital costs and GHG reductions from all the case studies is analyzed in Chapter 7. This analysis provides some general conclusions on the most cost effective means to reduce municipal GHG emissions (from a capital budgeting perspective).

The final chapter of this guide (Chapter 8) shows how the integration of a range of strategies can substantially reduce a municipality's overall emissions. The inventory process, Estimation Guidelines and other data tables in this guide have been developed in a consistent fashion, so that they can be used systematically to develop (or assess) a municipality's master plan for GHG reductions. By way of example, Chapter 8 shows how Toronto's GHG emission could be reduced by 2031 under current and aggressive plans.

References for Chapter 1

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CHAPTER 2: INVENTORYING MUNICIPAL GHG EMISSIONS

(C. Kennedy)

Many Canadian cities have already completed inventories of their greenhouse gas emissions under the Partners for Climate Protection (PCP) program. This chapter reviews the calculation of GHG emissions from major sources: electricity, heating fuels, and transportation fuels, as well as secondary sources, such as industrial process emissions, and waste. Emissions from agriculture, forestry and land use change are excluded. We also discuss additional sources of GHG emissions that can be attributed to cities, (such as aviation and marine transport, and upstream emissions), but which are excluded under the PCP program.

The global warming potential of GHGs attributable to cities, including carbon dioxide, methane, nitrous oxide and several other gases, is expressed in terms of carbon dioxide equivalents (CO_2e). From a practical perspective, emissions of CO_2 itself dominate the urban inventory, with methane of significance in the assessment of landfilled waste, and other gases mainly of significance in relation to the industrial operations where they are used, produced and/or released.

2.1 ELECTRICITY

GHG emissions (tonnes of CO_2e) attributable to total electricity consumption in a municipality are determined by use of the following calculation (Equation 2.1):

$$GHG_{electricity} = C_{electricity} \cdot L \cdot I_{electricity}$$

Electrical line losses ("L") range from 5 per cent to 15 per cent (i.e., the line loss factor in Equation 2.1 is between 1.05 and 1.15). These include losses from regional high voltage transmission lines and local losses within a municipality's distribution network.

The GHG emission intensity, $I_{electricity}$ (tonnes of CO_2e/GWh), is derived from the mix of power plants in the province (Table 2.1). It can be difficult to identify which specific power plants are serving a municipality; indeed, the mix often changes over time, with different sources used to meet base and peak loads. Where a municipality is seeking to reduce its GHG emissions from electricity emissions by installing its own renewable supplies, then a study of municipality-specific supply is warranted.

The electricity consumption component, $C_{electricty}$ (GWh), excludes consideration of combined heat and power (CHP) plants within the municipality and electricity derived from the combustion of waste. Emissions derived from CHP and waste combustion are calculated under the Estimation Guidelines related to heating fuels and waste, respectively, in this guide.

There is considerable variation in the GHG intensities of electricity supply among provinces. Alberta and Saskatchewan rely heavily upon coal combustion for power generation and, hence, have emission intensities above 800 tonnes of CO_2e/GWh. In contrast, British Columbia, Manitoba, Quebec and Newfoundland have no coal combustion; they generate most of their electricity from hydropower. Their electricity supplies are virtually carbon free. Ontario and New Brunswick derive a significant share of their electricity production from nuclear power and their emission intensity figures lie somewhere in the middle of the two extremes. These differences in sources of electricity substantially impact how difficult it can be for a municipality to become carbon neutral, and the types of strategy it may use to get there.

TABLE 2.1
PROVINCIAL ELECTRICITY GENERATION BY SOURCE & GHG EMISSION INTENSITY, 2006

	NF	PEI	NS	NB	QC	ON	MB	SK	AB	BC
Coal	0%	0%	63%	16%	0%	17%	1%	60%	84%	0%
Refined petroleum	2%	2%	5%	18%	0%	0%	0%	0%	0%	0%
Natural gas	0%	0%	3%	18%	1%	7%	0%	15%	12%	7%
Nuclear	0%	0%	0%	25%	3%	54%	0%	0%	0%	0%
Hydro	98%	0%	8%	21%	96%	23%	98%	22%	2%	91%
Biomass	0%	2%	2%	0%	0%	0%	0%	0%	0%	1%
Other renewables	0%	96%	1%	0%	0%	0%	0%	3%	2%	0%
Other	0%	0%	17%	3%	0%	0%	0%	0%	0%	0%
Total generation (GWh)	41,810	52	11,190	17,440	157,610	154,800	34,060	18,230	54,170	48,780
GHG intensity (t CO_2e/GWh)	15	192	549	366	6	180	10	810	930	20

Source: Environment Canada, 2008

HEATING AND INDUSTRIAL FUELS

Emissions in this category are primarily due to fossil fuels used for heating in buildings (e.g., space heating, water heating and cooking). Also included are fossil fuels used by combined heat and power (CHP) facilities within cities (mainly natural gas and oil) and, where applicable, fossil fuels used for heating in industrial processes.

GHG emissions (tonnes of CO_2e) for each fuel used, GHG_{fuel}, are determined by use of the following calculation (Equation 2.2):

$$GHG_{fuel} = C_{fuel} \cdot I_{fuel}$$

The value C_{fuel} (TJ) is the amount of fuel consumed, expressed in terms of its energy content. Table 2.2 gives the default IPCC (2006a) GHG emission factors for selected fuels, I_{fuel} (tonnes of CO_2 / TJ), which can be used for calculating direct emissions.

TABLE 2.2
DIRECT & LIFECYCLE GHG EMISSION FACTORS FOR SELECTED FUELS

	Energy content (TJ/ML)	**Direct emissions**[1] (t CO_2e/TJ)	**Lifecycle emissions**[2] (t CO_2e/TJ)
Gasoline (low sulphur)	34.8	72.2	94.9
Diesel	37.8	75.2	92.3
Jet kerosene	35.1	72.0	92.5 [3]
LPG (petroleum based)	26.8	66.1	81.0
Marine fuel	Varies	78.9	94.1
Natural gas (dry)	n.a.	56.1	67.9 [4]
Fuel oil	Varies	77.8	91.6
Coal			
Anthracite	n.a.	98.1	100.8
Coking/Bituminous	n.a.	94.4	107.1

Notes:

1. Adapted from IPCC; includes average tier 1 emission factors for CO2, CH4 and N2O.
2. Adapted from GHGenius (Canada).
3. The lifecycle emission factor for jet kerosene of 92.5 tonnes of CO2e/TJ was determined by assuming the same upstream contribution as diesel fuel.
4. The lifecycle emission factor for natural gas was determined from processing data from GaBi 4 (an environmental lifecycle analysis software) and distribution losses reported by TransCanada pipelines.

2.2 GROUND TRANSPORTATION FUELS

The primary fuels used for ground transportation within cities are gasoline and diesel, with small amounts of LPG and natural gas used in some cases. Emissions due to the use of electrified modes of transportation (e.g., subways and streetcars) are counted in the electricity category. Emissions from consumption of each fuel can be calculated using Equation 2.2 with emission factors from Table 2.2.

Emissions from ground transportation can contribute as much as 20 to 40 per cent of a city's GHG emissions, and are the greatest source of uncertainty in the total inventory due to the estimation procedures involved. Three different techniques can be used to estimate the volumes of gasoline, diesel and other ground transportation fuels used in cities:

- local fuel sales data;
- scaling from provincial data using motor vehicle registrations; or
- the vehicle kilometres travelled (VKT) within cities determined using a computer model or vehicle counting approach.

The differences between these techniques can be less than five per cent (Kennedy et al., 2009a).

2.3 INDUSTRIAL PROCESS EMISSIONS

Direct, non-energy related industrial emissions include those from the following sources:

- production of mineral products, such as cement, lime and soda ash
- production of metals, such as iron and steel, aluminum, zinc and lead
- chemical production, such as ammonia, petrochemicals and titanium dioxide
- consumption of petroleum products in feedstocks and other end uses, such as plastics, solvents, and lubricants.

In addition, certain industrial processes can generate emissions of methane, nitrous oxide, and fluorinated gases. Industrial process emissions do not include emissions from the combustion of fossil fuels for industrial heating.

Data for this category of emissions can be difficult to determine for some municipalities. Industrial facilities with emissions greater than 100,000 tonnes of CO_2e are required to submit an annual pollutants release report to Environment Canada. Data for specific facilities are available at: http://www.ec.gc.ca/pdb/ghg/onlinedata/DataAndReports_e.cfm

2.4 WASTE

Estimating the GHG emissions from landfill waste can be problematic. The IPCC (2006) recommends an approach, called First Order Decay that is based on the Scholl Canyon model, for estimating the methane emissions for a given year resulting from the decay of waste placed in the landfill during both that year and previous years. However, the data requirements are cumbersome, requiring 20 or more years of data for each facility within the city, as well as good estimates of decay coefficients.

The method below, a simplified adaptation of the IPCC (1997) approach called Total Yield Gas, is more pragmatic and is based on the amount of waste landfilled in the inventory year. The long term GHG emissions from landfill waste (tonnes of CO_2e) may be calculated using Equation 2.3:

$$\hat{GHG}_{landfill} = 21 \cdot M_{landfill} \cdot L_0 \left(1 - f_{rec}\right)\left(1 - OX\right)$$

The value $M_{landfill}$ is the mass of urban waste sent to landfill in the inventory year; L_0 is the methane generation potential; the value 21 is the 100-year global warming potential of methane (IPCC, 2006); and f_{rec} is the fraction of methane emissions that are recovered at the landfill. The oxidation factor (OX) is determined using Equation 2.5 and is typically no higher than 0.1.

The methane generation potential, L_0 (tonnes of CH_4 per tonne of waste), is determined using the IPCC (2006) approach in Equation 2.4 as follows:

$$L_0 = {}^{16}\!/_{12}\, MCF \cdot DOC \cdot DOC_F \cdot F$$

MCF is the CH_4 correction factor (equal to 1.0 for managed landfills); DOC is degradable organic carbon (tonnes of carbon per tonne of waste); DOC_F is the fraction DOC dissimilated (default range 0.5 to 0.6, and assumed equal to 0.6); F is the fraction of methane in landfill gas (with a range of 0.4 to 0.6, and assumed equal to 0.5); and 16/12 is the stoichiometric ratio between methane and carbon.

The degradable organic carbon (DOC) is estimated from waste fractions (f_i) as follows using Equation 2.5:

$$DOC = \sum_i W_i \cdot f_i$$

The weightings W_i are as shown in Table 2.3.

TABLE 2.3
WEIGHT FRACTION OF DOC IN WASTE STREAMS

Waste fraction	W_i
Food	0.15
Garden	0.2
Paper	0.4
Wood	0.43
Textiles	0.24
Industrial	0.15

Note: DOC is degradable organic carbon.
Source: Adapted from IPCC waste model spreadsheet, available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html.

2.5 AVIATION AND MARINE TRANSPORTATION

GHG emissions derived from air and marine transportation are rarely recorded in the inventories of Canadian municipalities. However, some large cities (e.g., London and New York City) do report them as additional sources of GHGs.

There is currently no standard approach for quantifying these emissions. It might be appropriate to include only those emissions associated with air and maritime travel by residents of a city, as well as the shipment of goods consumed by those residents. On the other hand, if a city is a major gateway, tourist destination or convention hub, the GHGs generated by visitors might be included in its inventory.

From a practical perspective, the volumes of fuel loaded onto planes and ships in a particular city's airports and marine transport terminals could be determined. GHG emissions could then be estimated using Equation 2.2 and the appropriate emission factor from Table 2.2.

2.6 EXAMPLE OF GHG EMISSIONS FOR THE CITY OF TORONTO

The 2004 GHG emissions for the City of Toronto (population: 2,613,832) can be used to demonstrate the inventory procedure.

In 2004, electricity consumption in Toronto totalled 91,516 TJ or 25,421 GWh (City of Toronto, 2007). The GHG intensity of Ontario's supply was 222 tonnes of CO_2e/GWh that year. The intensity decreased to 180 tonnes of CO_2e/GWh by 2006, as shown in Table 2.1, due to reduced use of coal generation. Allowing for line losses of 12 per cent (i.e., L = 1.12 in Equation 2.1), the GHG emissions produced in providing electricity to Toronto were 6,208 kilotonnes of CO_2e.

Heating and industrial fuel use in Toronto is predominantly natural gas, although small amounts of fuel oil and other fossil fuels may be used. Consumption of natural gas in 2004 was 165,182 TJ (Table 2.4). Using the IPCC emission factor of 56.1 tonnes of CO_2e /TJ (Table 2.4), the GHG emission from Toronto's natural gas use was 8,672 tonnes of CO_2e (using Equation 2.2).

TABLE 2.4
GHG EMISSIONS FROM ELECTRICITY & NAUTRAL GAS CONSUMPTION, CITY OF TORONTO, 2004

	Residential	Commercial & small industrial	Large commercial & industrial	Total
Energy (TJ)				
Natural gas	89,523	47,139	28,520	165,182
Electricity	19,098	64,995	7,432	91,516
GHG (kt CO_2e)				
Natural gas	4,700	2,475	1,497	8,672
Electricity	1,295	4,409	504	6,208

Source: Energy consumption data is from City of Toronto, 2007.

Based on traffic counts and road length data, the City of Toronto (2007) estimates that 24.6 billion vehicle kilometres were travelled by cars, trucks and motorcycles within Toronto. The estimated volumes of gasoline and diesel consumed were 2.61 million litres (ML) and 0.779 ML, respectively. GHG emissions from ground transportation were determined to be 8,772 kilotonnes of CO_2e.

No direct emissions from industrial processes were reported in the City of Toronto's inventory for 2004. There are a couple of cement plants and a lubricant centre in the wider Greater Toronto Area (GTA), which have total emissions of 3,185 kilotonnes of CO_2e (Kennedy et al., 2009a,b). These facilities generate emissions in excess of 100 kilotonnes of CO_2e per year, and are required to report their pollutant releases to Environment Canada. It is possible that there are additional facilities that generate CO_2e emissions below the Environment Canada reporting threshold located within the City of Toronto, but these are currently unreported.

Toronto Pearson Airport lies outside of the City of Toronto, in neighbouring Mississauga. In 2005, the volume of jet fuel loaded onto planes at Pearson was 1,830 ML. Combustion of this fuel while carrying passengers and freight away from the Greater Toronto Area produces emissions of 4,625 kilotonnes of CO_2e. None of this fuel is actually combusted in Toronto, and the airport serves Greater Toronto and other parts of Southern Ontario. Nevertheless, a substantial proportion of these aviation emissions could be attributed to residents and businesses in Toronto. This has not been accounted for in the City of Toronto's inventory.

The City of Toronto reports that 978 kilotonnes of CO_2e were emitted in 2004 from landfills storing residential waste from the city. This value is an estimate of emissions from "waste in place", rather than an estimate of total yield from this year's waste (as determined using Equations 2.3 to 2.5 above). Using the Total Yields Gas approach for both residential and commercial waste for the Greater Toronto Area, GHG emissions were estimated to be 1,811 kilotonnes of CO_2e. This estimate is based on a total landfill tonnage of 4,091,465 tonnes, with a composition as given in Table 2.5 (Kennedy et al., 2009a,b).

TABLE 2.5
COMPOSITION OF LANDFILLED WASTE (RESIDENTIAL AND COMMERCIAL), GREATER TORONTO AREA, 2005

Waste type	Waste fraction
Paper	33%
Food	14%
Plant Debris	7%
Wood/Textiles	6%
Plastic	12%
Other	28%

Source: Toronto City Summit Alliance, 2008

The City of Toronto's total GHG emissions from major sources for 2004 were 24,600 kilotonnes of CO_2e (Table 2.6). This value excludes emissions from non-energy related industrial processes, aviation and marine transportation, and the disposal of commercial waste, as well as minor sources and sinks, such as agriculture. (Note that the City of Toronto (2007) reports emissions of 24,400 kilotonnes of CO_2e for 2004; the minor difference with Table 2.6 lies in the emission factors used for ground transportation.)

TABLE 2.6
SUMMARY OF DIRECT GHG EMISSIONS FROM MAJOR SOURCES, CITY OF TORONTO, 2004

	GHG emissions (kt CO_2e)
Natural gas	8,672
Electricity	6,208
Gasoline	6,558
Diesel	2,214
Landfill waste	978
Total	24,630

2.7 UPSTREAM EMISSIONS

Beyond the six categories of GHG emissions described above, there are further emissions that can be attributed to cities, but typically excluded under the PCP program. These are the upstream emissions associated with mining, manufacturing, producing and transporting the food, fuels, goods and materials consumed in cities (Case 2.1).

These upstream emissions can be substantial. To demonstrate this, the lifecycle emission factors from Table 2.2 were used to recalculate the GHG emissions from transportation fuel combustion that could be attributed to the City of Toronto. GHG emissions from gasoline increased by 31 per cent, from 6,558 to 8,620 kilotonnes of CO_2e, and diesel emissions increased by 23 per cent, from 2,214 to 2,717 kilotonnes of CO_2e.

CASE 2.1
UPSTREAM EMISSIONS FOR THE CITY OF PARIS

Using methods developed by Bilan Carbon™, the City of Paris, France, has quantified the GHG emissions embodied in food, building materials and the transport of merchandise to the city.

The emissions embodied in the food eaten by Parisians, is estimated to be 1.2 tonnes of CO_2e per capita, with the consumption of meats making a particularly high contribution.

The construction of housing and offices in Paris generated emissions of 77,070 tonnes of CO_2e and 14,313 tonnes of CO_2e, respectively. The renovation of roads is estimated to account for a further 135,790 tonnes of CO_2e.

Each year, more than 30 million tonnes of goods enter or leave Paris. The transport of these goods via road, inland waterway, rail and air generates over 6.4 million tonnes of CO_2e. This value includes other upstream emissions associated with maintenance of vehicles and refining of fuels.

Reference: Mairie de Paris (2009) Le Bilan Carbone de Paris: Bilan des émissions de gaz à effet de serre.

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Part 2. *Strategies for Reducing GHG Emissions*

CHAPTER 3: BUILDINGS

(D. Bristow, R. Zizzo, R. Stupka and C. Kennedy)

As major consumers of heating fuels and electricity, the operation and maintenance of buildings account for a considerable proportion of GHG emissions generated in Canadian cities. Three broad strategies for reducing these emissions are presented in this chapter:

- reduce demand
- utilize solar energy
- exploit waste heat through ground source heat pumps

Other strategies involving changes to neighbourhood or local energy supply systems are covered in Chapter 5. The strategies considered in this chapter are all at the building scale.

3.1 STRATEGY 1: REDUCE ENERGY DEMAND

The foremost strategy for reducing building-related GHG emissions is to reduce energy demand. In simple terms, this means retrofitting or re-building residential, commercial and industrial buildings to increase the level of insulation, upgrade windows and reduce air leakage. Other sub-strategies in this category include the installation of energy efficient appliances and equipment, and the use of vegetation – green roofs and urban forestry – for reducing building energy demand.

TABLE 3.1
ENERGY INTENSITY (GJ/M2) OF THE CANADIAN BUILDING STOCK, BY PROVINCE, 2006

	Low rise residential	Apartments	Commercial / institutional
Ontario	0.83	0.68	1.65
British Columbia	0.68	0.65	1.26
Alberta	1.18	0.92	1.6
Saskatchewan	1.00	0.75	2.12
Manitoba	0.82	0.58	1.6
Quebec	1.01	0.81	1.8
New Brunswick	0.92	0.68	1.56
Nova Scotia	0.68	0.56	1.56
PEI	0.59	0.46	1.56
Newfoundland	0.75	0.59	1.26
Territories	0.69	0.58	1.26

Notes: Atlantic provinces treated as one region for commercial / institutional data
Source: NRCan NEUD tables (excludes industrial buildings), NRCan (2010).

Table 3.1 presents energy use per gross floor area for residential and commercial buildings in each Canadian province (for more detailed data see Appendix A). Variation among provinces depends on a number of factors, including climate and the average age of buildings. Ideally, municipalities using this guide will have established the energy intensity of their own building stock; if not, Table 3.1 can be used as a starting point.

By showing average values, Table 3.1 masks the considerable variation in building energy use within a city's building stock. As an example, Table 3.2 shows changes in the energy consumption of an average, single family (240 m^2) detached house in Toronto designed to the building standards of the era in which it was constructed. The 1930s version of the house consumes 2.7 times more energy than the same house built to R2000 standards.

TABLE 3.2
IMPACT OF BUILDING ERA & RETROFITTING ON ENERGY DEMAND OF DETACHED TORONTO HOME

Era	Description	**Annual energy use** per gross floor area (GJ/m^2)	
		Original	After basement & air leakage retrofits
Pre- World War II 1930s	Solid masonry construction without any additional wall or foundation insulation, block or masonry foundation basement. (R10 attic insulation; and 15 ACH @ 50 Pa air tightness)	1.91	1.49
Post-War 1960s	38 x 140 mm (2"x4") wood-frame construction, masonry veneer, exterior walls insulated to 1.76 RSI (R10), foundation un-insulated. (R14 attic insulation; and 8 ACH @ 50 Pa air tightness)	1.45	1.12
Post-Oil Crisis 1980s	38 x 140 mm (2"x6") wood-frame construction, masonry veneer, exterior walls insulated to 3.5 RSI (R20) with partial basement insulation (2.1 RSI (R12)) to 600 mm below grade. (R22 attic insulation; and 3 ACH @ 50 Pa air tightness)	0.92	0.83
R2000 house		0.71	Not applicable

Notes:

1. Based on a gross floor area of 240 m^2.
2. The retrofitting includes: insulating the interior of basement walls using 38 x 89 mm stud wall framing and 90 mm batt insulation to achieve 2.1 RSI insulation levels; installing polyethylene vapour barrier and gypsum wallboard finish; and performing comprehensive air leakage sealing on the whole house (with a 40 per cent reduction in air infiltration rates).

Source: Adapted from Tables 1, 3 and 5 of Dong et al., 2005.

3.1.1 BUILDING RETROFITS

There are many opportunities to reduce energy use in buildings through retrofitting. The example in Table 3.2 shows the impact of retrofitting residential homes using typical techniques (basement insulation, air leakage sealing). The potential energy savings are generally greater for retrofitting older homes (e.g., just over 400 MJ/m^2 for the 1930s house versus about 100 MJ/m^2 for the 1980s house). The percentage of energy saved ranges from 10 to 22 per cent.

A wider study of 3,116 potential retrofits to Toronto region homes found possible energy savings of up to 74 per cent. The average energy saving of Toronto homes in the EnerGuide for Houses Database was 22.4 per cent, as simulated by the Canadian Residential End-Use Energy Data Analysis Center (CREEDAC). The standard deviation was 15 per cent.

Table 3.3 summarizes the audit process and identifies the various building components that can be improved through a comprehensive building or facility audit.

TABLE 3.3
COMPONENTS OF A COMPREHENSIVE BUILDING OR FACILITY AUDIT

- Energy consumption profile analysis using previous two years of monthly energy bills (for electricity, natural gas and water)
- Sub-audit of building envelope, including infra-red photography of all exterior walls and the roof
- Sub-audit of HVAC (heating, ventilation and air conditioning) equipment
- Sub-audit of lighting, including walkthrough with light level meter to find locations that are under lit or over lit, and the identification of opportunities to use occupancy sensors
- Sub-audit of building automation systems to identify opportunities for additional automation
- Sub-audit of the energy efficiency of major appliances
- Sub-audit of other large energy consuming equipment inside the facilities, such as motors and power transformers
- Sub-audit of other large energy consuming equipment outside the facilities, such as exterior lighting and ramp snow melting heaters
- Sub-audit of water heating equipment
- Sub-audit to investigate whether there are any opportunities for heat recovery (ventilation heat recovery, drain pipe hot water heat recovery, process equipment heat recovery, etc.)
- Sub-audit to investigate whether there are any opportunities for demand response
- Sub-audit to determine the current level of culture of conservation among facility operators, managers and occupants (through the use of surveys)
- Sub-audit of the vehicle fleet, including specialized vehicles, such as forklift trucks
- Sub-audit to identify locations that are being over ventilated
- Sub-audit to identify locations that are being heated or cooled that do not need to be, or where a temperature setback can be used when unoccupied
- Sub-audit to identify opportunities to reduce the consumption of fossil fuels, such as the use of solar walls and geothermal heating and cooling systems
- The auditor can also indicate (on a general level only) opportunities to use on-site renewable energy equipment

Source: Region of Peel, Building Energy Audit Template, 2009.

Only a few studies of energy savings from retrofitting high rise buildings were found in our review. Estimation Guideline 3.1 is based on studies of a condominium (Hepting and Jones, 2008) and a 15-storey residential building (CMHC, 2004). Further study of commercial or industrial building retrofits is required.

ESTIMATION GUIDELINE 3.1
BUILDING RETROFITS

- Retrofitting residential homes can reduce the average energy demand of typical building stock by 20 to 25 per cent (primarily for heating). Potential energy savings for retrofitting the most energy inefficient homes can exceed 50 per cent.
- Retrofitting a high-rise apartment building can reduce its energy demand by 25 to 30 per cent (CMHC, 2004; Hepting and Jones, 2008). Savings of over 50 per cent have been posited for high-rise apartment buildings in Toronto.

3.1.2 NEW ENERGY EFFICIENT BUILDINGS

Primarily due to advances in building codes, newer buildings are typically more energy efficient than older ones. There is, however, potential to further increase efficiencies by designing residential homes that exceed R-2000 standards and commercial buildings that surpass the Model National Energy Code of Canada for Buildings (MNECB) (NRCan, 2007.

ESTIMATION GUIDELINE 3.2
NEW ENERGY EFFICIENT BUILDINGS

- Energy efficient homes meeting the R-2000 standard consume at least 30 per cent less energy than conventional new homes (NRCan, 2008).
- The energy intensity of new homes built to current building standards is about 15 per cent lower than the existing building stock.
- Commercial buildings can be designed with energy consumption 60 per cent below the Model National Energy Code of Canada for Buildings (NRCan, 2007),

CASE 3.1
REGENT PARK REDEVELOPMENT, TORONTO, ONTARIO

Regent Park is a 30-hectare (69-acre) publicly funded housing development in the east end of Toronto. The site is being redeveloped with stringent new building specifications that are estimated to be 75 per cent less energy intensive than similar conventionally designed buildings. Some of the energy saving measures include:

- advanced building envelope systems, including shading, as well as stringent insulation and windows
- 50 per cent higher insulation standards for walls, roofs and below grade
- efficient HVAC with heat recovery and radiant heating systems
- district energy cogeneration plant incorporating solar thermal collectors, ground source heat pumps and thermal storage

The redeveloped buildings will have an estimated average annual energy consumption of 36.4 MWh, compared to a conventional alternative estimated at 144.5 MWh. The district energy system is estimated to save 8,000 tonnes of GHG annually during phase one of the revitalization. Overall, GHG emissions are expected to be reduced by 80 per cent, from 39,300 to 7,900 tonnes of CO_2e per year.

Reference: Dillon Consulting, Regent Park Redevelopment Sustainable Community Design, October 2004. http://www.regentparkplan.ca/pdfs/revitalization/sustainability_report.pdf. Accessed November 4, 2008.

3.1.3 ENERGY EFFICIENT APPLIANCES AND LIGHTING

There are a number of efforts to promote the energy improvement of appliances. The ENERGY STAR labelling program is a voluntary consumer education initiative launched by the U.S. Environmental Protection Agency (EPA) in 1992 and now jointly operated with the U.S. Department of Energy (DOE). The total energy saving obtained during the first four years (1996-1999) of the ENERGY STAR campaign for appliances was 64 petajoules (Webber et al., 2000).

In Canada, the EnerGuide label, initiated by Natural Resources Canada, shows annual energy consumption for major home appliances under conditions of normal use (or an energy-efficiency ratio for air conditioners), with ratings ranging from the most energy-efficient to the least energy-efficient in each product category. In 2001, the EnerGuide and ENERGY STAR programs began to cooperate on their labelling provisions; currently, the ENERGY STAR symbol appears on the EnerGuide label of some products.

An example of the annual savings from installing energy-efficient appliances in a single-detached R-2000 house, accommodating a family of four, is given in Table 3.4 (Kikuchi et al., 2009). Data for this comparison are from the U.S. EPA/DOE (2006) and NRCan (2005). A 30 per cent saving in electricity use is achieved using the energy-efficient appliances, which is in the middle of the range given in Estimation Guideline 3.3 below.

TABLE 3.4
ENERGY USE BY APPLIANCES & LIGHTING IN A 4-PERSON HOME

Category	Conventional Appliance	Energy-efficient Appliance
Appliance [kWh/yr]		
Refrigerator	675	407
Freezer	377	360
Dishwasher including hot water	637	319
Clothes washer including hot water	838	195
Clothes dryer	900	785
Electric range	760	454
Other appliances	1614	1614
Indoor Lighting [kWh/yr]	1368	489
Exterior use [kWh/yr]	1460	1460
Total electricity consumption [kWh/yr]	8630	6083

Source: Kikuchi et al., 2009.

ESTIMATION GUIDELINE 3.3
ENERGY EFFICIENT APPLIANCES

- Typical ENERGY STAR labelled appliances can save 10 to 50 per cent energy compared to standard products (Brown et al., 2002).
- Compact fluorescent lamps (CFLs) typically use only one-quarter the electricity of standard incandescent light bulbs to provide the same amount of light.

3.1.4 VEGETATION – GREEN ROOFS AND URBAN FORESTRY

This section considers the impacts of vegetation in reducing building energy use (it does not address the sequestration of CO_2 through photosynthesis). The primary two vegetation strategies for reducing building energy use are installation of green roofs (Case 3.2), and planting urban trees close to buildings. (Planting of vertical gardens on the side of buildings is another available strategy, but is not covered here.)

The main mechanism by which a green roof reduces a building's energy use is reflectance of incoming solar radiation (Saiz et al., 2006). Green leaves absorb less radiation than most typical roofing materials, enabling roofs to remain cooler in the summer. Moreover, some of the incoming radiation is used by the plants in the process of evapo-transpiration. Further energy savings might also be achieved in the winter due to increased insulation provided by soil layers on green roofs, although this benefit is typically less significant than the reflectivity of the leafy material.

CASE 3.2
CALIFORNIA ACADEMY OF SCIENCES GREEN ROOF, SAN FRANCISCO, CA

This 18,300 m^2 green roof, costing approx $3.35 million, is comprised of seven hills. The soils are held in place by 50,000 porous biodegradable trays made of coconut husks and tree sap. The 1.7 million native plants that live on the roof were specifically chosen to self-propagate, resist salt spray from ocean air, and require little water. Therefore, the roof will not use any irrigation system.

References:

1. The Living Roof, California Academy of Sciences. http://www.calacademy.org/academy/building/the_living_roof.php. Accessed November 3, 2008.

2008 Awards of Excellence: California Academy of Sciences, Green Roofs for Healthy Cities. http://www.greenroofs.org/index.php?option=com_content&task=view&id=1039&Itemid=136. Accessed November 3, 2008.

Strategic planting of trees around buildings, can lower space heating and cooling energy demands through shading, reducing wind speeds, and related microclimatic effects. (McPherson et al., 1994; Engel-Yan, 2005).

ESTIMATION GUIDELINE 3.4
VEGETATION

- Savings in peak summer cooling loads of 25 per cent in rooms immediately below green roofs (Saiz et al., 2006).
- Green roofs typically reduce annual building energy demand by about five per cent (Brad Bass, personal communication).
- Shading and reduction in wind-speed from tree coverage can lower total annual heating and cooling loads by 5 to 10 per cent (McPherson et al., 1994).

3.2 STRATEGY 2: UTILIZE SOLAR ENERGY

Except for densely built urban centres, the solar radiation that strikes city neighourhoods far exceeds the anthropogenic energy that we pump into our cities. Even after accounting for losses in conversion, there is still great potential to meet much of our building energy needs from the sun. Here we consider building scale photovoltaics, solar water heating, solar air heating and passive solar design.

3.2.1 PHOTOVOLTAICS (PV)

Photovoltaic systems can be installed on roofs or walls of all types of buildings. They can be categorized as off-grid or grid-connected. Although off-grid systems led the market in the early 1990s, the predominant focus today is on grid-connected systems. Grid-connected systems can extract further electricity, as needed, from the utility grid, and excessive electricity can be delivered to the grid (Zahedi 2006, NRCan 2003). Therefore, they do not need battery units and are less expensive than off-grid systems.

Although in most cases photovoltaic systems are currently not as cost effective as conventional electricity supply, the market for photovoltaics has significantly expanded all over the world, especially in the U.S., Europe and Japan. With advancements in technology and decreases in manufacturing costs, the global production of photovoltaic cells has grown at an annual rate of 30 to 45 per cent since 2000, and this growth is expected to continue. The global solar electrical capacity in 2000 was 1 GW and is anticipated to increase to 140 GW by 2030 (Zahedi 2006).

The amount of electricity that can be generated with photovoltaics depends upon the amount of solar radiation, as well as the size, orientation and efficiency of the solar cells. Most populated areas of Canada have mean daily global radiation of between 3 and 5 kWh/m^2 for south-facing panels (tilted at an angle equivalent to latitude) (tilt = latitude). The typical efficiency at which this radiation is converted into electricity can vary between 7 and 13 per cent depending on the type of cells installed (Table 3.5).

TABLE 3.5
PHOTOVOLTAIC CELL EFFICIENCY & OUTPUTS

Cell type	**Typical efficiency** (%)	**Power rating** (W_p/m^2)
Monocrystalline silicon	13	0.13
Polycrystalline silicon	11	0.11
Amorphous silicon	5	0.05
Cadmium telluride	7	0.07

Source: Adapted from RETScreen; Also see Prasad and Snow, 2005.

ESTIMATION GUIDELINE 3.5
PHOTOVOLTAICS

Annual Energy Output ≈ 70 + 310 • average daily radiation

Annual energy output is expressed in kWh per kW of cell installed, and average daily radiation is in kWh/m^2 (based on data from the Canadian Forest Service).

CASE 3.3

BUILDING INTEGRATED PV, STILLWELL AVENUE TERMINAL TRAIN SHED, CONEY ISLAND, NY

The Stillwell Avenue Terminal, located on Coney Island, is the largest above-ground station in New York City's subway system. Approximately 50,000 visitors use this station every week. In 2004, the terminal was renovated to include a 7,060 m^2 solar roof that covers four platforms and eight tracks. The roof consists of 2,730 building integrated photovoltaic panels (BIPVs), which are approximately 5`x5`glass laminate panels made of clear glass and strips of thin-film amorphous silicon material. The active area of the PV modules is 3,809 m^2 and has a rated output of 199 kW at peak and an actual peak output of 160 kW. The panels contribute approximately 240,000 kWh annually to the station's power needs (enough to power about 20 average single-family homes). Moreover, the average transparency under the shed is 12 per cent, which reduces the lighting requirements. Using solar panels as building components is cheaper than independent arrays as they require no additional land or support structure while replacing conventional construction material. The project was named one of The American Institute of Architects Top Ten Green Projects in 2007.

Reference: The American Institute of Architects, Top Ten Green Projects – Stillwell Avenue Terminal Train Shed, last updated April 23 2007. http://www.aiatopten.org/hpb/overview.cfm?ProjectID=822. Accessed November 4, 2008.

3.2.2 SOLAR WATER HEATING

Solar water heaters are a relatively inexpensive technology which even in basic configurations may provide up to half of a building's hot water needs (under Canadian conditions). Solar water heating systems are generally composed of rooftop solar thermal collectors (Table 3.6), through which a flowing fluid (water, glycol or another fluid) is heated. In simple applications, the fluid (water) can directly contribute to the hot water needs of the building (Case 3.4). In other cases, sometimes involving a heat exchanger, the heat of the fluid can provide part of the building's space heating requirements, for example, through the use of under-floor heating, or in combination with underground energy storage (see Case 5.8).

ESTIMATION GUIDELINE 3.6

SOLAR WATER HEATING

Solar water heaters can provide 25 to 49 per cent energy savings for service hot water needs (NRCan, 2003b). See Figure **3.1**.

TABLE 3.6 SOLAR WATER HEATING COLLECTOR TYPES	
Collector type	**Characteristics**
Unglazed flat plate	Low cost, but vulnerable to thermal losses; best for pool heating applications
Glazed flat plate	Less vulnerable to thermal losses; mid-range in terms of cost; suitable for service water heating
Evacuated tube	Most expensive, best performance under varying climatic conditions

Figure 3.1 Potential Contributions of Solar Water Heaters to Energy for Water Heating in Selected Canadian Cities

Note: Assumes a freeze-protected system with 6 m^2 single-glazed flat plate solar collectors and two 270 litre hot water tanks.
Source: Solar Water Heating Systems: A Buyers Guide" Natural Resources Canada, 2000. Reproduced with the permission of the Minister of Natural Resources Canada, 2010.

CASE 3.4
SOLAR WATER HEATING, CITÈ JEAN MOULIN, PLANTES, PARIS

This €759,000 Euro ($1.13 million CAD) project, encompassing 13 buildings, aids in providing 637 residences with domestic hot water. The residents use 24,320 m^3 of hot water annually, which requires 1,112,000 kWh to heat. Flat plate solar collectors were installed in 2003 and have a combined area of 1,020 m^2 and a thermal power output of 665 kWtherm. The system has 85 m^3 of storage capacity. The solar water system reduces the final energy requirement of the buildings by 738,000 kWh per year, which reduce annual GHG emissions by 214 tonnes of CO_2e.

Reference: Solarge, Good Practice Database: Cite Jean Moulin, Plantes. http://www.solarge.org/index.php?id=1195&no_cache=1. Accessed November 4, 2008.

3.2.3 SOLAR AIR HEATING

Solar air heating is used to offset conventional energy demands for space heating or process heating. Typical systems consist of a solar collector, circulation system and control equipment. Solar collectors are generally one of three types: transpired plate, glazed panels or unglazed panels. Each type works in a similar fashion, whereby cool inlet air is heated by solar energy as it passes through the collector. The transpired plate consists of a large panel with several small holes that draw outside air into the system; other collector types generally have air inlets at the bottom. Once the heated air reaches the top of the collectors, it is distributed as pre-heated air into a conventional heating system or distributed directly to the internal space. In typical arrangements, the collectors are installed on the walls of a building, which has the added bonus of increasing the insulation value of the wall by capturing escaping heat. Newer types of solar air heating systems are paired with solar photovoltaic cells to take advantage of the waste heat from these cells.

ESTIMATION GUIDELINE 3.7
SOLAR AIR HEATING

Solar air heaters can provide 25 to 47 per cent energy savings for space heating needs (Agriculture and Agri-Food Canada, 1999).

CASE 3.5
CANADAIR FACILITY SOLARWALL, DORVAL, QUEBEC

Bombardier's 116,000 m^2 Canadair facility in Dorval is home to the world's largest solarwall. This wall is covered with millions of tiny holes about 1 mm in diameter that allow outside air to pass through. The wall is approximately 30 cm away from the main structure of the building which allows a cavity for air flow. As outside air is drawn into the cavity, it flows upwards and picks up the solar heat that the wall absorbs. When the heated air reaches the top of the structure it is sent to the nearest fan. From here it is either mixed with recirculated air and used to condition the space, or sent to the gas-fired make-up unit if more heat is required. This system allows for wall heat loss to be recaptured by the incoming air thus doubling the R-value of the wall to R-50. The system was completed in October 1996 and covers a total area of 8,826 m^2.

The total installed price of the solarwall was $2,575,000 CAD. The estimated cost for siding, insulation and make-up air units, which would comprise a conventional alternative, is $2,290,000. Therefore, the incremental cost of the solarwall was $285,000. The system delivers 23,000 GJ annually. After comparing the differences in electricity use between the conventional and solarwall system (if fuel cost is taken at $0.25/$m^3$), the system has a payback time of only 1.7 years.

Monitoring results show the combined effects of the solarwall – reduced heat loss and destratification of indoor air – results in a contribution of approximately 2.63 GJ/m^2 of collector area based on an eight-month heating season. Hence, the solarwall saves 720,400 m^3 of natural gas/yr, reducing GHG emissions by 1,342 tonnes of CO_2e /yr.

Reference: CADDET IEA Energy Efficiency, World's largest solar wall at Canadair facility, March 1999, RETSCREEN case study. http://www.canren.gc.ca/app/filerepository/085C7400AB7D48EDA563A9DD788709B7.pdf. Accessed November 4, 2008.

3.2.4 PASSIVE SOLAR DESIGN

Passive design optimizes energy use and building comfort in accordance with the local micro-climate through the application of architectural design, site planning, structural, building envelope and passive mechanical features (Mikler et al., 2008). Passive buildings take advantage of local climactic conditions by utilizing building components to maximize natural ventilation, day lighting, heating and cooling, thereby, reducing the building's overall energy consumption and the size of mechanical equipment required. This is accomplished by controlling heat transfer through radiation, conduction and convention and by the thermal storage properties of the structure itself.

Harvey (2006) defines a sustainable building as one "whose onsite energy use is so small that the remaining energy use can eventually be met entirely through renewable energy." This would mean that the energy intensity of new buildings could be reduced by a factor of four or five in OECD countries compared to average existing buildings (Harvey, 2006). Reductions of such size in heating energy use over conventional new housing, and factors of 10 to 25 compared to existing buildings are being achieved throughout Europe through the Passive House Standard (Harvey, 2006). Heating requirements of less than 15 kWh/m^2 and total energy consumption of less than 42 kWh/m^2 have been achieved cost effectively under this standard irrespective of climate (Harvey, 2006). Similar reductions in demand are shown in Figure 3.2, which compares three different building types (low rise compact, low rise and high rise) in Vancouver.

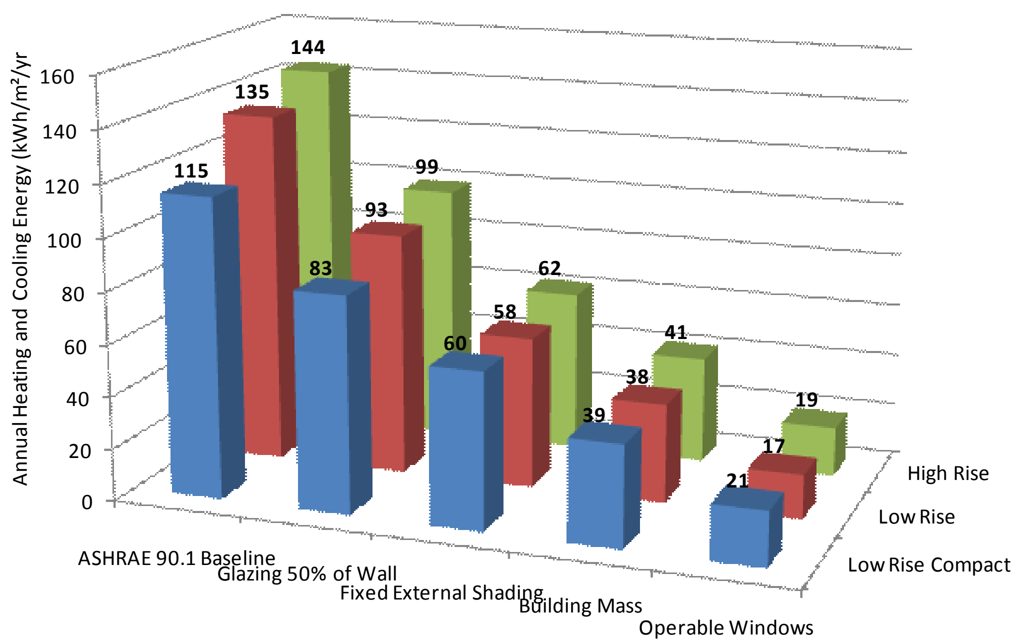

Figure 3.2 Potential Contributions of Annual Heating and Cooling in Vancouver Building with Passive Energy Improvements

Adaped from Mikler et al., 2008.

CASE 3.6
ENERGY BASE OFFICE, AUSTRIA

The Energy Base office building in Austria is currently the largest building constructed to the Passive House Standard. Completed in June 2008, the 11700 m^2 building uses 80 per cent less energy compared to a similar reference building. Heating and cooling loads are reduced through high performance thermal insulation, triple window glazing, heat recovery ventilation, elimination of thermal bridges and an airtight shell. This is complemented with day lighting to minimize the need for artificial lighting, natural convection to circulate air and ventilate the building, and the use of highly energy efficient mechanical systems. These measures allow the building to meet all of its heating and cool energy demand by ground water and solar energy. On-site building integrated PV is supplemented with off-site hydro power permitting 100 per cent of its energy demand to be met with renewable sources. This has resulted in CO_2 reduction of 300 tonnes compared to conventional buildings.

Reference: POS Sustainable Architecture (2008). Energy Base, Vienna- passive house in moderate climate Austrian Embassy, Jakarta-green building in tropic climate. ICLEI Local Governments for Sustainability. http://www.iclei-europe.org/fileadmin/template/events/lr_freiburg_2009/files/Presentations/Schneider_B2_1.pdf.. Accessed November 29, 2009.

There are a number of useful resources and information tools available for planning and implementing passive solar design.

- RETScreen has developed a *Passive Solar Heating Project Analysis* model that can be used for the preliminary analysis of designs for residential and low rise commercial buildings. By inputting building characteristics, the model will calculate energy production, lifecycle costs and GHG emission reductions relative to a base case building constructed according to standard practices in the region. The model considers the local climate, building orientation, proportion of glazing, window type and shading in order to optimize solar heat gains and reduce conductive heat losses (NRCAN, 2009).
- *Tap the Sun: Passive Solar Techniques and Home Designs* by the Canadian Mortgage and Housing Corporation (CMHC) provides fundamental information and design guidelines for the design of passive solar buildings (CMHC, 1998).
- *Design and Optimization of Net Zero Energy Solar Homes* (Charron and Athienitis, 2006) provides useful recommendations based on sensitivity analyses of key design characteristics, such as landscaping, floor plan and orientation, thermal mass, windows and other envelope features, as well as active solar and mechanical systems.
- *Passive Design Toolkit: Best Practices,* from the City of Vancouver, is a comprehensive source for complete passive design strategies that consider passive heating, cooling, ventilation and day lighting, energy modeling and case studies (Mikler et al., 2008).

Passive design is an integrated process that requires the collaboration of many disciplines in the design and construction phases, as well as education of the occupant. This way the systems are designed to maximize the impact of the passive features and the occupants are able to utilize those features as intended. As passive design is affected by the surrounding environment – such as solar access, wind and heat island – it is important that passive design is considered as part of a community energy system discussed further in Section 5.5.

3.3 STRATEGY 3: GROUND SOURCE HEAT PUMPS

Ground source heat pumps (GSHPs) are one of several types of earth energy systems encouraged in this guide. The other systems typically serve more than a single building; they are addressed in Chapter 5.

GSHPs are a clean and energy-efficient technology for heating and cooling buildings utilizing heat in the ground. The ground temperature of the earth is relatively constant compared to air temperatures. This moderate temperature variation keeps the ground warmer than the air in winter and cooler in summer. GSHP systems make use of this ground-air temperature differential. They can be applied to a wide range of uses: commercial, institutional and residential. In Canada, GSHPs are already used in all provinces. Manitoba and Ontario have a financing system that enables investors to pay back capital expenditures from savings derived from the use of GSHPs (Lund et al., 2005).

ESTIMATION GUIDELINE 3.8
GROUND SOURCE HEAT PUMPS

"…significant energy savings can be achieved through the use of GSHPs in place of conventional air conditioning systems and air source heat pumps. Reductions in energy consumption of 30 per cent to 70 per cent in the heating mode and 20 per cent to 50 per cent in the cooling mode can be obtained. Energy savings are even higher when compared with combustion or electrical resistance heating systems." (RETScreen)

CASE 3.7
GSHP AT THE METRUS COMMERCIAL BUILDING, CONCORD, ON

The Metrus Building has one of the largest ground source heat pump (GSHP) systems in the province of Ontario, augmenting the heating and cooling loads of this two-storey building of 3,250 m^2. The system is made up of 28 heat pump units placed throughout the building`s suspended ceiling and 88 boreholes located beneath the 1,800 m^2 parking lot. The 54 metre-deep boreholes are spaced 4.6 metres apart. Water is pumped through these boreholes via a closed pipe system to absorb the ambient ground heat or chill, depending on time of year. The year-round average ground temperature is approximately 10°C (50°F). Over the life of the project, CO_2 emissions are expected to be 2,862 tonnes lower than if electric resistance heating was used, or 182 tonnes less than if natural gas was used.

Reference: Natural Resources Canada, Ground-Source Heat Pumps Produce Savings for Commercial Building. http://www.canren.gc.ca/renew_ene/index.asp?CaId=48&PgId=1013. Accessed November 4, 2008.

CASE 3.8
GERMAN AIR TRAFFIC CONTROL HEADQUARTERS, LANGEN, GERMANY

The German Air Traffic Control headquarters building is located in Langen, a few kilometres southeast of the Frankfurt airport. The building serves the needs of 1,200 employees, while maintaining a target value for electricity and heat/cold demand of 100 kWh/m^2/yr (35 per cent below conventional office buildings). To accomplish this, the heated/cooled area of 44,500 m^2 is served by 154 boreholes, each 70 metres-deep, arranged in two configurations. The boreholes are spaced at five-metre distances and used as both heat and cold storage. The system stores heat and cold for seasonal use by heat pumps. The system provides the base of 340 kW for heating and 330 kW for cooling (which relates to 80 per cent of annual cooling and 70 per cent of annual heating). The boreholes are arranged in two fields of 5 x 20 and 3 x 18, use double U tubes and are located in an L shape. Peak cooling is met by conventional chillers while peak heating is covered by a district heating system. Simulations suggest that the design saves approximately €150,000 EUR ($225,000 CAD) in annual energy costs.

Reference: Buckhard Sanner, The Low-Energy-Office of Deutsche Flugsicherung (German Air Traffic Control) in Langen, with geothermal heat and cold storage. http://www.geothermie.de/oberflaechennahe/lowenergy.htm, Accessed November 4, 2008

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CHAPTER 4: TRANSPORTATION AND LAND USE

(S. Derrible, S. Saneinejad and C. Kennedy)

Arguably the most challenging areas for reducing GHG emissions are transportation and land use. As Kennedy et al. (2006) describe it:

> *"Designing corridors, streets and thoroughfares to provide safe movement and access to people and goods, by cost effective means, involves application of management and technology to resolve many social, economic and political forces. Add to this delicate balance a number of pressing environmental concerns, such as impacts of air pollution on human health, global climate change, and destruction of land ecosystems, poses a challenge that stretches human ingenuity and organizational capability."*

There are two distinct approaches to reducing GHG emissions from urban transportation. One seeks to substantially reduce automobile use, encouraging people out of cars into electric public transit supported by walking and cycling. The other approach is to change vehicle technology, for example, by providing infrastructure and creating market conditions for electric cars. A mixture of these two approaches can also be pursued.

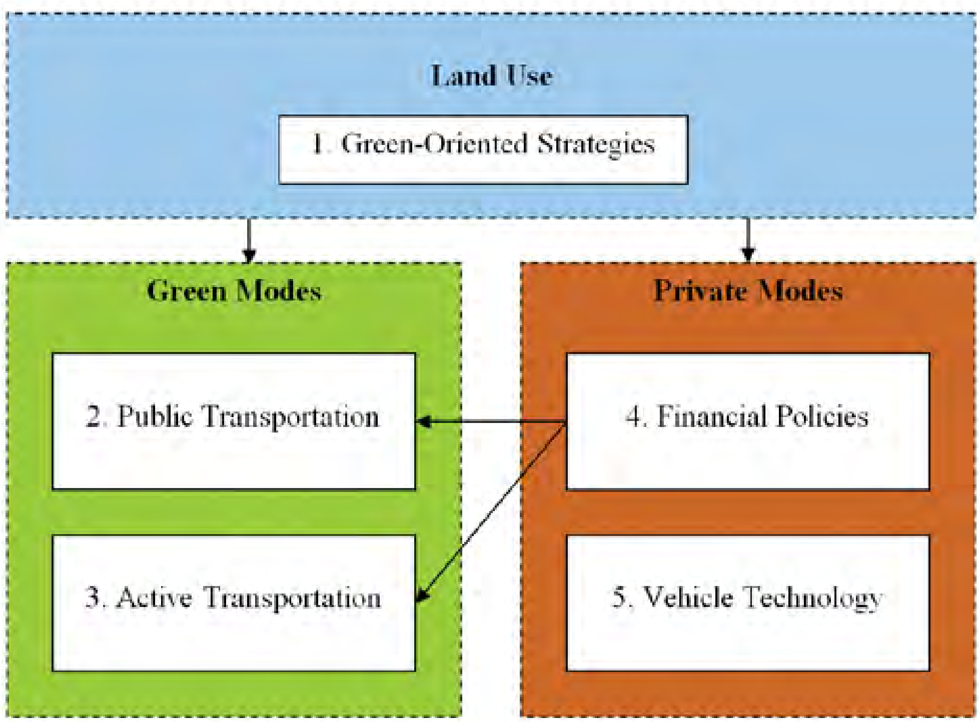

Figure 4.1 Interactions between Five Strategies Developed in this Guide

Figure 4.1 offers an illustration of the interactions between the five different strategies addressed in this guide. The first four strategies considered here all aim at reducing automobile use, either through changes to land use, investment in public transportation, the encouragement of active transportation modes (walking and cycling), or financial policies. The separation of these strategies is somewhat artificial; a substantial reduction in automobile use requires an integrated approach with actions in all four areas. Strategy 5 is to change vehicle technology.

These five strategies can also be accompanied or supported by campaigns/programs to change travel behaviours, whether it is by promoting carpooling to reduce auto use (e.g., Smart Commute in the Greater Toronto Area), or by initiating walking and cycling programs (e.g., Wheel 2 Work in Whitehorse).

The extent to which GHG emissions are reduced by using electric transit (Strategy 2) or electric automobiles (Strategy 5) depends on the electrical supply mix servicing a municipality. The GHG intensity of electricity supply in Canada varies from 6 tonnes of CO_2e/GWh in Quebec to over 900 tonnes of CO_2e/ GWh in Alberta (Table 2.1). Strategies for reducing GHG intensity of the electricity supply are discussed in Chapter 5.

Understanding the interaction between land use and transportation is particularly important. This is apparent from a study of mode choice within 1,717 traffic zones of the Greater Toronto Area (Green, 2006). Zones of mixed land use, providing close proximity to jobs, residences and amenities are more conducive for non-auto modes; the percentage of auto trips is 63 per cent compared to an average of 80 per cent for all zones (Table 4.1). An even lower automobile mode share of 56 per cent is found for zones that are well served by subway or light rail. If, however, a zone has both mixed land use and is well served by subway/light rail, then auto mode share decreases to 44 per cent. Clearly, appropriate land use is important for supporting public transportation.

TABLE 4.1
MODE SPLIT FOR TRANSPORTATION TOMORROW SURVEY ZONES, GREATER TORONTO AREA, 2001

	All TTS Zones	Zones with mixed land use	Zones well served by subway or LRT	Zones with mixed land use and well served by subway or LRT
Auto (%)	80	63	56	44
Transit (%)	12	20	27	28
Walk/Cycle (%)	6	15	15	25
Other (%)	2	2	2	3

Notes: Mixed land use is defined as that with greater than30 per cent residential area and greater than 18 per cent commercial area within one kilometre of the zone centroid. A zone with a Toronto Transit Commission (TTC) subway stop and/or a Spadina LRT stop within one kilometre of the zone centroid is considered to be well served (Green, 2006). "Other" modes might include taxi, motorcycle or school bus.

4.1 STRATEGY 1: APPROPRIATE LAND USE

Further to the benefits of mixed land use, it is well understood that energy used for urban transportation increases as population density decreases. This inverse relationship was established by Newman and Kenworthy (1991) as shown in Figure 4.2. Similar findings in terms of GHG emissions from urban transportation in ten global cities have been confirmed by Kennedy et al. (2009). Increasing population density through intensification of land use is the first strategy for reducing GHG emissions from urban transportation.

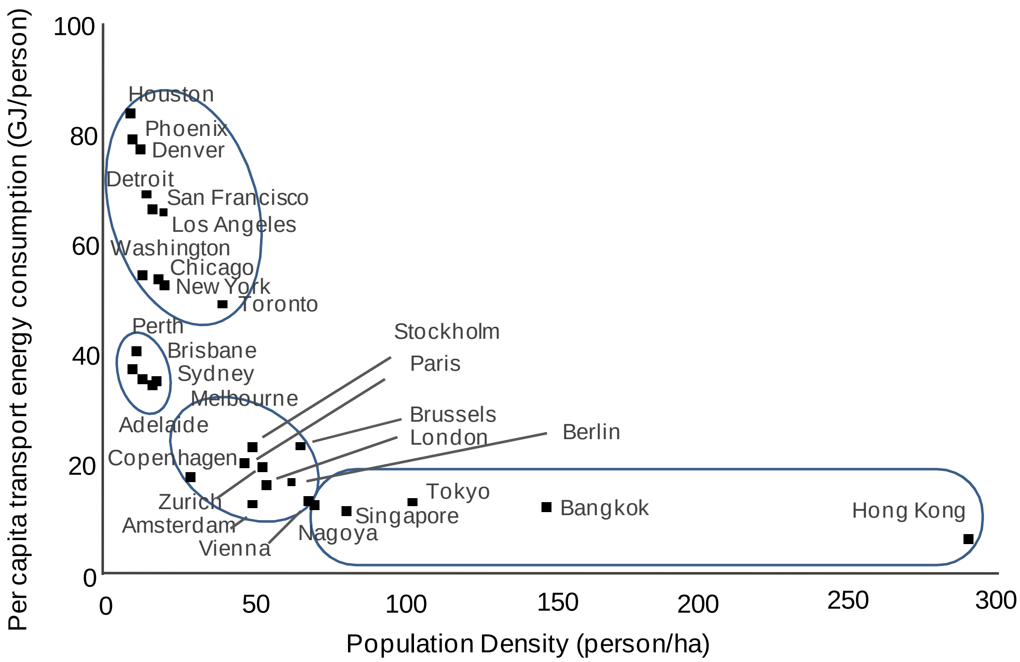

Figure 4.2 Annual Transportation Energy Consumption & Population Density

Adapted from Newman and Kenworthy, 1991.

Rather than using a relationship between population density and energy use, we start at a more fundamental level by developing an estimation guideline for passenger kilometres travelled. In transportation, the most important factor that influences GHG emissions is passenger kilometres travelled (PKT), which is the total number of kilometres walked, cycled, driven or otherwise travelled by a person over the course of a year (i.e., annual PKT). To further standardize the data, we need to divide PKT by population. Population density, along with the amount of economic activity in a city per capita (measured by GDP per capita in 2002 CAN$), are key determinants of the motorized passenger kilometres travelled (PKT) per capita in a municipality (Schafer 2000).

ESTIMATION GUIDELINE 4.1
MOTORIZED PASSENGER KILOMETRES TRAVELLED (PKT)

$$\text{Motorized PKT per capita} \approx 2.78 \cdot (\text{GDP per capita} / \text{population density}) + 4747$$
$$(R^2 = 0.80)$$

Where motorized PKT per capita includes trips by both public and private transportation; GDP is urban gross domestic product in 2002 CAD; population and population density are determined using the metropolitan area (housing, industrial and commercial areas, offices, city parks [but not regional parks], transport infrastructure, public utilities, hospitals, schools and urban wasteland). Data for the regression is compiled from 93 cities worldwide (Millennium cities database).

Estimation Guideline 4.1 for motorized PKT is the first of a linked series of empirical relationships developed for this chapter. Motorized PKT can be by automobile or public transportation. Strategies for increasing PKT by public transportation are addressed next. The automobile PKT is calculated by subtracting the public transportation PKT from the total motorized PKT.

These relationships have been incorporated into a new empirical model of GHG emissions from urban transportation developed for this guide. The structure or the model, called MUNTAG (MUNicipal Transportation And Greenhouse gases), is detailed further in Appendix B; notably, it includes a method to translate PKT per capita data into GHG emissions. In this chapter, only the relevant Estimation Guidelines are given. For further details on the architecture of the model, we refer the reader to Derrible et al. (2010).

Finally, it should be mentioned that the way GDP values are calculated can have some impact on the result. An employment-based GDP is preferred because this technique allows partial accounting of PKT made by commuters from neighbouring municipalities.

4.2 STRATEGY 2: PUBLIC TRANSPORTATION

Improving public transportation is seen as a key strategy in reducing GHG emissions for the transportation sector. Cities with high quality, reliable transit infrastructure and service typically show a high transit mode share and a lower transportation carbon footprint per capita. Public transportation relies on, in part, population density. This is true in some European and Asian cities where density is high and the auto mode is not a practical option due to congestion and related problems.

However, there are other factors in developing a well-used transit system, including coverage of service, connectivity and directness of network design (Derrible and Kennedy, 2009a). Moreover, land use and transportation are inter-dependent. As a result, by building more transit infrastructure and by improving the level of service, a city is likely to increase density and further improve its transit mode share in the medium to long term. Nevertheless, it can be difficult to choose a specific transit mode. Table 4.2 shows a possible relationship between land use density and the appropriate level of transit required.

TABLE 4.2
RELATIONSHIP BETWEEN LAND USE DENSITY & TRANSIT POTENTIAL, GREATER TORONTO AREA

Population per hectare	Units per hectare	Residential type	Type of transit service
Less than 20	Less than seven	Single detached	None. Requires dial-up cabs, jitneys, etc.
Up to 40	15	Single detached	Marginal transit. Buses every half-hour. Rush hour express bus.
Up to 90	35	Single detached, town houses	Good bus service.
120 to 130	52	Duplex, rows, triplex	Excellent bus service, possibly light rail.
140 to 250	75 to 160	Row houses, low rise apartments	Bus, LRT, streetcar.
200 to 350	175 to 300	Medium rise apartments, plus high rise	Can support subway and feeder bus network.

Source: Metrolinx (2008)

Travel demand, in terms of trips per hour, may be a more appropriate indicator of transit potential. Table 4.3 shows the typical line capacities (in spaces per hour) for the main modes of transit. All transit planning projects should consider these line capacities and try to maximize transit usage. Nevertheless, Tables 4.2 and 4.3 do not account for future demand growth, which is a crucial component of transit mode choice for new planning projects. Cities are dynamic systems and it is important to forecast future changes in land use and transit demand in order to be able to anticipate possible problems due to capacity constraints. In addition, adopting a higher grade of transit mode can serve as a means to orient and funnel development on specific and controlled corridors.

In this section, we have developed an Estimation Guideline for each public transport mode (i.e., conventional bus, light rail transit, subway and commuter rail). We have not been able to develop one for Bus Rapid Transit (BRT), although we provide an example. These estimation guidelines can be applied to both existing and planned infrastructure. The data required is track-km “L” in metres per hectare (m/ha) and number of vehicles “v” operating under maximum service per million people (see Appendix B for a method to calculate “v”); for conventional bus and commuter rail, only “v” is required.

(Note that the PKT values rendered by the estimation guideline are “per capita” as opposed to “per passenger”; therefore, to compute the total PKT, the per capita value should be multiplied by the entire population. Appendix B provides a method to determine vehicle-kilometres-travelled [VKT] per capita from the PKT values, and to then calculate the GHG emissions attributable to public transportation.)

TABLE 4.3
TRANSIT CHARACTERISTICS[1]

Mode category	**Right-of-way category**[2]	**Mode**[3]	**Wagons per transit unit**	**Line capacity** (spaces/hour)	**Operating speed at capacity Vo** (km/h)
Street transit	C	Bus	1	3,000 - 6,000	8 - 12
	C	Tram	1 – 3	10,000 - 20,000	8 - 14
Semi-rapid transit (medium performance)	B	BRT	1	6,000 - 24,000	16 - 20
	B	LRT	1 – 4	10,000 - 24,000	18 - 30
	A	AGT	1 - 6 (10)	6,000 - 16,000	20 - 36
Rapid transit (high performance)	A	LRRT	1 – 4	10,000 - 28,000	22 - 36
	A	Subway	4 – 10	40,000 - 70,000	24 - 40
	A	Commuter rail	1 - 10 (14)	25,000 - 40,000	30 - 55

Notes:

1. Adapted from Vuchic (2005a).
2. There are three possible rights-of-way (ROW). ROW A is an exclusive right-of-way (completely separated); ROW B is a semi-exclusive right-of-way (sharing crossroads with automobile traffic); ROW C is a shared right-of-way with auto traffic.
3. BRT stands for bus rapid transit, LRT for light rail transit, AGT for automated guided transit, and LRRT for light rapid rail transit.

Before looking at each transit mode specifically and developing estimation guidelines, we can review different indicators of transit efficiency. One potential measure of transit efficiency is the passenger-kilometres-travelled per transit-km offered. Table 4.4 presents the total annual PKT per km for each rail mode for five Canadian cities, as well as the European and North American averages. Values for the bus mode could not be calculated, since values of total bus route-km are not available. In Table 4.4, a higher value implies a better efficiency; for instance, the Montreal subway is more efficient than the Toronto subway, and the opposite is true for their respective commuter rail systems.

TABLE 4.4
PASSENGER KILOMETRES TRAVELLED (PKT) PER KILOMETRE OF TRACK

	Streetcar	LRT	Subway	Commuter rail
Toronto	13,309,671	–	15,364,738	1,969,227
Montreal	–	–	42,702,148	966,966
Ottawa	3,369,765	–	–	–
Calgary	–	10,007,934	–	–
Vancouver	–	–	19,130,976	800,175
European Average	–	3,383,406	26,339,997	5,875,131
NA Average	–	7,935,681	16,166,881	1,817,752

Note: Data was collected prior to the construction of any LRT lines in Toronto.
Source: Millennium cities database and Canadian Urban Transit Association

Consequently, we can review the energy efficiency of each mode. Table 4.5 presents the energy consumed in MJ for each transit mode per PKT for five Canadian cities, as well as the European and North American averages. Notably, the Toronto streetcars, Montreal subway, Calgary LRT, and Vancouver Skytrain (shown as subway) perform above the European and North American averages. We also note that a higher PKT per km of track requires less energy. Nevertheless, it should be noted that these values are also dependent on the specific technology chosen for each mode.

TABLE 4.5
ENERGY USE PER PASSENGER KILOMETRES TRAVELLED (MJ/PKT)

	Streetcar	LRT	Subway	Commuter Rail
Toronto	0.31		0.69	0.96
Montreal			0.41	2.25
Ottawa				
Calgary		0.25		
Vancouver			0.38	0.73
European Average	0.58	0.69	0.48	0.87
NA Average	0.65	0.60	0.60	1.37

Source: Millennium cities database.

4.2.1 CONVENTIONAL BUSES

The conventional bus constitutes one of the largest components of the public transportation infrastructure currently in place. However, its history has been episodic and the height of its popularity relatively recent; bus service first thrived only in the 1950s, whereas:

- the horse-drawn omnibus was invented in the early 1820s
- the subway was first introduced in the 1860s
- the streetcar arrived at the end of the 19th century

Bus service is considered to be "flexible": it does not need to be wired; it is not restricted to rails; and it can share a right-of-way. These attributes help explain its attractiveness for low demand corridors and as a feeder to higher grade transit modes. Capital cost requirements are also significantly lower compared to rail modes.

Nevertheless, a conventional bus system is a large emitter of GHG due to its most common fuel type, diesel; biodiesel would constitute a cleaner fuel. Moreover, recent technological advances have made it possible to develop hybrid-electric buses and hydrogen-powered buses. It is also possible to make them fully electric by using an overhead cable similar to streetcars (as such, they are called trolleybuses).

ESTIMATION GUIDELINE 4.2
CONVENTIONAL BUS

$$\text{PKT per capita} \approx 0.672 \cdot v - 24.31$$
$$(R^2 = 0.73)$$

Where PKT per capita is the total passenger-kilometres-travelled per year divided by the population; and "v" is the number of vehicles per million people under maximum service. Data for the regression is compiled from 34 U.S. cities (American Public Transit Association database).

Estimation Guideline 4.2 only considers the number of vehicles per million people under maximum service; a value of track-km in metres per hectare (m/ha) could not be collected since this mode shares its right-of-way with the auto traffic.

4.2.2 BUS RAPID TRANSIT (BRT)

The Bus Rapid Transit (BRT) has become a strong candidate for the future of public transportation. It combines the flexibility of a conventional bus, while offering the reliability of a light rail system. In other words, BRT enjoys a semi-exclusive right-of-way and does not require a separate depot to store the vehicles. Moreover, capital costs are lower than those for LRT projects. BRT is mostly applied on low to medium demand corridors.

One exemplary BRT system operates in Curitiba, Brazil (Case 4.1). However, BRT remains an on-going topic of debate in the transportation community. Despite its merits, BRT is not as permanent as rail-based modes and does not promote the image of modernity and durability associated with cities that invest in higher grades of public transit. In addition, past a certain capacity, BRT becomes more expensive to operate than a light rail system, due to factors such as costs of fuel and maintenance (Vuchic, 2005b). Effort should be put into designing a BRT line that can be readily converted to a LRT line in the future; one method is outlined by Wood (2006).

Although a BRT system uses the same technology as conventional buses, it may be more efficient since it carries more passengers and makes less frequent stops. The buses can also be powered by biodiesel, hydrogen or hybrid-electric motors. These factors may decrease its relative GHG emissions.

CASE 4.1
CURITIBA BUS RAPID TRANSIT, BRAZIL

The 1965 Master Plan for the city of Curitiba limited uncontrolled growth by directing development along linear corridors. As a result, the city's bus rapid transit system has been designed and expanded to encourage the replacement of cars as the primary means of transport. Also known as the "surface subway", the BRT network is comprised of 54 kilometres of exclusive bus lanes. Although the city of Curitiba has one of the highest automobile ownership rates in Brazil, about 70 per cent of commuters use the transit system daily. Ridership is reported to be 15,000 in peak hour, and more than 1.9 million passengers per day (in a city of 2.7 million). As the result of the successful BRT system, the typical morning inflow and evening outflow of commuters to and from the downtown area has been eased, resulting in a reduction in traffic congestion. In addition, the city's central area has been partially pedestrianized.

Reference: Bus Rapid Transit Policy Center, Integrated Transport Network (Curitiba), Description, 2005. http://www.gobrt.org/db/project.php?id=59. Accessed November 7, 2008.

A new technology, the rubber-tired tram, is emerging as a potential hybrid between the BRT and the LRT. One recent example is the Tram-on-Tyre project in Caen, France (Case 4.2). The technology is electrically powered, and the vehicles are equipped with rubber tires and guided by a central rail. Like the BRT, it does not require a special depot to store the vehicles, while the presence of a guiding rail gives this technology the solid image of a typical light rail system. Capital costs are also significantly reduced compared to light rail systems.

CASE 4.2
CAEN TRAM-ON-TYRE, FRANCE

Caen, with 114,000 inhabitants and 395,000 within its urban area, has constructed a 15.7 kilometre tramway (segregated streetcar) line along a north-south axis with branches at both ends. The line has 34 stations and a typical headway of four to five minutes (nine minutes on each branch). Every day, 40,000 trips are registered on the line. Instead of running on two rails, innovative rubber-tired vehicles are used and a single centre rail guides the tramway (Bombardier) vehicles. The technology, a hybrid between electric BRT and LRT, offers more comfort, safer braking and allows the vehicles to be stored in standard bus terminals. While capital costs are lower than for a standard LRT, the image of the Caen tram is as substantive as an LRT. A second line is currently being planned.

References:

1. Viacités, Accueil, Viacités: Syndicat Mixte de Transports en Commun de l'agglomération Caennaise. http://www.viacites.org/, Accessed November 8, 2008.
2. Railway-technology, Caen Tramway, France, Railway-technology. http://www.railway-technology.com/projects/caen/, Accessed November 8, 2008.

4.2.3 LIGHT RAIL TRANSIT (LRT)

The light rail transit (LRT) technology was first introduced in the late 1800s (based, essentially, on streetcar technology). The technology fell out of favour for some time before being resurrected in the late 1970s / early 1980s. There are now many light rail systems operating throughout North America and around the world.

This LRT mode normally has a semi-exclusive right-of-way (ROW B), although it can also enjoy a fully exclusive right-of-way. For instance, the Calgary C-train (case study 4.3) has an exclusive right-of-way in the suburbs that becomes semi-exclusive once it enters the core area.

There are a number of different LRT technologies available. For instance, light rail systems in France have low-floor vehicles and are lighter than their North American counterparts. LRT is also applicable to relatively small cities. In France, even small cities such as Orleans (120,000 inhabitants), have light rail systems. It is normally implemented on medium demand corridors and can act as a feeder to the subway mode.

The GHG emissions depend on the type of electricity generation, since this mode is fully electric. Nevertheless, LRT is more environmentally friendly than BRT since it does not produce any local air pollutants (Puchalsky, 2005).

ESTIMATION GUIDELINE 4.3
LIGHT RAIL TRANSIT (LRT)

$$\text{PKT per capita} \approx 140.34 \cdot L + 1.49 \cdot v - 15.12$$
$$(R^2 = 0.77)$$

Where PKT per capita is the total passenger-kilometres-travelled per year divided by the population; "L" is track length in metres per hectare (m/ha); and "v" is the number of vehicles (wagons) per million people under maximum service. Data for the regression is compiled from 22 U.S. cities (American Public Transit Association database).

CASE 4.3
CALGARY C-TRAIN, ALBERTA – RIDE THE WIND!

The C-Train is Calgary's wind-powered light rail transit system. The system uses 39,477 MWh of electricity annually (based on 2007 data). The program, branded as "Ride the Wind", is powered by wind energy supplied by 12 turbines, ranging between 0.6 to 2 MW. The turbines are installed in southern Alberta, on the tops of hills facing the Rockies, in order to take advantage of the strong westerly winds coming through the mountain passes. Calgary purchases wind power from ENMAX Energy Corporation, the city's electrical distribution system. It is the first public LRT system in North America to power its train fleet with wind-generated electricity. The C-Train is now 100 per cent emissions free. The annual GHG emissions saved, in comparison to equivalent automobile ridership, is 590 kilotonnes of CO_2e.

References:

1. Ride the Wind!, The C-Train, Re-Energy. http://www.re-energy.ca/ridethewind/backgrounder.shtml Accessed November 7, 2008.
2. Personal correspondence with the City of Calgary.

4.2.4 SUBWAY

The subway is also an established transit mode, first introduced in London, England, in 1863. It is considered the highest grade of urban transit, since it offers high to very high capacity and can accommodate short headways (waiting time between vehicles) thanks to its exclusive right-of-way. There are many examples of subway networks in the world. Some of the best examples include the Paris, Moscow, Tokyo and Madrid (Case 4.4) networks.

The technology is normally implemented on high demand corridors. The minimum population required to develop a subway can vary; for instance, the smallest city to have a subway line is Lausanne (130,000 inhabitants) in Switzerland.

A subway line can also generate wealth for a city. High density land uses tend to concentrate along subway lines, which can also strengthen the core of a city (Cervero, 1998). However, implementation must be done carefully in order to maximize transit usage. For instance, long lines extending to the suburbs may only be used heavily during peak-hour periods (Vuchic, 2005a).

A full characterization of the subway networks in the world is available from Derrible and Kennedy (2009b) and can serve as a guide for the planning of new projects or the extension of existing systems. GHG emission levels are linked to the electricity generation source.

ESTIMATION GUIDELINE 4.4
SUBWAY

$$\text{PKT per capita} \approx 420.20 \cdot L + 2.00 \cdot v - 32.67 \; (R^2 = 0.96)$$

Where PKT per capita is the total passenger kilometres travelled per year divided by the population; "L" is track length in metres per hectare (m/ha); and "v" is the number of vehicles (wagons) per million people under maximum service. Data for the regression is compiled from 11 U.S. cities (American Public Transit Association database).

CASE 4.4
MADRID SUBWAY SYSTEM, SPAIN

Madrid's metro system is the second largest metro system in Europe, which is impressive given the city's relatively small population of approximately 3 million (5 million in the metropolitan area). The system is also one of the fastest growing in the world, with 75 kilometres of new subway lines built between 1999 and 2003, and 36 new stations between 2003 and 2007. In addition to the extensive metro network, Madrid also supports a dense network of suburban trains. The network comprises 285 stations on 12 lines, totalling 283 km, 92 per cent of which is underground. Some of the highlights of the system include fast rides, affordable fares and great progress in system expansion. The network-wide ridership is 280,000 passengers in peak hour and peak direction.

References:

1. Schwandl, Robert. Madrid Metro, 2006, Urban Rail. http://www.urbanrail.net/eu/mad/madrid.htm, Accessed November 7, 2008.
2. Reynolds, Robert. Madrid System Improvements 2003-2007. http://people.reed.edu/~reyn/Madrid.2003.2007.html Accessed November 7, 2008.
3. Consorcio Regional de Transportes de Madrid. Metro-ML/Tranvia System. http://www.ctm-madrid.es/servlet/CambiarIdioma?xh_TIPO=3 Accessed November 7, 2008.

4.2.5 COMMUTER RAIL

Commuter rail lines are regional transportation systems rather than urban transit systems. They offer high capacities and speeds. Rail lines normally link the central business district (CBD) of a city to its surrounding communities and trains are run more frequently during rush hours. They can be operated by the regional or national transportation authority or a combination of both. For instance, the Paris, France, commuter rail (RER) has two lines operated by the RATP (Paris transit authority) and three lines operated by the SNCF (national railway company).

Commuter rail systems can also become part of the subway network within the city limits by having shorter station spacings and offering the same fares as the subway (e.g., S-Bahn in Berlin, Germany).

Overall, the fare scheme is usually based on a zoned system, with shorter distances being less expensive. The GHG emissions linked with commuter rails vary greatly according to the power source. Some systems still use diesel cars, and hence are larger emitters of GHG, whereas most recent systems are fully electric and depend on the electric grid. Since commuter rail systems often have long lines and few stops, track-km may not be a significant measure to include in the estimation guideline (statistical indicators also proved not to be significant), which explains why only the number of vehicles per million people (v) is included in Estimation Guideline 4.5.

ESTIMATION GUIDELINE 4.5
COMMUTER RAIL

$$\text{PKT per capita} \approx 3.10 \bullet v - 11.00$$
$$(R^2=0.96)$$

Where PKT per capita is the total passenger kilometres travelled per year divided by the population; and “v” is the number of vehicles (wagons) per million people under maximum service. Data for the regression is compiled from 13 U.S. cities (American Public Transit Association database).

4.3 STRATEGY 3: ACTIVE TRANSPORTATION

More than a quarter of trips in the U.S. are to destinations less than a mile away (Pucher & Renne, 2003), and 75 per cent of such trips are made in automobiles (Killingsworth et al., 2003). Similar values are anticipated for Canadian cities and towns as the transportation and land use status of the two countries are quite similar. Walking and cycling, therefore, offer great potential for reducing GHG emissions by replacing short automobile trips. In addition, active transportation modes can significantly support, and be supported by, public transit, which results in further reductions in GHG emissions. In the Netherlands 10 to 30 per cent of bus trips and 30 to 40 per cent of train trips destined to the city center were made using the bicycle as a transit access mode in 1997 (CROW, 1997). Bikeshare programs, such as Vélib' in Paris (Case 4.5), have numerous bicycle stations located at subway stations in order to promote such trips.

Built environment attributes that influence active transportation mode share include land use mix and density, connectivity, safety and length of the available travel network. Although there are other influencing factors, such as natural environment features and socioeconomic attributes of trip makers, the section focuses on the built environment, which is more strongly influenced by strategies implemented by municipalities.

Increasing short trip opportunities through intensifying residential and employment density, coupled with mixed land use strategies, provide trip makers with more destinations that are within walkable and bikeable distances. Figure 4.3 illustrates the strong correlation between residential density and walk mode share in 39 US cities based on data from Alliance for Biking & Walking (2007).

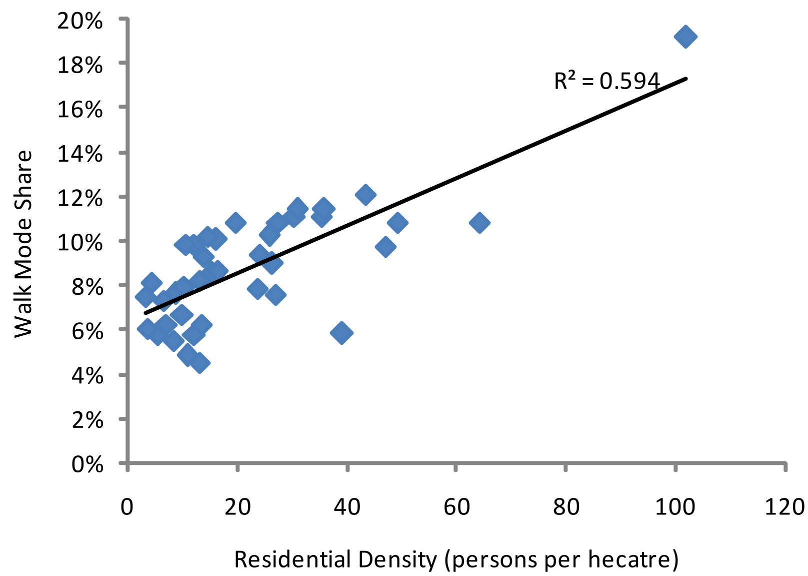

Figure 4.3 The Effect of Residential Density on Walk Mode Share (as a percentage of all trips)

Note: Data plotted for 39 U.S. cities.
Data Source: Alliance for Biking & Walking (2007).

The relative cost of other available transportation options is known to be a significant factor in the decision to walk or cycle. Strategy 4 introduces potential financial policies to steer mode choice towards less carbon intensive alternatives.

Connectivity of the street network is an important determinant of active transportation mode share. The intertwined roads and dead-end of modern day subdivision developments provide few direct routes for pedestrians and cyclists. In contrast, the traditional grid street pattern makes active transportation options much more attractive. Intersection density (ID) can be used as a measure for quantifying the connectivity of the road network. Analysis of 24 cities in California reveals that the average 1% walking and cycling mode share for cities with low IDs (about 25 intersections per square kilometre) increases to 5% for cities with higher IDs (about 40 intersections/ km^2) (Garrick, 2008).

It is evident that changing the road network for existing development is not an easy task and would involve retrofitting neighbourhoods and adding walk and cycle routes. New developments, however, have great potential for supporting active transportation. One effective strategy is to apply the Canadian developed concept of "fused grid", which is a street design concept that provides high levels of connectivity for walk and cycle modes while deterring automobile use. This can be achieved through numerous traffic calming strategies such as installing speed bumps or humps, enforcing speed limits, changing the pavement texture at pedestrian crossings, and introducing car-only cul-de-sacs (CMHC, 2004).

Stated preference surveys have revealed that convenient and safe travel routes and crossings are important factors in choosing to walk or cycle. High vehicle traffic volumes are commonly associated with low willingness to walk or cycle, since they reduce the sense of safety. Implementation of traffic calming strategies can create more attractive walking and cycling conditions. Provision of sidewalks and bicycle lanes are also very effective in increasing individuals' sense of safety. This strategy was a great contributor to the success of bicycle share programs, such as Paris's Vélib' (Case 4.5). In Barcelona, the provision of bicycle lockers and bicycle parking posts at frequent locations, including transit stops, significantly increased the level of convenience associated with this mode of travel. Our analysis of 17 U.S. cities shows that addition of 100 bicycle parking posts per 10,000 residents can increase bicycle mode share percentage by more than 1.5.

It is argued that individual and social attitudes, such as auto drivers' attitudes toward cyclists and bicycle culture in a community are equally important factors in the decision to own and use a bicycle (Xing et al., 2008). Improving attitude towards walking and cycling can be induced through a variety of promotional programs such as the active transportation social marketing campaign in Whitehorse, Yukon, branded as "Wheel 2 Work" (see Case 4.6). This initiative has been quite successful in spite of Whitehorse's cold climate. Strong positive attitude towards cycling has resulted in very high mode shares in cold cities, such as Copenhagen, or rainy cities, such as Amsterdam.

TABLE 4.6
BUILT ENVIRONMENT FACTORS INFLUENCING ACTIVE TRANSPORTATION MODE SHARE

Influencing factor	Control-ability	Impact on ridership	Potential strategies	Examples	
				Location	References
Social and individual attitude	Medium	High	Launching promotional programs aimed at improving individual attitudes and drivers' attitudes towards pedestrians and cyclists.	Wheels 2 Work campaign, Whitehorse, Yukon Driver education, Netherlands & Germany	Case study 4.6 Pucher & Buehler, 2008
Network connectivity	Low - High	High	Increasing intersection density by designing shorter blocks, fewer dead-ends. Applying fused grid community design schemes. Giving pedestrian and cyclists priority at crossings.	Fused grid scheme, Stratford, ON	CMHC, 2004

Cost of other transportation alternatives	High	High	Employing parking costs, tolls, taxes, and area pricing (see Strategy 5 for details).	See Strategy 4b and 4c	See Strategy 4b and 4c
land use mix and density	Low- High	Medium	Setting appropriate zoning for existing and new development. Supporting infill development.	Hammarby Sjostad, Sweden	CABE, 2005
Sense of safety, network length	High	High	Building continuous on-street bike lanes and off-street bike trails.	Portland, Oregon Copenhagen, Denmark	Pucher & Buehler, 2008
Sense of safety, auto traffic level	Medium	Medium	Implementing traffic calming measures, such as lower speed limits, chicanes, and the fused grid scheme. designating car-free zones	Numerous Dutch cities Freiburg, Germany	Pucher & Buehler, 2008 Case study 4.7
Convenience	High	High	Implementing bikeshare programs. Providing bicycle parking posts, lockers and racks on transit buses.	Vélib' bikeshare, Paris Bicing,bikeshare, Barcelona MetroLink, Halifax	Case study 4.5 C40 Cities, 2008 HRM, 2007

There are numerous strategies that can be implemented in order to reduce GHG emissions by replacing auto trips with active modes and supporting transit trips. However, a number of uncontrollable variables must be taken into consideration when evaluating the impact of such strategies on mode share. Table 4.6 summarizes the built environment factors and provides some examples of strategies related to each factor, in addition to a relative measure of controllability and level of impact.

Campaigns and programs can also be effective in promoting active transportation. The main objective is to change travel behaviours. Such campaigns can be initiated by municipalities or even residents with the support of municipalities. The Bike Plan from the City of Toronto (2001) is one such example, where a series of measures are adopted to facilitate cycling in the city.

Similar to the approach taken for public transit, an estimation guideline is established by a regression analysis, here using data from a sample of 24 U.S. cities collected by the Alliance for Biking & Walking (2007). This model estimates the percentage of motorized trips replaced by cycling trips as a result of implementation of bicycle facilities. The explanatory variables are the density of bicycle network (in m/ha) and the number of bicycle parking spaces at transit stations per one million people. The bicycle mode share, as a percentage, represents the proportion of trips reduced in all other motorized modes discussed in the previous strategies. As a result, in order to measure the GHG reduction impact of this mode, it is assumed that an equal proportion of PKTs of all motorized modes would be eliminated by the bicycle mode.

ESTIMATION GUIDELINE 4.6
BICYCLE FACILITY

$$\text{Per cent motorized trips replaced by cycling (\%)} = 0.0762 \cdot L + 4.8 \times 10^{-5} \cdot P$$

$(R^2=0.74)$

Where "L" is the total length of bicycle facilities per area of influence in metres per hectare (m/ha); and "P" is the number of bicycle parking spaces at transit stations per one million people. Data for regression is compiled from 25 U.S. cities (Benchmarking Data: Bicycling & Walking in the U.S., 2007).

CASE 4.5
VÉLIB' – PARIS BIKE SHARE PROGRAM, FRANCE

Vélib' is a public bicycle rental programme that was implemented in Paris, France, and is estimated to save 18,000 tonnes of CO_2e per year. The entire scheme originated from the Vélo'v programme in Lyon. Automated rental bike stations are located throughout the city; there are 1,451 stations holding over 20,600 bikes (300 metres apart) and 35,000 bike racks. It is available 24 hours a day, every day. The first half-hour is free, the second costs €1, the third is €2, and every subsequent half-hour is €4. Prices decrease with subscription, to €29 for a year, €5 for seven days, 1€ for a day. The project was implemented and is operated by JC Decaux, a French outdoor advertising company. JC Decaux pays Paris City Hall €3.5M a year, in exchange for 1,280 advertising spaces of 2 m^2 and 348 spaces of 8 m^2. In addition, all revenues generated by the program go automatically to City Hall (about €15M). By summer 2009, the system will have been extended to 30 suburban neighbourhoods and will have increased the total number of bikes to 25,000, 1,751 stations and 40,000 bike racks.

References:

1. Vélib', Vélib', Marie de Paris. http://www.velib.paris.fr/ Accessed November 8, 2008.
2. Politique.net, Vélib' à Paris: les chiffres cachés, October 16 2007, Politique.net. http://www.politique.net/2007101601-velib-a-paris-les-chiffres-caches.htm Accessed November 8, 2008.

CASE 4.6
BIKE CAMPAIGN – WHITEHORSE, YUKON

"Wheel 2 Work" is an active transportation social marketing campaign to encourage bicycle use (particularly for the home-work trip) during the summer season through prize incentives. The City of Whitehorse (21,000) has recently invested in bicycle network infrastructure including: the upgrade of multi-use paths to facilitate access to the downtown; expansion of a bridge to accommodate cyclists; construction of a roundabout for safety reasons; and the implementation of artisan-designed bike racks. The program was dubbed a success with 210 participants, 108 of whom logged about 40,000 km for 2006. The Planning and Development Services Department is also orienting new development towards a more pedestrian and bicycle-friendly style. An estimated 4.5 tonnes of GHGs were reduced in 2006.

Reference: Urban Transportation Showcase Program, "Wheel 2 Work" in Whitehorse, July 7 2007, Transport Canada. http://www.tc.gc.ca/programs/environment/UTSP/wheel2work.htm Accessed November 8, 2008.

4.4 STRATEGY 4: FINANCIAL POLICIES

Internal combustion engine (ICE) automobiles have ascended to the top of the transportation pyramid since the 1930s. They now make up the largest portion of transportation trips in most developed countries. This domination does not come without problems: not only are automobiles the largest emitters of GHGs in the transportation sector, they also challenge the very fundamentals of sustainability.

Although cars are purported to provide more convenient means of transportation, they are also the primary cause of heavy congestion. Congestion is a common phenomenon in history; for instance, the first subway in London was built to overcome problems of congestion due to streets crowded with pedestrians, horse-drawn vehicles, etc.

The current circumstances have become so dramatic that they carry with them environmental, health-related, even financial costs. It is broadly accepted that action has to be taken to address these problems. This section outlines several strategies – primarily financial – that address the reduction of automobile usage (i.e., VKT) in a direct manner.

The costs of an average car can be divided into two distinct categories: external and internal. The bulk of the external costs – including the construction and maintenance of road facilities, policing, municipal services and air/water pollution – are not paid directly by auto users. The internal costs, on the other hand, are paid directly by auto users. We further partition these internal costs into two sub-categories: fixed and variable. The fixed internal costs are related to vehicle ownership, license plates and, to some extent, insurance. The variable internal costs are day-to-day costs such as gasoline price, irregular parking, tolls, etc.

Figure 4.4 provides a breakdown of the three types of costs for an average car. About one-third of the costs are external (35 per cent), and not assumed by auto users. Fixed internal costs represent 28 per cent of the total and do not directly affect frequency of auto use. Only 37 per cent of the total costs of car use, the variable internal costs, are actually felt by auto drivers on regular day-to-day basis and, therefore, exert a direct impact on their daily travel behaviour.

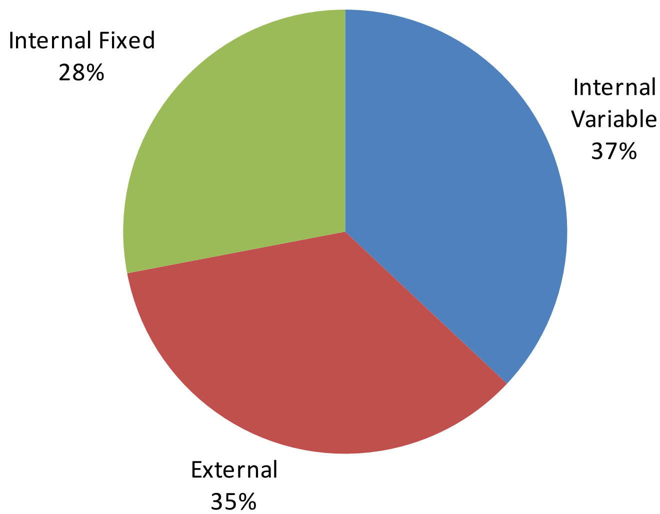

Figure 4.4 Distribution of Average Car Costs

Adapted from : Litman, 2009.

We identify two related economic approaches to reduce VKT per capita. The first is to increase the components of the variable internal costs (i.e., increase gasoline price at the pump). The second is to redistribute the external costs so that it is paid internally; this process is called "internalising externalities" and is common in the economics literature; for a review see Litman (2009). In this guide, we mainly consider new schemes of internalisation. We only briefly discuss accounting for environmental issues in gasoline price (e.g., setting a price such as $4/L); this method is politically challenging. Instead, we focus on practices that also generate new revenues, such as area pricing and the introduction of tolls, from which profits can then be re-distributed accordingly.

A further alternative is to ban the use of automobiles in certain areas of a city. This process is called pedestrianization and seems to be quite popular, especially in Europe (although impacts on overall VKT are difficult to establish). It is the first strategy addressed in this section.

Campaigns/programs can be used to effectively promote initiatives such as carpooling (e.g., Smart Commute in the Greater Toronto Area), although we spend little time on these programs in the guide.

Mathematically, to quantify the impacts of a strategy on travel behaviour, transportation economists measure elasticity—the percentage change in demand per increase in price. For transportation, a strategy is considered elastic if an increase in price influences the VKT.

Before looking at the various strategies, it should be emphasized that increases in gasoline price have a significant impact on total VKT (Table 4.7). To illustrate the concept of elasticity, in the long term, an increase of one per cent in gasoline price will reduce VKT by auto-drivers by 0.31%. The cross-elasticities to public and active transportation are lower. Elasticity values found in the literature are relatively consistent. For instance, Goodwin et al. (2004) reported total VKT long term elasticities of -0.29 and total VKT short term elasticity of -0.10. These are similar to values in Table 4.7 from TRACE (1999) and are also consistent with other studies. Even though municipalities do not have much control over the price of gasoline, its influence relative to other strategies can be appreciated.

TABLE 4.7
TOTAL VKT ELASTICITY OF GASOLINE PRICES

	Auto drivers	Auto passengers	Public transportation	Active transportation
Short term	-0.15	+0.25	+0.20	+0.11
Long term	-0.31	+0.13	+0.12	+0.11

Note: Values are reported for short term and long term.
Source: Adapted from TRACE (1999).

4.4.1 PEDESTRIANIZATION

Pedestrianization means excluding private cars from a geographical area of a city and making it accessible solely by active and public transportation. It is relatively common in some parts of the world, particularly Europe (e.g., Freiburg, see case study 4.7) and some North American cities (e.g., Ottawa, ON; Denver, CO; Portland, OR). This can either be implemented in well established neighbourhoods or in run-down districts needing rehabilitation. Pedestrianized areas often become major recreational areas (i.e., shopping, entertainment, etc.) and can also help preserve historical districts from degradation. These areas often become highly popular and enjoy true economic success (Clarke and Dornfeld, 1994), as well as many other social and environmental benefits, ranging from improved air quality to aesthetics to safety (Pitsiava-Latinopoulo and Basbas, 2000).

In terms of GHG emissions, the local area naturally improves significantly; nevertheless, it is hard to observe the real impact at the city scale (i.e., total VKT). While we have not found any specific studies in the literature to produce an Estimation Guideline, Hass-Klau (2002) has shown that length of pedestrianized-streets by population (m/pop) has a positive effect on ridership of light rail systems.

CASE 4.7
PEDESTRIANIZED CITY CENTRE, FREIBURG, GERMANY

The city of Freiburg has achieved great results in reducing car use through a combination of transportation and physical planning strategies. Aside from improving public transit services, automobile use has been restricted by pedestrianization of the city centre since 1973, implementing area-wide traffic calming schemes, and restricting access to and increasing the price of parking. The city has an extensive downtown car-free network, covering an area of 0.5 square kilometres. The streets are shared by pedestrians and a number of tram lines that service the city centre. The pedestrianized area, also known as Altstadt, is divided into three zones. In one zone no motor traffic is allowed, while only delivery vehicles are allowed in the other two zones, one during morning and evening hours, and the other during day hours only.

Reference: Beatley, Timothy (1999). Green Urbanism: Learning from European Cities, Washington DC: Island Press. pp 97-98.

4.4.2 PARKING PRICE

Raising parking prices is another effective method to reduce GHG emissions from automobiles. The availability of free or cheap parking significantly increases the likelihood that commuters will use the auto mode (Hess, 2001). Additionally, high parking prices may deter entire categories of auto trips (e.g., home-work trip), as opposed to simply reducing the length or number of individual trips. As a result, strong parking policies can have a more significant impact on GHG emissions.

In the literature, elasticity of demand to parking prices varies greatly. For instance, Miller (1993) shows that in Toronto, parking pricing elasticity is greater than 1.0. The context is also important. Parking prices in the central business district (CBD) are usually higher than parking prices elsewhere; therefore, a one per cent increase in each will not have the same impact. For this guide, we chose to use elasticities reported in TRACE (1999) for gasoline prices. Although the values are significantly lower, we assume they represent an approach suited for a regional or urban analysis, as opposed to local scale impacts (e.g., CBD). Moreover, TRACE (1999) also includes cross-elasticities to public and active transportation, and the elasticities also refer to VKT.

ESTIMATION GUIDELINE 4.7
PARKING PRICE

Total VKT long term elasticity:

- Auto drivers ≈ - 0.07
- Auto passengers ≈ + 0.01
- Public transportation ≈ + 0.01
- Active transportation ≈ + 0.02

Total VKT short term elasticity:

- Auto drivers ≈ - 0.03
- Auto passengers ≈ + 0.04
- Public transportation ≈ + 0.02
- Active transportation ≈ + 0.04

Where "Total VKT" is the total vehicle-kilometres travelled per year. Elasticity implies that a 1% increase in parking price will reduce total VKT of auto-drivers by 0.07% in the long term. Source: TRACE (1999, Table 27).

4.4.3 TOLLS, TAXES, AREA PRICING AND OTHER STRATEGIES

There are several other strategies that have been implemented to deter automobile use and reduce the level of congestion. These can be categorized as methods of "internalising externalities". All these strategies can have a wide range of impact on VKT. There is no one strategy that has proven to be completely effective; instead a series of measures should be taken to significantly reduce VKT.

Results vary according to location, present conditions and context. In this section, we outline the main strategies that have been implemented around the globe (Table 4.8). While it is not possible to establish Estimation Guidelines, we highlight two major studies that have been carried out in Auckland, New Zealand, and Washington, DC, which modelled the responses to several travel demand management strategies in terms of VKT reductions.

TABLE 4.8
POPULAR STRATEGIES TO REDUCE TRAFFIC CONGESTION

Name	Description	Examples	References
Area pricing	Daily toll to enter and travel within designated area.	London, UK Singapore	Litman (2006) TCRP (2003)
Cordon tolls	Daily toll to enter designated area; the cordon is usually a set of highways or major arteries encircling the CBD.	Norway, several cities	TCRP (2003)
Road tolls	Toll to travel on a certain corridor.	Highway 407, Toronto, ON National highways, France	TCRP (2003) Bousquet (2001)
High occupancy vehicle (HOV)	Lane(s) on highways or major arteries reserved for vehicles having more than one occupant.	Multiple examples in North America (e.g., Mississauga, ON; Pittsburgh, PA)	TCRP (2006)
High occupancy toll (HOT)	HOV lanes where single occupant vehicles can travel by paying a toll.	San Diego, CA Houston, TX	TCRP (2003)
Distance-based tax (pay-as-you-drive)	Tax applied on a per kilometre (or per mile) basis to all automobile owners. It can be amalgamated with insurance.	Denmark (not yet applied) Several insurance companies	Agerholm et al. (2008) Litman (2008)
Emissions tax	Tax applied to certain types of vehicles (large emitters) to enter and travel within one area.	Berlin, Germany London, UK	LEEZEN (2009)

Note: List of references is not exhaustive, but can be referred to for further information.

A study was produced for the city of Auckland, New Zealand (MoT, 2006) analyzing the impacts of five different strategies on VKT reduction. Table 4.9 presents the results. Note that the reductions in auto use are measured in VKT, whereas the increases in public and active transportation are expressed in mode share (i.e., PKT). The first two strategies involve cordon pricings (i.e., encircling of an area) where auto users have to pay a toll to enter an area. The third strategy is similar to the famous London congestion pricing scheme (Case 4.8) and is called area pricing. The fourth strategy looks at the implementation of tolls on highways and major arteries and is called a "strategic network". The fifth strategy imposes a parking levy on all auto users (public and private properties) in the regional CBDs. The double cordon pricing scheme was the most effective in reducing auto VKT and, hence, in reducing GHG emissions.

TABLE 4.9
STUDY OF RESPONSES TO TRAVEL DEMAND MANAGEMENT STRATEGIES, AUCKLAND, NZ[1,4,5]

	Single cordon ($2)	**Double cordon** ($2)	**Area pricing** ($3.40)	**Strategic network** ($4.10)	**Parking levy** ($6.85)
Total auto VKT [2]	-6.50%	-10.70%	-9.30%	-6.00%	-3.00%
Public transportation[3] mode shift	+1.90%	+3.2%	+3.2%	+1.00%	+2.30%
Active transportation[3] mode shift	0.00%	+0.34%	+2.03%	+0.18%	+0.49%

Notes:

1. The project was commissioned by the Ministry of Transport (MoT) of New Zealand, and carried out by a consortium of consultants led by Deloitte.
2. Total Auto VKT reports percentage difference in total VKT.
3. Public Transportation and Active Transportation report additional mode share in response to these strategies.
4. Monetary values are reported in CA$.
5. Table was adapted from MoT (2006).

Another comprehensive study of travel demand strategies was produced by Harrington et al. (2008) for Washington DC (Table 4.10). The study considered three different cordon tolls strategies: downtown cordon (small area), beltway cordon (larger area) and double cordon (including the two former). Harrington et al. also analyzed the impacts of a freeway toll, a comprehensive toll (charging all vehicles on every road) and a distance-travelled tax (called VMT tax). The advantage of this study is that it reports the total number of VKT affected by the policies. It is clear that a distance-based tax would prove to be the most effective by reducing VKTs by as much as 14.6 per cent. This is the most effective technique to reduce GHG emissions.

TABLE 4.10
STUDY OF RESPONSES TO TRAVEL DEMAND MANAGEMENT STRATEGIES, WASHINGTON, DC[3,4]

	VMT tax	**Comprehensive toll**	**Freeway toll**	**Double cordon**	**Beltway cordon**	**Downtown cordon**
Per cent of VMT affected	100%	100%	26%	7% [3]	7% [3]	1.1% [3]
Tolls rates	10¢/mile	Variable	Variable	downtown: $2.18 beltway: $3.43	$2.77	$4.70

Average cost / VMT (¢/mile)	7.9	3.3	0.7	0.4	0.3	0.2
VMT % change [4]	-14.60%	-7.10%	-2.10%	-1.30%	-0.90%	-0.80%

Notes:

1. All currencies were kept in US$.
2. Table was adapted from Harrington et al., 2008.
3. Per cent trips, not VMT.
4. "VMT % change" row reports changes to total vehicle-miles travelled; this value can be adopted for VKT due its dimensionless characteristic.

CASE 4.8
CONGESTION CHARGING, LONDON, UK

Vehicles which drive within a clearly defined zone of central London between the hours of 7 a.m. and 6 p.m., Monday to Friday, have to pay an £8 daily Congestion Charge. Payment of the charge allows drivers to enter, drive within, and exit the Charging Zone as many times as they wish on that day.

The Congestion Charge was first introduced in Central London in February 2003 (with the daily charge set at £5 per day to travel between 7 a.m. and 6.30 p.m.). In July 2005, the charge rose to £8, and the zone was extended in February 2007 when the hours of operation were reduced. There is no charge for driving on the boundary roads around the zone. In addition, there are a number of routes that enable vehicles to cross the zone during charging hours without paying – the Westway and a route through the centre of the zone running north to south. If the Congestion Charge is not paid a Penalty Charge Notice (PCN) for £120 is issued to the registered keeper of the vehicle. This is reduced to £60 if paid within 14 days, but if a PCN is not paid within 28 days the penalty increases to £180.

Net revenue raised from Congestion Charging is spent on improving transport in London. Traffic levels and congestion immediately decreased after the implementation. However, five years later, it seems congestion has reverted to pre-charging levels. In 2007/08, the scheme generated net revenue of £137M ($234 million CAD).

Implementation of London's congestion pricing is estimated to have saved about 110,000 to 120,000 tonnes of total CO_2 emissions per year.

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Transport for London, Congestion Charging, Transport for London. http://www.tfl.gov.uk/roadusers/congestioncharging/ Accessed November 8, 2008.

Evans, R., Central London Congestion Charging Scheme: ex-post evaluation of the quantified impacts of the original scheme, Transport for London. http://www.tfl.gov.uk/assets/downloads/Ex-post-evaluation-of-quantified-impacts-of-original-scheme-07-June.pdf Accessed November 8, 2008.

4.5 STRATEGY 5: CHANGING VEHICLE TECHNOLOGY

Changing vehicle technology is another strategy to address GHG reduction requirements for the transportation sector. It is a very different approach to those presented so far in this chapter. Strategies 1 to 4 aim to reduce or deter automobile use and promote alternative transportation modes, such as transit, walking and biking. Strategy 5 outlines the potential environmental benefits of switching to greener technologies from the current use of fossil fuels to power automobiles.

Although this strategy could curb climate change-related problems linked to transportation (assuming all sources of energy are carbon neutral), it would not address other important issues, such as congestion and safety that are of paramount importance for the sustainability of a city. Nevertheless, private vehicles are essential to the economy and social welfare of a city. This must be recognized in order to understand the reality and scope of the sustainable transportation challenge. Instead, the use of automobiles should be minimized and they should be powered by less polluting sources.

In 2007, 96 per cent of transportation-related energy consumption in the U.S. was supplied by petroleum-based fuels (source U.S. Energy Information Administration, EIA). Ideally, the automobile might become the second or third option rather the primary travel choice. In this section, we look at several potential candidates for the task of changing technology and detail the benefits in comparison to fossil fuels.

A study on the potential of alternative fuels to de-carbonize Canada has been carried out by Steenhof and McInnis (2008). For this guide, we have looked at three potential alternative fuels: biomass, fuel cells, and electricity. Table 4.11 presents the current emission factors for four types of vehicles fuelled by three conventional petroleum-based fuels.

TABLE 4.11
AVERAGE EMISSION FACTOR FOR FOUR TYPES OF VEHICLES[1]

	Passenger car	Light truck	Truck	Diesel bus
Fuel	Gasoline	Gasoline	Diesel	Diesel
L/100 km [note 2]	9.1	16.7	n.a. [3]	62.5
g CO_2e/km	297	472	1,393	1,670

Notes:

1. Data was adapted from GREET 1.8c model (Argonne National Laboratory, 2009), Beer et al., 2000, and Lenzen, 1999.
2. The “L / 100 km” are approximated values.
3. This figure is not available for the truck category since it is a mix of light-commercial, medium and heavy trucks.

In this section, we did not develop Estimation Guidelines since the figures presented were taken largely from single sources and thus their applicability is not straightforward. Assessments of different fuels are highly dependent on vehicle location and lifecycle boundaries. To fully estimate total GHG emissions of alternative vehicle technologies, a case by case basis approach should be taken. For instance: for biomass fuels, one has to consider the feedstock transportation cost; for fuel cells, the origin of hydrogen is of significant importance; for electric vehicles, the carbon intensity of the electric-grid needs to be taken in account. In this section, we offer a general perspective of the different fuels. The figures quoted in tables can be used to estimate GHG reductions linked to changing vehicle technology.

4.5.1 BIOMASS

In this guide, biomass refers to ethanol and biodiesel (for buses and trucks). These types of fuels are made from plants (e.g., sugar cane, corn) and burn like fossil fuels. In some respects they are more environmentally friendly than fossil fuels since plants require carbon dioxide. Yet while biofuels can reduce the carbon footprint of an entire region, their use in city streets still generate exhaust emissions that can cause serious health issues. They are generally seen as a solution for the short to mid-term. Moreover, since these fuels are made from plants, they exercise a pressure on the commodity world market, which could eventually be detrimental to global social welfare. Nevertheless, there could be great potential if biofuels are used with hybrid-electric vehicles (see Section 4.5.3).

Table 4.12 shows the effect of using different blends of biomass from different sources relative to gasoline consumption and carbon emissions. Low blends (10 per cent) have little impact on either consumption or emissions. However, an 85 per cent blend can have a significant impact; in particular E85 from cellulosics reduces emissions by 69 per cent.

TABLE 4.12
EFFECTS OF USING BIOMASS AS A FUEL

	E10 Corn	E85 Corn	E10 Cellulosics	E85 Cellulosics
Reduction of gasoline consumption	6%	73%	6%	71%
Reduction of carbon emissions	1%	6%	6%	69%

Notes: E10 and E85 refer to a 10% and 85% blend respectively. Reductions given are tank-to-wheel values, ie., for combustion during vehicle operation only.

Source: Adapted from West (2008).

Biodiesel produced from biomass can be used to fuel diesel-powered vehicles, such as public transportation buses and trucks. For a 20 per cent blend of biodiesel, carbon emissions from buses would be reduced from 1,670 grams of CO_2e/km to 1,400 grams of CO_2e/km, a 16 per cent reduction (adapted from Beer, 2000). Table 4.13 Effects of Using 20% Biodiesel Blend (BD 20) shows the reduction of diesel consumption and carbon emissions from a 20 per cent blend of biodiesel (BD 20) for buses, and combined trucks and buses. Note that the sources for this figures are different, which explains the discrepancy between the two. This also shows the importance of context, as GHGenius is a Canadian model while Beer (2000) considers the Australian environment.

TABLE 4.13
EFFECTS OF USING 20% BIODIESEL BLEND (BD 20)

	Combined trucks & buses	Buses
Reduction of diesel consumption	19.20%	--
Reduction of carbon emissions	3.55%	16%

Source: Adapted from Beer (2000) and GHGenius (2009).

4.5.2 FUEL CELL VEHICLES

Fuel cell vehicles (FCVs) use the chemical reaction between oxygen and typically hydrogen to create electricity that is used to power an electric engine. Although FCVs use electric engines, their fuel is different than electric vehicles (EVs), and their emissions are not reliant on the electricity grid. The advantages of this technology are its mile range (comparable to ICE) and the ability to refuel quickly (as opposed to EVs).

The future of fuel cells has been challenged this past decade due to technological constraints in producing the hydrogen fuel. If this constraint is resolved, fuel cells could also be coupled with hybrid-electric vehicles as a means to power vehicles in a carbon neutral manner.

Table 4.14 presents the average GHG emissions for various fuel cell powered passenger cars relative to gasoline. The hydrogen FCV has significantly lower GHG emissions than the gasoline vehicle, although the source of hydrogen always has to be considered.

TABLE 4.14
AVERAGE GHG EMISSIONS OF FUEL CELL (FC) POWERED PASSENGER CARS

	Gasoline	Natural gas FC	Gasoline FC	Hydrogen FC
g CO_2e/km	280.3	90.7	169.3	99.7
% difference with gasoline	–	67.6%	39.6%	64.4%

Source: Adapted from Bauen and Hart, 2000.

Public transportation buses can also be powered by fuel cells to reduce the carbon footprint of the public transportation sector. Figure 4.5 shows the average emissions of transit buses in Vancouver, BC, when powered with different fuels.

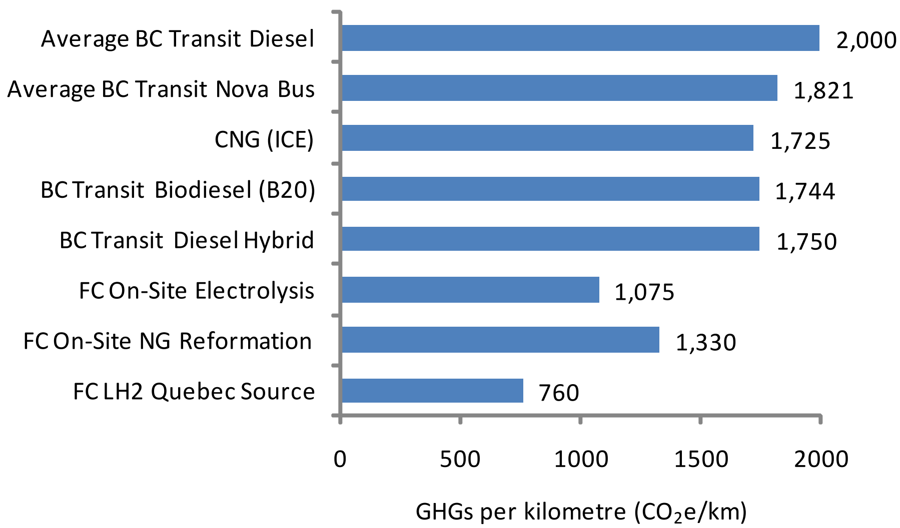

Figure 4.5 Average GHG Emissions of Buses in Canada

Notes: CNG stands for compressed natural gas; B20 is equivalent to BD 20; FC stands for fuel cells. Source: Adapted from Wise, 2008.
Source: Adapted from Wise (2008)

4.5.3 PLUG-IN HYBRID AND HYBRID ELECTRIC VEHICLES

Electric vehicles are possibly the best alternative for the long term. Hybrid gas-electric vehicles (HEVs) are the models currently being commercialized. HEVs switch between gasoline and electricity to power the engine (e.g., Toyota Prius). Plug-in-hybrid electric vehicles (PHEVs) should be available in the near future. They are similar to HEVs with the possibility of "plugging in" and recharging the batteries from a household outlet. In the future, fully electric vehicles (EV) that power solely on electricity could be marketable.

GHG emissions from electric vehicles depend heavily on the carbon intensity of the electric grid (see Table 2.1and Chapter 5). Some countries, including Australia and Israel, have already started to regulate their automobile fleets (Case 4.9). A review of existing PHEVs and a more detailed analysis of carbon emissions are presented in Bradley (2009).

Table 4.15 shows the average percentage reduction in gasoline consumption and carbon emissions for four different types of vehicles by five different types of fuels. The table shows that HEVs and PHEVs are much more efficient than internal combustion engine (ICE) vehicles even when using gasoline as their source of power. Using biomass as a fuel also reduces fuel consumption and carbon emissions. This is especially true when E85 from cellulosics is used as the fuel; carbon emissions are reduced by 93 per cent. Similar to biomass, fuel cells could be used to power HEVs and PHEVs. However, we have not been able to acquire data on the matter; see Suppes (2006) for more information.

TABLE 4.15
EFFECTS OF HEV AND PHEV ON GASOLINE CONSUMPTION & CARBON EMISSIONS

	Fuel consumption (L/ 100km)	Gasoline	E10 Corn	E85 Corn	E10 Cellulosics	E85 Cellulosics
Percentage reduction of gasoline consumption relative to gasoline case						
Gasoline	11.24	0%	6%	73%	6%	71%
HEV 30	5.24	54%	56%	89%	56%	88%
PHEV 20	3.63	66%	70%	92%	70%	91%
PHEV 30	2.77	75%	77%	95%	77%	94%
Percentage reduction of carbon emissions relative to gasoline case						
Gasoline	11.24	0%	1%	6%	6%	69%
HEV 30	5.24	52%	53%	56%	56%	85%
PHEV 20	3.63	75%	74%	76%	73%	91%
PHEV 30	2.77	83%	83%	84%	84%	93%

Notes: Gasoline refers to a conventional gasoline-powered mid-size car; E10 and E85 refer to a 10% and 85% blend respectively; HEV 30 stands for 30 mile electric-only range; PHEV 20 and PHEV 30 stand for 20 mile and 30 mile electric-only range, respectively. Reductions given are tank-to-wheel values, ie., for combustion during vehicle operation only.

Source: Adapted from West (2008).

Finally, we compare the performance of ICE with battery electric vehicles (BEVs) and fuel cell vehicles (FCVs). Table 4.16 shows that BEVs are about 65 per cent more efficient than equivalent ICE cars. FCVs are also more efficient than ICE cars, but by a lesser percentage. Nevertheless, there appears to be a 75 per cent efficiency loss during charging and storage in batteries (Gilbert, 2007).

TABLE 4.16
COMPARISON OF ENERGY USE BETWEEN AN ICE, BEV & FCV

	ICE Honda Civic 2.2L-CTDI (diesel)	BEV Mitsubishi Lancer Evolution MIEV	Fuel cell Honda ZC2
Rate of energy use (MJ/100km)	197	69	124
Per cent reduction from ICE	-	65%	37%

Source: Adapted from Gilbert (2007).

CASE 4.9
BETTER PLACE ELECTRIC VEHICLE NETWORK, ISRAEL

In addition to projects in Australia and Denmark, sustainable transportation company Better Place is developing an electric vehicle network in Israel. The electric car infrastructure will consist of electric vehicles and innovative battery technology, as well as battery exchange stations and charging spots powered by renewable energy. Charging spots will be located around a community, so that batteries are automatically charged as vehicles are parked. For longer trips (greater than 100 miles), roadside battery switching stations will replace depleted batteries with a fully charged one. The experience will be automated, never requiring the driver to leave the vehicle. The business model is similar to that of a mobile phone carrier whereby users pay for use of the network. The vehicles will cost very little, and drivers will pay to use the charging spots and roadside battery switches that make electric driving possible across the country. If electricity is obtained from renewable sources, the electric vehicle network will result in zero transportation emissions.

Reference: Better Place, Our Bold Plan. www.betterplace.com/our-bold-plan/ Accessed November 10, 2008.

Overall, there are several viable options for green vehicle technologies. Municipalities can provide leadership by encouraging and supporting the commercialization of these low emissions vehicles through the greening of their own fleets, regulating taxi fleets and providing reduced parking fees or other advantages to green vehicles. In doing so, municipalities can substantially reduce their own transportation carbon footprint from their corporate fleet (e.g., police, paramedic, waste management, public works vehicles) by purchasing or leasing vehicles with better fuel efficiency.

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CHAPTER 5: ENERGY SUPPLY

(R. Zizzo, R. Stupka, D. Bristow, D. Rulff and C. Kennedy)

Municipalities can reduce their GHG emissions through building and transportation strategies (discussed in Chapters 3 and 4). However to approach carbon neutrality, cities will also have to become increasingly involved in the business of energy supply. The generation of electricity and provision of heating fuels to cities are typically handled by public or private companies, often operating quite independently of cities. Municipalities can, however, do much to foster the development of a carbon-free energy supply through their financial power and planning controls.

The strategies considered in this chapter operate primarily at the local or neighbourhood scale. Cities can encourage the development of local sources of electricity generation and facilitate the development of district heating and cooling systems. Such neighbourhood energy supply systems can include underground thermal energy storage systems and combined heat and power plants. Building scale energy systems, such as photovoltaics, solar heating and ground source heat pumps, were covered in Chapter 3. Here, the focus is on the local scale.

5.1 STRATEGY 1: ELECTRICITY FROM RENEWABLE SOURCES

The generation of carbon-free electricity in or near cities depends very much on the natural resources available – the wind, solar radiation, tides, waves, and geothermal resources. Case 5.1 highlights a single wind turbine located in Toronto, which exploits gusts off Lake Ontario to displace a modest 380 tonnes of CO_2e per year. Of course, much higher GHG savings could be achieved by constructing a field of off-shore turbines in the lake (as is currently planned). Generation of electricity from the wind is primarily dependent on average wind speeds, as reflected in Estimation Guideline 5.1.

CASE 5.1
TREC WINDSHARE, TORONTO, ON

The Toronto Renewable Energy Cooperative (TREC) WindShare undertook the first installation of a wind turbine in an urban setting in North America. It was installed in 2002, at Exhibition Place in Toronto, near the shore of Lake Ontario, at a capital cost of $1.6 million. The turbine is rated at 750 kW and is grid connected. The single turbine has an average annual production of 1,400 MWh and displaces up to 380 tonnes of GHGs per year.

Reference: Toronto Renewable Energy Cooperative, WindShare, http://www.trec.on.ca/projects/windshare.html, accessed October, 2008.

ESTIMATION GUIDELINE 5.1
WIND POWER

Annual energy production per turbine is approximately equal to:
(power rating of turbine) • [0.84 • (average annual wind speed in m/s) - 2.4]

The guideline assumes the average annual wind speed entered represents the average annual wind speed at the hub height of the installed turbine(s). It is based on the following turbine speeds: cut in = 4 m/s, rated at = 12 m/s, cut out = 20 m/s. Finally, the calculation neglects varying climatic conditions (such as temperature and precipitation and variation in the direction of wind).

Fortunately, Eastern Canada is already blessed with substantial hydropower. Municipalities with access to suitable rivers may encourage development of smaller hydroelectric facilities, such as in Case 5.2. The size of hydro turbines depends on the flow of the water. Generating equipment with lower flow and higher head is typically less expensive than systems with higher flow and lower head.

CASE 5.2
CORDOVA DAM, MARMORA, ON

This small hydroelectric facility has a rated capacity of 800 kW and is approximately 88 per cent efficient. The dam is situated at an existing Ministry of Natural Resources dam at the site of an old fish hatchery. The capital cost of the project was $1.8 million, with annual operating and maintenance costs of $35,000.

Reference: CanREN, Cordova Dam, http://www.canren.gc.ca/renew_ene/index.asp?CaId=49&PgID=333, accessed October, 2008.

ESTIMATION GUIDELINE 5.2
HYDRO POWER

Hydro Power, $P \approx 7 \cdot Q \cdot H$

Where "P" is power (kW); "Q" is flow in cubic metres per second (m^3/s); "H" is head in metres. "Small hydro" is 1 MW to 50 MW. "Mini" hydro is 100 KW to 1 MW. "Micro" hydro is projects less than 100 kW. Source: RETScreen.

Unlike wind and sunshine, other potential renewable sources of electricity generation can be location-specific. Estimation Guidelines for wind power, hydropower and photovoltaics are given above and in Chapter 3. For the more location-specific strategies, we provide case examples 5.3 to 5.8, rather than further Estimation Guidelines. Some of these cases provide world-leading examples of electricity generation from renewable sources. Generation of electricity from waves, as at Aguçadoura in Portugal, or tides, as at Strangford Lough in Northern Ireland, are strategies that might be pursued by municipalities on the east or west coasts of Canada. Concentrating solar thermal electricity plants, such as those in Seville, Spain, and Kramer Junction, California, require high levels of solar radiation, perhaps only reached in southern parts of Alberta and Saskatchewan. Large-scale photovoltaic plants, similar to that at Olmedilla de Alarcón, Spain, require similar conditions to be most cost effective. Generation of electricity from geothermal currents, as in Sonoma County, California, is best suited to Western Canada.

CASE 5.3
AGUCADOURA WAVE POWER PLANT, PORTUGAL

The Aguçadoura power plant is the first operational commercial wave farm in the world. The first phase, which consists of three generators, came online in September 2008 with a peak capacity of 2.25 MW. When the remainder of the project is completed 21 MW of capacity will be installed. The generators are tethered three miles off the coast of Portugal.

Reference: Pelamis Wave Power, World's First Commercial Wave Power Project Goes Live, www.pelamiswave.com/media/worlds_first_wave_farm_goes_live_press_release_copy1.pdf, accessed October, 2008.

CASE 5.4
SEAGEN TIDAL SYSTEM STRANGFORD LOUGH, NORTHERN IRELAND

The 1.2 MW tidal stream generator installed 400 metres off the coast of Northern Ireland is the first of its kind. The generator consists of two turbines, each 16 metres in diameter, placed side by side and connected by arms to a central tower. The turbines rotate at only ten to fifteen rotations per minute (making them unlikely to pose a threat to wildlife). The system operates some 18 to 20 per day and, as the bulk of the system is under water, does not pose a visual distraction.

The SeaGen system installed at Strangford has the capability of generating approximately 4,500 MWh/year (allowing for 10 per cent downtime with a new technology). The UK figure for displaced carbon is based on an average 0.45 kilograms of CO_2/kWh (DEFRA 2005). On this basis, SeaGen will displace emissions of 2,025 tonnes of CO_2 per year. A study at Edinburgh University suggested that SeaGen will pay back the energy involved in its manufacture, installation, 25 years of operation and decommissioning in less than 12 months.

The capital costs of SeaGen installations depend on the size of project and site conditions. Costs were initially in the order of $6 million/MW installed for small early stage projects, but will fall to about half this level for larger projects in 5 to 10 years time. Annual operating and maintenance costs are likely to be in the order of $50,000 to $150,000/year per MW installed. Revenues are generated from the sale of between 2,600 and 4,500 MWh/yr of electricity per MW installed.

References: Leonardo Energy, World's first tidal stream generating system, http://www.leonardo-energy.org/drupal/node/3587, accessed October, 2008.
Frankel, P., 2008. Marine Current Turbines Limited. personal communication.

CASE 5.5
PS10 SOLAR CENTRAL RECEIVER STATION, SEVILLE, SPAIN

The first commercial grid connected Solar CRS (Central Receiver Station) has a peak power capacity of 11 MW. The project consists of 624 120 m^2 heliostats that reflect sunlight onto a receiver at the top of a 100 metre-tall tower, which produces steam to drive a turbine. The station cost €35 million Euros ($52.3 million CAD) to construct and produces 24.3 GWh of electricity per year (12 to 15 per cent of this is provided by natural gas) There are plans to expand the system to 300 MW by 2013 which would be enough to power 180,000 homes (approximately the size of Seville).

References: Abengoa Solar, PS10: The first commercial tower of the world, http://www.abengoasolar.com/sites/solar/en/our_projects/solucar/ps10/index.html, accessed November, 2008.
IEA SolarPaces, Spain PS10, http://www.solarpaces.org/Tasks/Task1/PS10.HTM, accessed October, 2008.

CASE 5.6
SEGS SOLAR THERMAL ELECTRICITY PLANT, KRAMER JUNCTION, CA

This 354 MW solar thermal electricity plant consists of over 900,000 curved concentrating solar collectors covering 650 hectares. The curved mirrors focus the sun's rays on an absorber pipe that runs parallel to the mirrors. The heated fluid in the piping runs the turbines that generate electricity. The system was constructed in phases, with the first begun in the mid-1980s.

Reference: Wikipedia, SEGS, http://en.wikipedia.org/wiki/SEGS, accessed October, 2008.

CASE 5.7
PARQUE FOTOVOLTAICO OLMEDILLA DE ALARCON, SPAIN

This 60 MW station is the largest operational photovoltaic power plant in the world. The plant came online in the fall of 2008 and consists of 162,000 PV modules. The power plant, which cost €376 million Euros ($561 million CAD), produces approximately 85,000 MWh/year

Reference: Leonardo Energy, Almedilla do Alarcón, http://www.nobesol.com/?seccion=4&subseccion=2&contenido=40, accessed October, 2008.

CASE 5.8
THE GEYSERS, GEOTHERMAL POWER, SONOMA COUNTY, CA

The Geysers is the largest geothermal power project in the world. The project consists of 22 plants and currently has a total capacity of 750 MW. The project provides about 60 per cent of the electricity for the coastal region between the Golden Gate Bridge and the Oregon border. Calpine Corporation owns the majority of the plants.

Reference: Wikipedia, The Geysers, http://en.wikipedia.org/wiki/The_Geysers, accessed October, 2008.

5.2 STRATEGY 2: UNDERGROUND THERMAL ENERGY STORAGE

The need for space heating and cooling in buildings is due to the thermal disparity between ambient conditions and human comfort. In the winter, the ambient air is cold and natural gas is typically burned to increase the temperature of the air to a comfortable level. In the summer, ambient air is hot and electricity is used to run condensing air conditioners which cool the air. The required winter resource, heat, is abundant in the summer. Similarly, the required summer resource, chill, is abundant in the winter. From this elementary perspective, it is apparent that the needs for space heating and cooling are a result of temporal disparity. To solve this mismatch, thermal energy must be stored in the season where it is abundant and utilized in the season where it is scarce. One way to do this is through underground thermal energy storage (UTES).

When storage occurs on the time scale of seasons, the storage medium volume must be very large. The earth itself turns out to be an extremely good storage medium, having high thermal capacity, which can be utilized at relatively low cost. Geological formations, including fractured igneous rock, permeable sedimentary rock (aquifers), soil, gravel, and groundwater, are all capable of seasonal thermal energy storage. Underground storage tanks can also be used as an artificial form of UTES, although these are usually more expensive (Wong et al., 2007). More competitive UTES systems use aquifers or boreholes.

5.2.1 AQUIFER THERMAL ENERGY STORAGE (ATES)

Aquifer thermal energy storage (ATES) is the least expensive of all natural UTES options (Wong et al., 2007). This system uses saturated groundwater aquifers as the storage medium, with water accessed through a number of pumping wells. If the system is used for both heating and cooling purposes, separate hot and cold wells must be present. During the summer, cold water is extracted from the cold well and run through a heat exchanger. The water provides cooling to the building while acting as a thermal sink for the waste heat. After leaving the heat exchanger, it is pumped into the hot well. This process continues all season. Some systems add extra heat to the water through solar collectors prior to returning it to the hot well; however, this is not required for all systems. When heating is required during the winter, the flow is reversed. Hot water travels from the hot well into the heat exchanger where it provides heat while retaining chill. This cold water is then sent to the cold well, and this process continues all season.

The use of an aquifer system is clearly reliant on the geology of the site and can only be employed in areas of specific geologic deposits. The most common geology used for ATES is a sandstone aquifer with high porosity and permeability. Igneous rock formations (bedrock) can also be used in areas with a significant degree of fracturing. An important consideration when designing these systems is groundwater flow, since it can add to thermal losses. A numerical study on a porous medium with homogeneous hydraulic properties concluded that a protective hydraulic screen is required if groundwater flow exceeds 0.05 metres per day (20 metres per year) (Van Meurs and Hoogendoorn, 1983). However, the majority of aquifers in urban areas have much slower rates and thus groundwater flow is usually not a critical design issue. When fractured rock aquifers are used, acceptable groundwater flows must be determined on a site-specific basis since ATES losses will greatly depend on the degree and orientation of the fractures.

One of the main constraints on ATES systems is that they must remain thermally balanced, meaning that the amount of thermal energy taken out of the aquifer must equal the amount of thermal energy injected over the course of a year (Dickinson et al., 2009; Snijders, 2008). If this constraint is not met (or nearly met) the long term effect can be considerable thermal change to the aquifer. This can result in geochemical and biological changes in the rock and microorganisms within, which can have detrimental effects on the functioning of the system over the long term.

ATES systems are especially popular in Northern Europe, with more than 750 major projects to date. Nearly one-third of all new commercial buildings in the Netherlands have an ATES system installed (Snijders, 2008).

ESTIMATION GUIDELINE 5.3
AQUIFER THERMAL ENERGY STORAGE

ATES systems typically achieve: a 60 to 80 per cent reduction in cooling electricity requirements; and a 20 to 30 per cent reduction in heating primary energy requirements. Source Snijders (2008).

5.2.2 BOREHOLE THERMAL ENERGY STORAGE (BTES)

Borehole thermal energy storage (BTES) systems are comprised of long boreholes, anywhere from 20 to 400 metres deep. Each borehole contains a U-tube which links to a central piping system at the surface. This technology can be applied to almost any ground condition from clay to bedrock. Warm water, or a water-glycol mixture, is pumped through the U-tubes, travelling down, then back up each borehole. The heat is transferred from the heat carrier fluid to the ground by conduction. Over the course of a season, the borehole field is continually heated. When the winter arrives, the flow is reversed, and heat is extracted from the field and delivered to the building.

The flexibility of this technology to almost any ground condition has made BTES systems one of the most popular forms of UTES. The first field experiments for a BTES system occurred in 1976 in France, and the first large-scale system was brought online in 1982 near Luleå, Sweden. The largest BTES field in the world was built in 1995, consisting of 400 boreholes with a depth of 135 metres, and located at Richard Stockton State College, Pomona, NJ (Nordell and Hellstrom 2000).

Two systems have recently been developed in Canada. The first is North America's second largest field, built in 2004 at the University of Ontario Institute of Technology. The field consists of 370 boreholes to a depth of 200 m (Wong et al., 2007). The second Canadian example is the 52-house Drake Landing Solar Community in Okotoks, Alberta (Case 5.8). This project uses both a BTES field and two above-ground water thermal storage tanks. These secondary TES systems can be charged and used in times of higher demand, when the UTES is unable to meet the load. The overall efficiency of the Okotoks system is remarkable, providing a 90 per cent reduction in primary energy use relative to conventional systems. Due to the significant costs associated with drilling multiple deep boreholes, BTES is the most expensive of the natural UTES options (Wong et al., 2007), but, BTES systems are feasible for a significant range of project types and settings.

ESTIMATION GUIDELINE 5.4
BOREHOLE THERMAL ENERGY STORAGE

BTES systems can provide up to a 90 per cent reduction in primary energy for heating when coupled with solar collectors, secondary storage tanks and high efficiency buildings (Wong et al., 2007).

UTES systems should not be confused with their more popular geothermal relative, ground source heat pumps (GSHPs). GSHPs (discussed in Chapter 3) make use of the constant ground temperature that is found slightly below the ground surface. UTES, on the other hand, changes the sub-ground temperature and utilizes that resource at a later time.

CASE 5.9
DRAKE LANDING SOLAR COMMUNITY, OKOTOKS, AB

The Drake Landing Solar Community is comprised of 52 single family R-2000 homes. The homes are connected to a district heating system that includes solar collectors and a borehole energy storage system. The borehole field consists of 144 boreholes, each 35 metres deep, 150 mm in diameter, and spaced 2.25 metres apart. The system contains 24 parallel circuits, each having six boreholes in series. During the winter, the homes are heated using solar energy captured during the summer and stored in the boreholes.

This system saves more than 110 GJ of energy, and 5 tonnes of GHGs per home each year. The R-2000 single family homes are 30 per cent more efficient than conventional homes. Overall, 90 per cent of the space heating needs are met by solar thermal energy.

References: Drake Landing Solar Community, http://www.dlsc.ca, accessed October, 2008. Wong et al., 2007

5.3 STRATEGY 3: DISTRICT HEATING AND COOLING

A district energy system is a network of pipes that supply heating and cooling from one or more sources directly to a group of connected buildings. Common technologies used in district energy systems are: heat only, combined heat and power (CHP), chilled water, and thermal energy storage (TES) (Gilmour and Warren, 2007). Modelling results for the Canadian District Energy Association (CDEA) found that by connecting all residential and commercial buildings to a high efficiency natural gas-fired district energy system, 9 per cent (or 57 million tonnes) of CO_2 and 11 per cent of Canada's total energy consumption could be avoided annually (Gilmour and Warren, 2008). According to a 2008 national survey conducted by the CDEA (2009), there are currently 118 district energy plants in operation across Canada.

The following summarizes the main categories of district energy production:

> **District heating**: a network for heated fluid, most commonly hot water or steam. Heat energy can be generated using conventional boilers (natural gas, coal, fuel oil, etc.), alternative energy systems (solar thermal, geothermal), thermal waste from industrial processes (waste incineration, manufacturing, refineries, etc.), or as a by-product of power generation (Co-gen, which is discussed further in the following section).

> **District cooling**: a network for chilled fluid, most commonly water or refrigerant mix (e.g., glycol-water). Cooling potential is supplied by conventional chillers (e.g., steam-driven, chemical absorption, electrical, centrifugal-steam, etc.), heat pumping (e.g., to thermal reservoir, whether air or water), or direct exchange with a cold medium (e.g., deep lake water).

District energy can provide significant economic, operational and ecological advantages over conventional energy systems. This is because these systems are able to utilise a variety of fuel sources from both renewable and non-renewable sources, allowing for fuel switching depending on resource availability or price fluctuations (Wilson, 2007). This can also include diverting waste heat or cooling from a building or process to areas where there is a demand, thus reducing consumption from external sources, using less fuel and providing added security from a diverse supply mix. Engineering and equipment costs can be greatly reduced in a district system because a boiler is not required in every building. This can result in valuable space savings and reduced maintenance costs. The additional space could be the most significant savings for some developments (Wilson, 2007).

ESTIMATION GUIDELINE 5.5
ENERGY SHARING FROM INDUSTRIAL PROCESSES

GHG savings of 26.4 kilograms of CO_2e per GJ of shared energy were estimated for a study in Calgary by the Canadian Urban Institute (2008).

ESTIMATION GUIDELINE 5.6
DISTRICT SPACE AND WATER HEATING

GHG savings of 24.2 kilograms of CO_2e per GJ energy produced by a district system were estimated for a study in Calgary by the Canadian Urban Institute (2008).

CASE 5.10
DISTRICT HEATING NETWORK, COPENHAGEN, DENMARK

The DH system in the municipality of Copenhagen covers 98 per cent of the annual heating and hot water demands. Owned by Copenhagen Energy Ltd., it is comprised of a 1,500 km double-pipe network that serves 30,000 customers (roughly 33,000 square meters or 500,000 inhabitants). Annual production amounts to 19,500 TJ, the bulk of which is generated by 10 CHP plants with a total combined capacity of 2,000 MW. One-third of this production is fuelled by biomass and waste incineration processes. The DH network is part of a larger system, serving another 15 smaller municipalities with a total annual heat consumption of 33,000 TJ. Copenhagen DH is beginning to incorporate geothermal (13 MW at Amager CHP), solar (280 kW at Amager CHP, to be completed by end of 2009), and district cooling, which will use water from the canal for an estimated 29.3 per cent of the load (expected 15 MW plant by spring 2010 in Kongens Nytorv area). With the existing system, a 40 to 50 per cent reduction in CO_2 emissions from equivalent oil or gas-fired boiler systems is achieved.

Reference: Director Peter Elsman (Sept. 2009). Copenhagen District Heating System. Application for the 'Global District Energy Climate Award.' Copenhagen Energy Ltd. Municipality of Copenhagen. http://www.copenhagenenergysummit.org/applications/Copenhagen,%20Denmark-District%20Energy%20Climate%20Award.pdf

CASE 5.11
ENWAVE DEEP LAKE WATER DISTRICT AIR CONDITIONING, TORONTO, ON

The Enwave district energy system in Toronto can provide enough cooling for one hundred towers. The system operates by pumping cold water from the bottom of Lake Ontario throughout the buildings in the downtown core. The cold water cools the buildings through a series of heat exchangers. The water is then also used to service the drinking water needs of the city. The system eliminates 79,000 tonnes of CO2e per year, reduces electricity demand by 90 per cent compared to conventional systems, and reduces power demand by 61 MW.

Reference: Enwave, Deep Lake Water Cooling, www.enwave.com/dlwc.php, accessed October, 2008.

5.4 STRATEGY 4: COMBINED HEAT AND POWER

Co-generation or combined heat and power systems (CHP) are systems that simultaneously produce heat and power. In conventional power plants, where electricity is produced by combustion of fossil fuels or alternative fuels such as biofuels, efficiencies from the power generated typically range between 25 and 55 per cent; the remaining energy is lost to heat and the mechanical energy needed to drive the generator. In a CHP system the heat energy is recovered, increasing the overall efficiency to between 60 and 90 per cent depending on the application (RETScreen International, 2009).

The waste heat, delivered in the form of either steam or hot water, can be utilized for spatial heating and cooling (via chillers), water heating, process heating and cooling applications (RETScreen International, 2009). In such applications, a demand for the waste heat would need to be found in order to realise the efficiency benefits of co-generation and distances from the source should be minimized to reduce transportation losses and the costs of insulated pipe (Harvey, 2006). Unlike low temperature district energy systems, CHP systems require insulated piping thus making the distance from the source to the use very important, and separate heating and cooling pipes would be required. The importance of load diversity and high intensity to create an efficient district energy system means that CHP systems promote compact mixed use development while minimising energy waste, infrastructure and utility costs (Gilmour and Warren, 2008). General guidelines are that buildings should be at most 200 to 300 metres apart with no more than 1 to 2 kilometres from the largest buildings to improve their financial viability (Wilson, 2007). District energy systems can, however, effectively extend tens of kilometres even though losses increase further from the energy source (Harvey, 2006). Some general costing information of district energy components is presented in Table 5.1.

TABLE 5.1
CONSTRUCTION COSTS FOR COMPONENTS OF COMMUNITY ENERGY SYSTEMS

Free-standing building to house boiler plant	\$500,000 - \$1,000,000+
Natural gas hot water boiler plan, 4 MW	\$500,000 - \$1,000,0000
Wood waste hot water/steam boiler plan, 1.5 MW	\$1,000,000 - \$1,500,000+
Hot water distribution piping, existing development	\$800 - \$1,400 / metre
Building connections, existing properties	\$15,000 - \$90,000 / building
Engineering, construction management & other project administration	10% - 15% of capital cost

Source: *Wilson, 2007.*

ESTIMATION GUIDELINE 5.7
BUILDING INTEGRATED COMBINED HEAT AND POWER

For CHP fuelled by natural gas:

$$\text{Annual GHGs saved} \approx (0.00262 \cdot \text{Grid Emission Factor} - 0.765) \cdot P \cdot f$$

Where "P" is the power rating of the CHP unit (typically between 30 kW and 250 kW), and "f" is the fraction of hours per year the system operates (typically this is somewhere between 2,080 and 8,760 hr). The grid emissions rate of the given jurisdiction (province) is represented in tonnes of CO_2e/GWh and needs to be greater than 292 tonnes of CO_2e/GWh to provide GHG savings.

Reference: *US EPA, 2009. CHP Emissions Calculator. http://www.epa.gov/chp/basic/calculator.html, accessed April 2009.*

Based on typical performance parameters of microturbine CHP (Table 5.2) the cost of reducing one ton of CO_2e by this technology is between \$2,400 and \$12,900 (US).

TABLE 5.2
TYPICAL PERFORMANCE PARAMETERS OF MICROTURBINE CHP*

Cost & Performance Characteristics	System 1	System 2	System 3
Nominal Electricity Capacity (kW)	30	65	250
Compressor Parasitic Power (kW)	2	2	8
Package Cost (2007 $/kW)	$1,290	$1,280	$1,410
Total Installed Cost (2007 $/kW0	$2,970	$2,490	$2,440
Electric Heat Rate (Btu/kWh), HHV	15,075	13,891	13,080
Electrical Efficiency (percent), HHV	22.6%	24.6%	26.09%
Fuel Input (MMBtu/hr)	0.422	0.875	3.165
Required Fuel Gas Pressure (psig)	75	75	75
CHP Characteristics			
Exhaust Flow (lbs/sec)	0.69	1.12	4.7
CT Exhaust Temp (degrees F)	530	592	468
Heat Output (MMBtu/hr)	0.17	0.41	1.2
Heat Output (kW equivalent)	50.9	119.5	351.6
Total CHP Efficiency (percent), HHV	63.8%	71.2%	64.0%
Power/Heat Ratio	0.55	0.53	0.69
Net Heat Rate (Btu/kWh)	7,313	5,796	6,882
Effective Elecrical Efficiency (percent), HHV	46.7%	58.9%	49.6%
*For systems commercially available in 2007			

Source: EEA/ICF, Table 1 from the US EPA, 2008.

5.5 STRATEGY 5: INTEGRATED COMMUNITY ENERGY SYSTEMS

Applying a compendium of the solutions in this guide at a community level can lead to overall efficiencies and cost savings. Systematic and appropriate infrastructure and land use planning could reduce emissions by 65 Mt, or 20 percent of the national reduction target of 330 Mt by 2020 (DSMWG, 2009). Integrated community energy systems could result in GHG reductions of over 43 percent (DSMWG, 2009).

Decentralizing local energy production can increase reliability and efficiency and minimize transport losses by up to 15 per cent.

A community can provide a sufficient economy of scale for infrastructure investment, opportunities for integrated resource recovery. This scale takes advantage of load diversity (thus maximizing the use of energy producing infrastructure), opportunities of synergies, and allows for a mix of different energy sources to be employed (thus providing a more reliable local energy system).

By integrating land use and transportation planning, management of solid waste, liquid waste, potable water, energy systems and other GHG reduction strategies, the city's infrastructure could become more efficient and able to maximise the recovery of "value" from waste resource streams providing a new net revenue source for the municipality (Slater, 2009). Figure 5.1 shows several energy generation opportunities for different community waste streams.

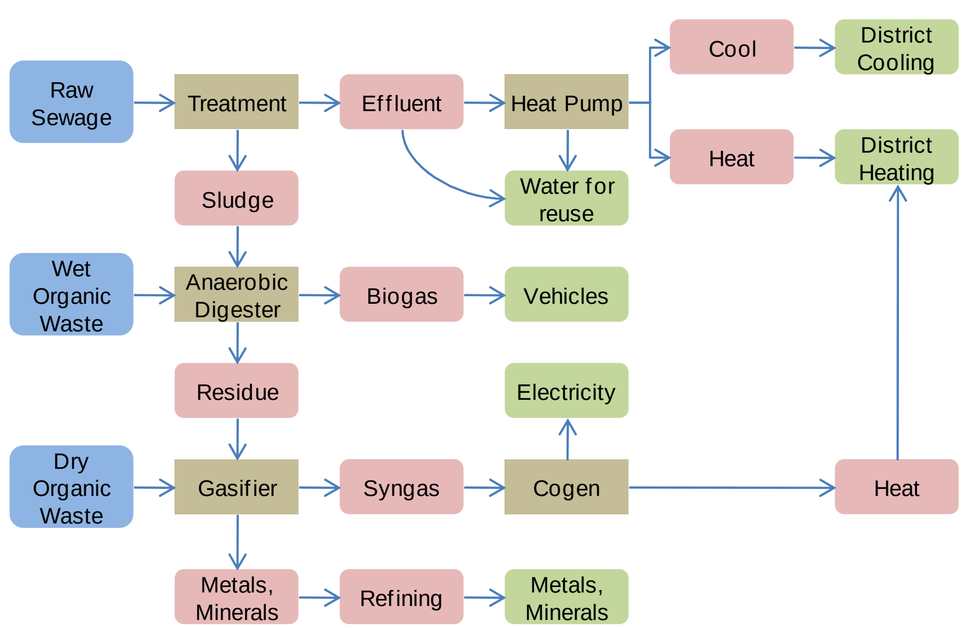

Figure 5.1 Integrated Resource Recovery Potential from Municipal Waste

Adapted From: Figure 1, IRM concept Design Aqua-Tex Scientific Consulting Ltd. (2008).

An independent study of integrated resource recovery conducted in 2008 for the Province of British Columbia found that a 20 to 25 per cent reduction of GHG emissions could be achieved for a region with a population 350,000. Energy recovered from waste could heat 30 per cent of the community's homes and electricity could power at least 10 per cent of the community's homes. Enough biofuels could also be recovered to run at least 10 per cent of the vehicles in the community (Aqua-Tex Scientific Consulting Ltd., 2008; Slater, 2009).

The same land use planning principles that reduce transportation emissions – density, diversity and site design – hold true for the planning of a community energy system. Compact development alone can reduce both transportation and building energy use by between 20 to 40 per cent (Ewing, 2008).

Building mix, spatial distribution, roof areas, infrastructure, occupancy, and material, waste and energy flows are all characteristics that could be manipulated to create a more energy efficient and energy producing form. Spatial data management using GIS can be a helpful approach to collect energy use data, identify opportunities for community energy systems, and analyze spatial issues.. This helps in identifying symbiotic relationships, identifying constraints, and supporting strategic planning and decision making.

A combination of heat sources, such as geothermal loops, treated wastewater, methane gas, waste heat from industry, refrigeration plants or ice rinks on a community scale, could be connected to the same system and leveraged to become important energy sources (Wilson, 2007). In such a way, district energy systems can also maximise the efficiency of renewable energy infrastructure. Since systems are often sized to deliver energy for peak loads, other users can benefit from excess capacity in off-peak times. In ground source heat exchanges, heating and cooling loading can be balanced by connecting buildings with converse load profiles that allows the temperature of the ground to remain more stable during the long term, achieving more reliable, efficient, and less costly loops.

In existing developments, clusters of buildings can be identified to take advantage of untapped potential for renewable technology, such as solar, wind, geothermal, hydro, bio-fuel and cascading of energy. Official community plans could strategically locate certain building types and land uses in existing neighborhoods and, through the process of intensification, to build an efficient community energy system that reduces the overall building, energy and transportation-related GHG emissions.

Examples of strategic planning could be locating an ice arena or grocery store in a residential neighborhood. While the energy needs of a residential development is heating-dominated in the winter, the arena and grocery store require significant refrigeration and reject heat in the winter. Therefore, such buildings would be ideal for the service of a district geothermal system. Similarly, a school which is unoccupied in the summer could be an energy producer for the community if the roof is equipped with solar thermal collectors to provide hot water and solar PV to provide electricity during the electricity intensive summer months.

CASE 5.12
WHISTLER ATHLETES VILLAGE, WHISTLER, BC

The municipality of Whistler partnered with Terasen Energy Services to develop a district energy system for the Whistler Athlete's Village. The system makes use of a variety of low grade heat sources, ranging in temperature from 5°C to 45°C, upgraded with heat pumps in every building. The low-grade heat sources allow the system to use un-insulated distribution pipes. The primary sources of heat are from closed and open loop geo-exchange, landfill gas, and wastewater treatment plant effluent.

Reference: McDonald, N and V, William. (2008), Whistler Athletes Village District Energy Sytem (DES) Heat Extraction from the Whistler WWTP. s.l.: Presentation, 2008.

CASE 5.13
SOUTHEAST FALSE CREEK, VANCOUVER, BC

A Neighbourhood Energy Utility (NEU) was established to provide both water and space heating to all new buildings in the community of Southeast False Creek. The system is designed to use a variety of waste energy opportunities that would not be available at the individual building scale. Approximately 70 per cent of the heating demand is supplied from sewage heat recovery from untreated sewage. The heat is extracted via a heat pump with a coefficient of performance of 3.5 to upgrade the low grade thermal energy to 65°C. The remaining demand is supplied by solar thermal collectors and by backup high efficiency natural gas boilers. Cooling is provided using air source heat pumps that reject heat into the parkade eliminating the need for roof top cooling towers. Overall, GHG emissions are 50 per cent less than conventional energy sources. The NEU currently services 585,000 m^2 of development, 85 per cent of which is residential, on an 80 hectare site. Future plans are to extend the system to 1.2 million m^2 of floor space.

References: City of Vancouver Sustainability Group. (2008), Neighbourhood Energy Utility. City of Vancouver. http://vancouver.ca/sustainability/building_neu.htm. accessed July 28, 2009.
NRCan, Natural Resources Canada (2009a) False Creek Neighbourhood Energy Utility. Canmet Energy. http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/buildings_communities/communities/publications/false_creek.html. accessed July 28, 2009.

Landscaping can also be used for passive cooling and to reduce the urban heat island. In addition, the repair of aging infrastructure or the construction of new transit lines could yield opportunities to install a district energy system. For more information on urban landscaping, see Section 3.1.4.

In Toronto, the Mayor's Tower Renewal Project aims to retrofit 1,000 aging post-war apartment buildings to become more energy efficient. At the same time, communities could benefit from the redevelopment of the surrounding green spaces (with public spaces and mixed uses) and connections to district renewable energy systems (City of Toronto, 2008). Many of these towers are clustered and can form community energy hubs through district energy systems that could reduce carbon emissions by 75 per cent of their current output (City of Toronto, 2008).

CASE 5.14
REVELSTOKE COMMUNITY ENERGY SYSTEM, REVELSTOKE, BC

The Revelstoke Community Energy Corporation provides a 1.6 kilometre-long low temperature district energy system. The system delivers steam to local industry and hot water for space and water heating to buildings. Energy is produced by the burning of wood waste from nearby Downie Mills. The system is a new revenue source for the city, displaces 45,000 GJ of fossil fuel energy, has saved the saw mill from closure, improved air quality and reduces GHG emissions by 3,700 tonnes annually.

Reference: NRCan, Natural Resources Canada (2009b) Revelstoke Community Energy Association. Canmet Energy. http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/buildings_communities/communities/publications/revelstoke.html. accessed July 16, 2009.

For new developments, energy use can be optimized through strategic site planning. New communities could be planned to maximize solar access for active solar collectors, passive day lighting, heating and cooling. Urban form factors that affect the potential to construct low-energy buildings include the following.

- The street pattern would allow most buildings to be oriented for optimal solar access (within 25 degrees of south).
- The natural terrain can provide wind shelter and allow for closer spacing of taller buildings while maintaining solar access.
- The dimensions of the urban canyon, which relates the building heights and road width, determines the availability of direct sunlight and air flow. Some commercial and industrial buildings that have a cooling dominant load or unconditioned spaces, such as parkades, could be located in shaded areas.
- The location of vegetation can reduce wind, heat island and cool buildings.
- Municipal regulations could determine building form, lot dimensions, setbacks, heights, etc., that affect solar access and landscaping.

Site planning techniques for optimal solar access can be found in Chrisomallidou (2001) and Erley, et al. (1979). A further example application is given in Case 8.2; Bed Zed, a master planned community in a suburb of London, England, was developed to maximise passive design and was able to achieve an 81 per cent reduction in energy use for heating, and a 45 per cent reduction in electricity use.

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CHAPTER 6: MUNICIPAL SERVICES

(E. Mohareb)

Municipal services provide energy and GHG savings opportunities over which cities may exercise direct control. How cities manage their wastes, maintain their water infrastructure or plan their urban canopy has an impact on their emissions inventories.

Material and nutrient flows through cities and towns are key determinants of local economies. Through the extraction and processing of raw materials to the sale of finished goods, manufacturing economies supply an economic influx into communities. Inevitably, waste products result from the numerous stages of manufacture, from initial processing to final sale. From processing and extraction residues, to packaging materials and finished goods, proper disposal of waste is an ongoing concern for municipalities. The method of disposal will contribute either directly (e.g., methane emissions from landfills) or indirectly (e.g., offsetting emissions from material reuse) to a municipality's GHG inventory. The best waste management practice needs to be assessed based on availability of resources and infrastructure.

Urban water systems also contribute a significant proportion of municipal (corporate) electricity demand and, hence, GHG emissions, through the treatment and pumping of water / wastewater. By addressing demand and treatment energy efficiency, it is possible to lower these emissions.

From the sequestration perspective, a number of options exist within municipalities to capture carbon emissions. It is possible to quantify the carbon capture benefits of urban green spaces, such as parkland, street trees and forests. In addition to the energy services provided through evaporative cooling and shading, plants convert CO_2 to biomass through photosynthesis. The fertilization of plants, specifically food crops, in greenhouse environments using the emissions from clean burning fuels represents an offset of fossil sources of heat and carbon. Some regions in Canada also have the local capacity for geological carbon storage in saline aquifers and depleted oil and gas fields. Finally, municipalities have the option of purchasing carbon credits to offset corporate projects where GHG emissions cannot be avoided.

Waste Management

Waste management emissions are commonly perceived as the "low-hanging fruit" of reductions strategies (see Section 7.3). Many of the mitigation technologies are well established (e.g., methane capture from landfills) and have a relatively low cost per unit of GHG emissions avoided. The greatest source of GHG emissions from waste management comes from disposal in sanitary landfills; methane gas, a potent GHG (with a global warming potential of 25 when amortized over a century; IPCC 2007), is produced during the degradation of organic material under the anaerobic conditions within a landfill. This is the most common practice in Canada, with 95 per cent of disposed waste in 2000 being deposited in landfills. Incineration is used to eliminate the remaining 5 per cent (Statistics Canada, 2005).

Additionally, 95 per cent of 2007 national GHG emissions from waste were from landfill operations, with the remaining coming from wastewater treatment (4%) and incineration (1%).

Landfills

The production of methane, as well as other components of landfill gas (LFG), by anaerobic bacteria follows the general chemical reaction from Tchobanoglous et al. (1993) given below. Organic matter in this case represents food, paper, lumber and other waste stream components derived from biological materials.

$$\text{Organic matter} + H_2O \rightarrow \text{biodegraded material} + CH_4 + CO_2 + \text{other gases}$$

The methane (CH_4) content of landfill gas is estimated to be between 45 to 60 per cent on a dry volume basis. While CO_2 is also a component of LFG (40-60%), it is produced through the degradation of materials that are biogenic in nature (e.g., from plants that have fixed CO_2). As a result, it is assumed that the net CO_2 emission from landfill gas is zero (neglecting emissions related to extraction of raw materials, fabrication and consumption of goods). Other gases, including nitrogen and sulphur compounds, constitute a relatively small fraction of LFG.

To understand what can be achieved through better management of solid waste, the components of waste streams must be examined. Statistics Canada (2005) provides national data on the composition of residential waste, seen in Table 6.1. Degradable materials, including organics, paper, lumber and animal wastes, account for more than 66 per cent of this waste. Increased diversion will result in reductions in GHG emissions.

TABLE 6.1
CANADIAN RESIDENTIAL WASTE COMPOSITION

Sector	Percentage Total Waste
Organics	40%
Paper	26%
Plastics	9%
Metals	4%
Glass	3%
Other (including textiles, lumber, animal wastes, tires)	18%

Source: Statistics Canada, 2005

As a guide for non-residential waste, Table 6.2 summarizes the composition of waste generated by this sector in the Greater Toronto Area (GTA). Compared to residential waste, the percentage organic content is lower, but paper content is higher.

TABLE 6.2
GREATER TORONTO AREA NON-RESIDENTIAL SOLID WASTE

Sector	Percentage Total Waste
Organics	19%
Food	9.5%
Yard waste	1.5%
Wood waste	7%
Paper	42%
Plastics	9.5%
Metals	10.5%
Glass	1%
Construction & demolition	7%
Other (including textiles, lumber, animal wastes, tires, hazardous waste)	7%

Source: Toronto City Summit Alliance, 2008.

Estimation Guideline 6.1 may be used to calculate GHG emissions from landfills, using IPCC (1996) methodology. An example calculation of DOC is provided in Chapter 2, using waste composition from the GTA.

ESTIMATION GUIDELINE 6.1
LANDFILL GAS EMISSIONS

$GHG_{landfill} = 7.56 * M_{landfill} * DOC * (1 - f_{rec})$

Where: $M_{landfill}$ = waste deposited in landfill (metric tonnes)
f_{rec} = fraction of methane recovered
$DOC = \sum_i W_i f_i$; Degradable Organic Carbon,

The coefficient 7.56 is calculated from the original equation found below:

$$GHG_{landfill} = 21 * M_{landfill} * L_o(1-f_{rec})(1-OX)$$

Where OX = Oxidized fraction (assumed to be 0.1)

$$L_o = {}^{16}/_{12}\ MCF * DOC * DOC_F * F$$

And MCF = CH_4 correction factor (equal to 1.0 for managed landfills);
DOC = degradable organic carbon (t C / t waste);
DOC_F = fraction DOC dissimilated (default range 0.5 to 0.6; assumed = 0.6);
F = fraction of methane in landfill gas (range: 0.4 to 0.6; assumed equal to 0.5);
16/12 = stoichiometric ratio between methane and carbon.

From Kennedy et al., 2009a

Examining the overall waste picture, it is clear from Table 6.3 that non-residential waste diversion is below that of residential (18.7 per cent versus 28.8 per cent diversion rate). This landfilled waste represents a valuable energy and materials resource, as well as an opportunity for reducing GHG emissions.

TABLE 6.3
COMPARISON OF RESIDENTIAL & NON-RESIDENTIAL WASTE

	2004	2006
Disposed	25,226,765	27,249,178
Residential	8,961,583	9,238,376
Non-residential	16,265,183	18,010,801
Recycled	7,112,735	7,749,030
Residential	3,363,803	3,744,843
Non-residential	3,748,934	4,004,187
Organics	1,519,601	2,006,461
Cardboard/boxboard	1,332,774	1,471,315
Newsprint	1,254,678	1,261,891

Source: Adapted from Statistics Canada, 2006.

Other Sources of GHG Emissions from Waste

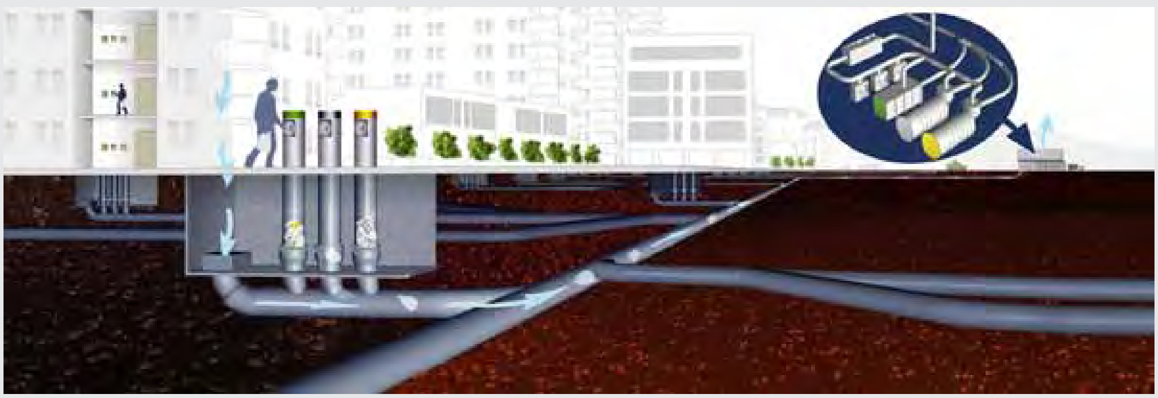
In addition to landfill gas, GHG emissions are released during waste collection and landfill operations. For the City of Ottawa, Mohareb et al. (2008) found that GHG emissions associated with waste handling are predominantly from LFG production, while collection of waste is relatively minor (roughly 8 per cent of base case gross emissions, estimating that waste trucks travel roughly 35 kilometres one-way to the landfill site).

The City of Toronto's 2004 emissions inventory shows that GHG emissions from transporting waste constitute less than 10% of the waste-related emissions (ICF, 2007), even though much of the city's solid waste was transported to landfill sites in Michigan over 350 kilometres away. When compared with total community GHG emissions, the percentage attributable to waste transport was just 0.1%, while LFG generation was responsible for 1% of the total.

It should be noted that GHG reductions from the elimination of methane emissions from landfill operations (through LFG capture or alternative management strategies, such as incineration) will lead to a greater proportion attributable to collection. Case 6.1 presents one solution designed by the Swedish firm Envac to address collection emissions.

CASE 6.1
ENVAC AUTOMATED WASTE COLLECTION SYSTEM, WEMBLEY CITY, LONDON

Envac has developed a system which reduces the distance driven by waste collection vehicles. Using an automated, fully-enclosed vacuum system, solid waste is transported to a central collection station for transport to final destination (landfill, composting, etc.). Waste collection vehicle operation is reduced, resulting in reduced transportation-related GHG emissions. In addition, source separation is improved, increasing landfill diversion rates and reducing GHG emissions directly (by reducing the amount of degradable waste deposited in landfills) and indirectly (through reduced material embodied energy requirements from recycling). Collected wastes can be further sub-divided into an organic stream to be digested for biogas production (representing a potential for waste-to-energy production). An installation has recently been completed at Wembley City, London. According to one analysis provided by Envac, installations costs were comparable to traditional UK infrastructure, while annually operating costs were reduced by nearly 45 per cent. The Wembley installation saves 360 tonnes of CO_2e per year.



Visualisation of Envac Collection System
Source: Wacker, 2010.

Reference:

1. Envac (2008). Press – Quintain and Envac launch the UK's first underground vacuum waste system at Wembley City. Available http://www.envac.net/frameset.asp. Accessed November 7, 2008.
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6.1 STRATEGY 1: INCREASED SORTING & RECYCLING

Not all municipalities include the emission reductions derived from recycling in their GHG inventories. By recycling materials, and offsetting the demand for virgin materials, significant energy savings are realized. A study by the U.S. EPA demonstrates that lifecycle emission reductions are of the order one tonne of CO_2e per tonne of material recycled (Table 6.4).

TABLE 6.4
NET GHG EMISSIONS FOR VARIOUS RECYCLED MATERIALS

Recycled material	Emissions versus virgin materials ($t\ CO_2/t$ of material)
Aluminum cans	-4.11
Steel cans	-0.54
Glass	-0.09
HDPE	-0.42
LDPE	-0.51
PET	-0.47
Corrugated cardboard	-0.94
Office paper	-0.87
Carpet	-2.18
Personal computers	-0.69
Dimensional lumber	-0.74

Source: Adapted from EPA, 2006.

In municipalities that source or process these materials locally, emission reductions will be realized on their industrial inventory figures. Otherwise, while lifecycle emissions are reduced and valuable materials are diverted from landfills and utilized, impacts on municipal GHG emissions will be minimal.

6.2 STRATEGY 2 - ORGANIC WASTE DIVERSION

6.2.1 WASTE SEPARATION

If organics are segregated into a separate waste stream, such as through a source-separated organic (SSO) system, controlled anaerobic digestion of these wastes can produce two useful by-products: compost and biogas. Finnveden et al (2005) suggest compost compost can displace artificial fertilizers (which are themselves energy and GHG-intensive). In addition, the production of compost reduces the potential for LFG production by reducing the quantity of material degraded under anaerobic conditions in landfill. Some municipalities have successfully implemented sophisticated waste separation systems, such as in Sydney, Australia (Case 6.2).

CASE 6.2
SYDNEY WASTE DIVERSION

Using a sophisticated source separation system, Sydney is diverting approximately 70 per cent of its municipal solid waste from landfill. In addition, an anaerobic digestion process produces methane from degradable organic carbon that, in turn, is converted to organic fertilizer (30,000 tonnes per annum). The methane is combusted to produce the electricity that powers the separation facility. In addition, the facility is able to extract all process water needs from the treated waste. Sydney's waste diversion system saves 210,000 tonnes of CO_2e per year.

Reference: Climate Leadership Group (2008). Best Practices – Waste Management, Sydney, Australia. Available http://www.c40cities.org/bestpractices/. Accessed November 7, 2008.

6.2.2 ANAEROBIC DIGESTION

Multiple treatment options exist for the diversion of organic waste from landfills. Digesters have been installed in a number of municipalities that present the opportunity of methane collection, which can then be used to produce electricity. Wastewater sludge stabilization through anaerobic digestion provides an additional source of biogas. Case 6.3 describes operations of a wastewater treatment facility in Malmö, Sweden, where organic waste and wastewater sludge are co-digested to produce biogas for buses.

CASE 6.3
WASTEWATER SLUDGE TREATMENT, MALMÖ, SWEDEN

Malmö has implemented a program to recover the nutrients and energy from wastewater. An anaerobic digestion facility, which was initially used to stabilize wastewater sludge, was expanded in 2002 to increase capacity and allow for the treatment of source separated organics. (It has been illegal to deposit organic waste in landfills in Sweden since 2005). Biogas from anaerobic digestion is produced for vehicle use, offsetting CO_2 from the burning of petroleum products and CH_4 emissions from the digestion of sludge. Additionally, a phosphorous and nitrogen recovery system is in place, where phosphorous is then utilized for agricultural use.

Digesters (left) from La Cour Jansen et al. (2004) at the Sjölunda Wastewater Treatment Plant in Malmö (right) from VA SYD (2010).

References:

1. La Cour Jansen J, et al., 2004. Digestion of sludge and organic waste in the sustainability concept for Malmö, Sweden. Water Science and Technology, **49 (10)**, 163-169.
2. Davidson Å, et al., 2007. Anaerobic digestion potential of urban organic waste: A case study in Malmö. Waste Management and Research, **25** (2), 162-169.

The energy production potential of organic wastes has also been of increasing interest in Canada, with municipal SSO diversion becoming commonplace. Industrial, commercial and institutional (IC&I) producers of organic waste can also contribute to a concerted effort to increase organics diversion and improve the potential yield of biogas. An example is given in Case 6.4, where a business zone spreading across municipalities has developed a plan to exploit its waste resources.

CASE 6.4
ANAEROBIC DIGESTION OF ORGANIC WASTE, GREATER TORONTO AREA

"Partners in Project Green" within the Pearson Eco-Business Zone in the Greater Toronto Area has recognized the value of their organic waste resource. Over 200,000 tonnes of organic waste is produced each year, of which 100,000 tonnes are estimated to be deposited in landfills. A feasibility study estimates 80,000 tonnes of CO_2e could be reduced through diversion from landfills and processing in anaerobic digesters. Additional benefits include:
A new locally-sourced, base load energy resource to be converted to either electricity, heat for districting heating systems or both (with every 1 kWh electricity generated, 1.1 kWh of thermal energy can be recovered)

Employment from construction and operations of digester facilities and increasing local technical expertise that accompanies this job creation
Creation of carbon credits in the context of a national / international trading scheme

Reference: Philip R, 2009. Partners in Project Green – Pearson Eco-Business Zone – Biogas Feasibility Study. Final Report.

6.2.3 COMPOSTING

Residential composting units provide a less capital-intensive alternative to the processing of organics at a central facility. Though the option to produce and capture biogas from anaerobic digestion is lost, methane emissions are reduced due to the generally aerobic conditions in backyard composting. However, it is important that these composters remain small in size; A study by Beck-Friis et al. (2000) showed methane emissions for a small (1 metre radius) compost heap to be roughly 8,100 $mg/m^2/day$, which is 25 per cent that of a larger (2.5 to 3.0 m radius) heap. This compost could then be used as fertilizer, reducing the need for artificial fertilizers.

Large-scale, open composting operation models are presented by the EPA (2006). In their study, they assume that no methane emissions result from well-managed centralized composting facilities. Net GHG emissions from these operations (after considering energy usage from transportation and turning of compost and carbon stored in humus) were roughly -0.06 tonnes of CO_2e per tonne of organics. Hobson et al. (2005) noted that there is the potential for anaerobic zones to exist in windrow composting operations even with regular turning, suggesting that a more conservative assumption should be used. For example, IPCC (2006) use a default emission factor from composting of 0.1 tonnes of CO_2e/tonne of wet compost deposited.

6.3 STRATEGY 3: WASTE INCINERATION & GASIFICATION

As stated earlier, the second most common form of waste disposal in Canada is incineration, handling 5 per cent of all waste (Statistics Canada, 2005). While concerns over air emissions (NO_X, SO_X, polychlorinated dioxins/furans, lead, mercury, etc.) have sparked public opposition to incineration, the process is capable of achieving lifecycle CO_2 emission reductions (Ruth 1998; EPA 2006).

Some of the negative perception of incineration stems from historical practices when facilities operated with little-to-no pollutant controls. Psomopoulos et al. (2009) describe a time where New York City had over 18,000 residential incinerators in operation, the ecological impacts of which can still be measured in soil cores from Central Park. Today, the average emissions of modern incineration facilities fall well within federal/provincial standards for dioxins and furans, SO_2, mercury and other pollutants. While there remains some public concern over the long term health effects of extremely low levels of dioxins and furans, environmentalists are also worried that the demand for high Btu wastes, such as plastics and paper that facility operators say are needed to run incinerators in a cost effective manner, could further disrupt the already volatile markets for recyclables.

Assuming a waste-to-energy (WTE) system is in place, there is potential for indirectly reducing GHGs in three ways:

1. Electricity generation from fossil sources is displaced by electricity produced from waste combustion.
2. WTE facilities recover metals for recycling, reducing process energy required to extract and process virgin materials.
3. WTE diverts wastes from landfill, reducing the generation of landfill gas (LFG) emissions.

Though CO_2 emissions are produced during the combustion process, only non-biogenic sources should be considered for climate impacts (consistent with IPCC methodology); CO_2 emissions from burning paper products, lumber or food wastes are not counted. However, CO_2 emissions from non-biogenic sources (such as plastics) are counted (as well as N_2O emission from the combustion process) and must be weighed against any GHG emission reductions achieved.

Table 6.5 shows net GHG emissions for various materials. The emission reductions achieved by incineration are lower than those achieved through reuse or recycling, but could be considered in markets where recycling may not be economical. Additionally, with proper diversion of plastic wastes, emissions totals will be more favourable.

TABLE 6.5
NET GHG EMISSIONS FROM COMBUSTION (MASS BURN) OF VARIOUS MATERIALS

Combusted Material	Net Emissions ($t\ CO_2$/t of material)
Aluminum cans	+0.02
Steel cans	-0.47
Glass	+0.01
HDPE	+0.33
LDPE	+0.33
PET	+0.36
Corrugated cardboard	-0.18
Office paper	-0.17
Carpet	+0.16
Personal computers	-0.06
Dimensional lumber	-0.21
Food waste	-0.05

Source: Adapted from EPA, 2006.

Combustion facilities are generally placed under two broad categories: mass burn and refuse-derived fuel (RDF) (EPA 2006). Mass burn facilities generate electricity and steam from the direct combustion of waste, while RDF facilities process waste to some degree (ranging from simple separation of incombustible materials to gasification of waste) to provide a higher quality fuel for the combustion process.

One Canadian company, Plasco Energy Group Inc., is currently marketing a waste gasification system for a WTE application. Through the gasification and refinement of solid waste, the Plasco system is able to transform it into valuable materials (sulphur, construction aggregate, potable water and energy). According to the company website, the electricity generated produces nearly 60 per cent fewer CO_2 emissions when compared to coal power generation (Plasco Energy Group, 2008).

6.4 STRATEGY 4: METHANE CAPTURE

Landfill gas (LFG) contains methane, a powerful GHG. To prevent its release, numerous municipalities have installed LFG capture systems. Gases are collected through a network of piping and either flared or utilized for energy services (i.e. electricity generation). As of 2006, there were 52 LFG collection systems operating in Canada (Environment Canada, 2008). These collected roughly 314 kilotonnes of methane in that year, 28 per cent of the total generated (Table 6.6). Additional and expanded LFG capture systems could further reduce municipal/national GHG emissions.

TABLE 6.6
NATIONAL METHANE GENERATION & FATE FOR SANITARY LANDFILLS

CH_4 Generated	CH_4 Captured	CH_4 Released
1.12 Mt	28% (314 kt; 155 kt flared, 159 kt used for energy projects)	72% (810 kt)

Source: Environment Canada, 2008.

CASE 6.5
LANDFILL GAS COLLECTION, TORONTO, ON

The City of Toronto has taken the initiative in reducing GHG emissions from landfills. With the City's installation of a landfill gas (LFG) collection systems and the operation and energy sales from LFG electricity generation (using either steam turbines or reciprocating engines), CH_4 emissions have been dramatically reduced. Royalties paid to the city in return for providing exclusive rights to the LFG produced at the sites have helped cover the installation costs of the collection systems. The capital costs of the Keele Valley installations were $12 million for the gas collection system and $20 million for construction of power plant. Other benefits included odour management and reduction of the risk of explosion posed by subsurface methane.

References:

1. Lou Ciarduollo, 2009. Personal Communication, March 3, 2009.
2. Climate Leadership Group (2008). Best Practices, Toronto, Canada: C40 Cities. Available: http://www.c40cities.org/bestpractices/. Accessed November 7, 2008.

The U.S. EPA has conducted an analysis of three landfill conditions which affect lifecycle GHG emissions:

- landfill gas (LFG) generation
- creation of carbon sinks (not all the carbon captured by biogenic means is released into the atmosphere)
- displacement of fossil-fuelled electricity generation (in the case of energy production from LFG)

The studies producing these data assumed ideal conditions for degradation (i.e., sufficient moisture and nutrients). A summary of the resultant emissions from key organic materials is presented in Table 6.7. Landfill gas recovery operations are estimated to have an average efficiency of 75 per cent, and 10 per cent of methane is assumed to be oxidized (EPA, 2006).

TABLE 6.7
LIFECYCLE GHG EMISSIONS RESULTING FROM WASTE DISPOSAL IN LANDFILL (WITH & WITHOUT LFG COLLECTION)

Landfilled material	**Emissions from landfilling** (tonne CO_2e per tonne of material)		
	No LFG collection	LFG collection with flaring	LFG collection with energy
Corrugated cardboard	0.46	-0.07	-0.14
Office paper	1.17	0.27	0.13
Newspaper	-0.14	-0.33	-0.36
Yard trimmings	0.06	-0.13	-0.17
Dimensional lumber	0.02	-0.24	-0.28
Food waste	0.43	0.10	0.06

According to the results presented in Table 6.7, the benefits of LFG collection are apparent from a GHG perspective. However, it is shown that certain materials will always result in net emissions, even with a LFG collection system in place. These materials (i.e., food waste, office paper) would be best kept out of landfills through source separation.

6.5 STRATEGY 5: WATER DEMAND MANAGEMENT

The provision of water services (both drinking water and wastewater delivery, collection and treatment) are a significant contributors to municipal GHG inventories. Significant electricity use is incurred in powering pumping stations and treatment facilities. In the City of Toronto's 2004 inventory, water infrastructure was the third largest producer of GHGs, after buildings and landfills, at 159,000 tonnes per year (City of Toronto, 2007). Table 6.8 highlights some of the energy conservation opportunities and strategies for water and wastewater systems.

TABLE 6.8
ENERGY CONSERVATION OPPORTUNITIES FOR WATER & WASTEWATER SYSTEMS

- Leak check of all compressed air and vacuum lines (large water pumps use vacuum priming systems)
- Piping insulation audit to identify piping where the insulation is damaged, missing, waterlogged or inadequately thick
- Use of metering, sub-metering and energy management software to allow the analysis of consumption profiles
- Establishment of performance/procurement standards for buildings and equipment
- In plant district heating, identification of any opportunities to obtain waste heat from neighbours (which can, for example, free up digester gas from process uses to cogeneration use instead)
- Optimizing the use of any available digester gas (for cogeneration and plant district heating)
- Use of green procurement or sustainable procurement to support many of the above items. The overall objective of sustainable procurement is to improve the financial, environmental and social performance of an organization through its procurement activities and practices
- A control system to optimize the pumping of water (automatically selecting the most efficient pumps to meet water demand and shifting as much pumping as possible to off-peak hours through the use of water reservoirs)
- A comprehensive energy audit of the treatment processes, both for water and wastewater

Source: Region of Peel, personal communication.

ESTIMATION GUIDELINE 6.2
URBAN WATER SYSTEMS

Electricity required for water treatment and distribution is 580 kWh per ML; and wastewater pumping and treatment is 550 kWh per ML.

(Based on a study of the City of Toronto by Sahely and Kennedy (2006).)

The principal strategies for the reduction of these emissions are demand management and elimination of leaks. Case 6.6 provides one example of how good monitoring systems can save energy and water, while reducing GHG emissions. Water demand techniques can include provision of rain barrels for stormwater collection (which also reduces water pollution issues associated with water runoff and stormwater management) and local by-laws to curb usage.

CASE 6.6
IMPROVED WATER DISTRIBUTION SYSTEMS, TOKYO, JAPAN

Tokyo has implemented a sophisticated leak detection system, with a focus on same-day-repairs, which has resulted in a 50 per cent reduction in water wastage in one decade. The reduced energy requirements for water distribution has resulted in a reduction of CO_2 emissions of 73,000 tonnes annually.

Reference:

Climate Leadership Group (2008). Best Practices, Tokyo, Japan: C40 Cities. http://www.c40cities.org/bestpractices/. Accessed November 7, 2008.

6.6 STRATEGY 6: URBAN GREENERY

Urban greenery provides a diverse range of community benefits, from aesthetics to cooling services, and its existence serves both mental and physical needs. A municipality can enact policies to protect and enhance its green spaces, providing a carbon sink which could help it to become carbon neutral within its own boundaries.

Further to the many energy saving services they provide, urban forests and green spaces also sequester CO_2 during the growing season. Pataki et al. (2006) report gross sequestration due to urban trees in the U.S. at 22.8 Mt of carbon per year. Assuming a ratio of carbon to CO_2 of 1:3.67 (mass of C:mass of CO_2), this offset represents roughly 1.3% of total American emissions (EPA 2008). Pataki et al. provide a figure of 2 kg of carbon per square metre of canopy cover as a median value for the carbon sequestration by urban trees. Estimation Guideline 6.3 is based on this median value.

ESTIMATION GUIDELINE 6.3
URBAN FOREST CARBON SEQUESTRATION

GHGsequestered (tonnes CO_2) = 700 t CO_2 / km^2 * AUF

Where AUF is the area of urban forest (km^2) (Pataki et al., 2006, 2002-2102)

Green roofs can also play a role in GHG emission reduction. The emission reduction benefits of the green roofs are many, both direct and indirect. Green roofs sequester CO_2, provide evaporative cooling benefits, reduce solar absorption, mitigate heat island effects, and reduce thermal conductance through roofs (Saiz et al., 2006). As well, stormwater runoff can be reduced, providing further ecological benefits.

Regarding carbon sequestration, Getter et al. (2009) found that extensive green roofs provide the potential for removing significant amounts of carbon (375 grams of carbon per square metre). Their estimates for the City of Detroit suggest that covering the total roof area of industrial and commercial buildings with green roofs would result in the sequestration of over 55 kilotonnes of carbon per year, the equivalent of taking more than 10,000 SUVs off the road.

A number of urban centres (e.g., Port Coquitlam) are considering making green roofs mandatory on buildings of a specific size, which would lead to wider adoption and greater effect on heat island reduction (and associated cooling demand) and further sequestration of carbon.

6.7 STRATEGY 7: URBAN AGRICULTURE & CO_2-ENRICHED GREENHOUSES

The source of the food we eat impacts both the sustainability and food security of cities. Generally speaking, cities are not self sufficient for food due to the limited arable land within their boundaries. As a result, the produce and other groceries delivered to urban residents have accumulated many "food miles" prior to consumption. There has also been growing concern over the disposal of organic wastes in the urban environment, including wastewater biosolids, which represent a high concentration of nutrients that are not always fully utilized. Municipalities can develop greater consciousness of these issues through the promotion of urban agriculture, through urban greenhouses and open plots.

One approach to address these issues has been the development of the urban agricultural park. The concept of an agricultural park is one that has been very successful in Stockholm, Sweden. The Rosendal's Garden park incorporates the concept of "biodynamic" gardening, a practical demonstration of nutrient cycling in action (Rosendals Tradgard, 2008). Organic vegetables grown in plots and greenhouses on-site are sold to the public or served in the garden's cafeteria. Food waste generated from the kitchen and the cafeteria are transferred to a compost pile. This compost is collected the following year to provide soil enrichment for new crops. The agricultural park connects urban residents with food production, garnering a greater appreciation of energy inputs and resultant GHG emissions.

The food miles issue, while highly publicized, is not the sole indicator of food sustainability. The method of production dominates the lifecycle emissions associated with food; Weber and Matthews (2008) found that 83 per cent of the average American's food carbon footprint was attributable to food production. Transportation-related emissions contributed just 0.36 tonnes of CO_2e/year per household, or just four per cent of the 8.1 tonnes of CO_2e total. The research suggests that changes in agricultural practices and diet will lead to much greater reductions in GHG emissions associated with food. As Table 6.9 shows, there is significant variation in the carbon intensity of different food products.

TABLE 6.9 LIFECYCLE CARBON INTENSITY OF VARIOUS FOOD CATEGORIES	
Food product	**Carbon intensity** (kg CO_2 / kg)
Red meat	22
Cereals / carbs	3
Chicken / fish / eggs	6
Dairy	4
Fruit / vegetables	2

Source: Estimated from Weber & Matthews, 2008.

While organic agriculture (and other low impact techniques) and reduced-meat diets can lower emissions, the question of emissions from urban greenhouse vegetables should be addressed. Since many greenhouse operations require heat and CO_2 fertilization, a common practice has been natural gas combustion to provide these needs. A study by Huang and Bi (2007) demonstrated one approach to reduce these emissions by using flue gases from the combustion of animal wastes to fertilize crops. This system resulted in offsetting 320 tonnes CO_2 per year for a 1,000 m^2 area.

One organisation in the Netherlands has attempted to focus on the concept of "closed-loop" agriculture. The Innovatie Network (2008) has been developing strategies involving the cycling of waste energy and materials back into food production processes. A linear food system leaves waste and food production disconnected; Innovatie Network's concepts reuse wastes from compatible industries for food manufacturing (similar to biodynamic agriculture). One such example is the Happy Shrimp Farm, which is designed to use waste heat from a power plant in a shrimp aquaculture operation.

6.8 STRATEGY 8: GEOLOGICAL SEQUESTRATION

Sequestration of CO_2 in the context of emissions trading schemes has become an increasingly attractive option. As it may be difficult to completely eliminate all fossil fuel requirements, sequestration of CO_2 in suitable geological formations (coal beds, deep saline aquifers, deep ocean waters or depleted oil and gas fields) presents another means to reach carbon neutrality (Harvey, 2009). Large point sources of CO_2 emissions, including power stations or cement kilns, are prime candidates for geological sequestration and may be considered if a suitable reservoir exists.

NRCan (2008) lists a number of sites suitable for carbon capture and storage (CCS) in Atlantic, Central and Western Canada. National capacity for CO_2 storage in the formations listed are estimated to be roughly 18,000 Mt (Gunter et al., 1998). A study by Shafeen et al. (2004a; 2004b) suggests that in Ontario, the total reservoir potential of two major saline aquifers is roughly 730 Mt of CO_2 at a cost of between $7.50 and $14 (USD) per tonne. NRCan (2008) estimates that sequestered CO_2 emissions from suitable emissions sources for CCS could reach 600 Mt per year nationally by 2050 (40 per cent of national totals projected for that year).

Harvey (2009) describes the general process for carbon capture and storage (CCS) as follows:

1. CO_2 is separated from flue gases using one of four principle processes (absorption, adsorption, membrane separation, or cryogenic separation).
2. Compression/liquefaction of separated CO_2 is performed to facilitate transportation.
3. CO_2 is transported (by pipeline or ship) to its final reservoir.
4. CO_2 is pumped into the reservoir.

All of these processes require energy and, hence, impose an energy penalty; if the processes are fossil fuel driven they would also impose a carbon penalty. Electricity generation is of particular concern for all municipalities; Energy efficiency penalties for electricity generation stations range from 6 to19 per cent for natural gas plants, and from 5 to 13 per cent for coal-fired plants (Damen et al., 2006). When considering the global average efficiency of natural gas and coal are 34 per cent and 40 per cent respectively (IEA, 2008), these reductions can severely limit the viability of CCS.

There is great cost uncertainty associated with CCS technologies at present, which may deter municipal investment. One case cited by Harvey (2009) demonstrates this: the Saskatchewan-based Integrated Gasification Combined-Cycle power generation development was abandoned after its capital costs rose from \$3,778/kW to \$8,444/kw. Compared to the best currently available natural gas combined-cycle power plant at less than \$1,000/kW, it will be difficult to justify these costs. In the short term, it would seem as though geological sequestration will be difficult to commercialize.

6.9 STRATEGY 9: PURCHASING CARBON OFFSETS

One final strategy for reducing the carbon footprint of municipal services is to purchase emissions offsets. By purchasing offsets, a municipality funds a project that has been deemed to be less carbon-intensive than the status quo (e.g., renewable energy, reforestation). Sold at a “market price” per tonne of carbon or CO_2 reduced, the offset funding reduces some of the financial burden levied against project proponents for emission reductions. The offset purchaser can then claim the GHG reduction against their own carbon balance, moving it towards net zero. Case 6.7 illustrates this concept further.

CASE 6.7
CARBON OFFSETS, SAN FRANCISCO, CA

A particularly innovative carbon offset program can be found in the City of San Francisco. Typically, these offset projects benefit an external community, assuming they offer a more cost effective means to achieve emission reductions. The City of San Francisco has opted to create their own offset initiative which funds projects within the city, lowering the emissions attributable to its own urban system. It has begun setting up infrastructure for this program through contributions made to offset air travel of municipal employees. Residents have the opportunity to purchase offsets as well, benefiting projects within their own community, e.g., solar panel installations on low-income housing.

Reference: San Francisco Government, 2007. Press Room – Mayor Newsom Unveils First-Ever City Carbon Offsets to Fight Global Warming. http://www.sfgov.org/site/mayor_index.asp?id=72509. Accessed November 7, 2008.

Researchers at the David Suzuki Foundation (2009) have recommended that the following criteria be considered prior to purchasing carbon offsets:

1. Additionality – The offset-related project must be funded, at least in part, by the sale of the carbon credits.
2. Auditing – Unbiased, qualified, third-party auditors must validate and verify emission reductions.
3. Permanence – Emission reductions must not be reversible (such as the emission reductions credited to a forest which has burned down).
4. Unique Ownership – There must be no double counting due to unclear ownership rights.

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Part 3. *Getting to Carbon Neutral*

CHAPTER 7: COMPARISON OF STRATEGIES

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In developing this guide to reducing municipal GHG emissions, we have analyzed over 70 case studies, many of which have been presented as boxed examples throughout the text. As well as supporting the Estimation Guidelines, the case studies provide a substantial dataset for comparing the different strategies for reducing GHGs permitting us to assess the magnitude of GHG reductions achievable and the cost effectiveness of different strategies. The case studies also provide some qualitative insights into other benefits of the GHG reduction strategies, and the barriers that were overcome in their implementation.

7.1 CASE STUDIES

In selecting the case studies, we sought to establish leading-edge examples of initiatives that municipalities, cities or regions are taking to reduce GHG emissions, both in Canada and worldwide. The criteria for selecting case studies were discussed in Chapter 1.

Many candidates for case studies were known to the authors from past experience in researching and teaching the principles of sustainable urban design. Members of the Sustainable Urban Infrastructure Group conduct research on a wide range of topics including:

- green buildings (Zachariah et al., 2002; Dong et al., 2005; Saiz et al., 2006)
- urban water systems (Sahely and Kennedy, 2007; Racoviceanu et al., 2007)
- sustainable urban transportation (Kennedy, 2002; Kennedy et al., 2005)
- alternative energy systems (Kikuchi et al., 2009)
- sustainable neighbourhoods (Engel-Yan et al., 2005; Codoban and Kennedy, 2008)
- urban metabolism (Sahely et al., 2003; Kennedy et al., 2007).

Most student members of the research team had taken a course from the first author that applies the principles of industrial ecology to the design of sustainable cities (Kennedy, 2007). The course entails review of case studies as part of the design process.

The geographical extent of the chosen case studies is biased towards, first, Canada and, second, North America and Western Europe. The locations of the case studies are shown in Figure 7.1 – a screenshot of a Google map taken from the project website. Clearly it would be useful to include more examples from other parts of the world, especially Asia. (Suggestions for further infrastructure projects that substantially reduce GHG emissions can be submitted on the project website: www.utoronto.ca/sig/g2cn).

Information on each case study was first assembled from websites describing the infrastructure or other relevant literature. This information was then e-mailed to owners, designers or managers of the infrastructure, who were invited to verify, update and add to the case study descriptions.

Figure 7.1 Locations of Case Studies for the Getting to Carbon Neutral Project

Source: adapted from the project website at www.utoronto.ca/sig/g2cn

In some cases, we were able to obtain information only on energy saved, or vehicle kilometers reduced – and so we determined the GHG savings ourselves. If the case study involved electricity supply from a renewable source, we established the GHG savings relative to the conventional supply, based on provincial, state or national GHG intensity as documented, for example, by the Ontario Power Authority (OPA, 2007) or U.S. Energy Information Administration (EIA, 2006). In order to calculate GHG savings of the MetroLink express bus project in Halifax, we multiplied the number of round trips made in the year 2008 by the average daily GHG savings per rider based on using the private automobile. This method is assuming that all riders used the private automobile prior to using MetroLink. Similar assumptions are made by a number of other agencies in calculating and reporting GHG savings of other case studies presented in this report.

7.2 GHG SAVINGS

The GHG reduction strategies can be classified in terms of those that are minor, medium and major in scale. Table 7.1 provides the preliminary hypothesis for our work, indicating the scale of engagement for several example strategies (many of which have been included in this guide). Those with higher scales of engagement were generally expected to entail higher investment and produce higher GHG reductions (relative to strategies in the same row). We did, however, expect the research to find significant variation in the GHG reductions per dollar of investment between the strategies listed.

TABLE 7.1
PRELIMINARY CLASSIFICATION OF GHG REDUCTION STRATEGIES BY SCALE OF ENGAGEMENT

Category	Minor	Medium	Major
Transportation / Land use	High occupancy vehicle lanes; smart commute; car-pool networks; car share Natural gas vehicles (e.g., municipal buses) Bus rapid transit On-road bike lanes Bike share	Financial penalties to auto use (e.g., tolls, congestion charging) Incentives for use of low-emission vehicles. Light rail transit Segregated bike lanes	Pedestrianization of city centres Infrastructure for plug-in-hybrid electric vehicles Subways Bicycle highways
Buildings	Building energy retrofits Green roofs ENERGY STAR buildings	Improved building operations Photovoltaics Solar water/ air heaters Ground source heat pumps	Demolition & reconstruction with high energy efficiency green buildings
Energy	Vertical axis wind turbines	District energy systems Borehole or aquifer thermal storage	Nuclear power plants Concentrating solar generation
Solid Waste	Landfill methane capture Vacuum collection of solid waste	Solid waste incineration/ gasification	Increased recycling Greening supply chains

Water / Wastewater	Reduced demand through low flush toilets or low flow shower heads	Reduced demand through grey water systems	Anaerobic wastewater treatment plants
Carbon Sequestration	Planting of urban forestry Algal CO_2 Fixation	Residential scale urban agriculture in CO_2-enriched greenhouses	Industrial scale urban agriculture in CO_2 -enriched greenhouses Carbon offsets

Although there are exceptions, the information on GHG savings from the case studies generally supports the classification of strategies shown in Table 7.2. All of the case studies investigated in this work, except the four integrated sustainable communities (Cases 8.1 to 8.4), are listed in Table 7.2. In only 34 cases was it possible to establish the annual GHG savings achieved.

Most of the transportation / land use case studies are considered to be of a minor scale of engagement (Table 7.2). Where data were obtained, it generally supports the minor classification. The main exception is the Paris' bike share scheme, which is large enough in scope to save 18 kilotonnes of CO_2e per year, which is considered a medium scale of impact. Moving in the opposite direction, the buses on the Port Coquitlam hydrogen highway are only a small scale example of providing low-emission vehicles, and would be more appropriate in the minor category

The main disparity in the transportation projects lies with the light rail and subway projects. The classification scheme in Table 7.1 recognizes that the subway mode is a higher order form of public transit, with higher capacity and usually greater expense. The GHG savings for the Calgary LRT case are, however, much greater than for the Rennes subway line. The Rennes subway case covers just one single line in a relatively small city. The Calgary case includes the whole LRT system, which is a quasi-regional rail system serving the outer parts of the city.

GHG savings in the buildings category are generally smaller than those in the transportation category, as might be expected (Table 7.2). Only in the case of major demolition of a housing estate and reconstruction with energy efficient buildings are GHG savings over 10 kilotonnes of CO_2e per year realized. The magnitude of the savings are found to be as expected, with perhaps only the building integrated PV system on Coney Island classified at a scale too high.

GHG savings for all of the energy supply projects were determined and, again, were generally close to expectations (Table 7.2). The Okotoks, Alberta, BTES system is relatively small (serving only 50 houses) and could be moved to the minor category; its GHG savings are similar to those of the large wind turbine in Toronto.

In only a few of the municipal services cases (waste, water and sequestration) were GHG savings established. Some of the projects may be out of place. For example, the methane capture case from Toronto was for a large landfill, so should likely be elevated from the minor scale. The doubling of Chicago's tree canopy is also a large undertaking, which may save as much as 170 kilotonnes of carbon per year.

Overall, however, the classification scheme in Table 7.1 is reasonably well supported by the data from the case studies.

TABLE 7.2
CASE STUDIES INVESTIGATED IN DEVELOPING THIS GUIDE (INCLUDING ANNUAL GHG SAVINGS (KT CO_2E) WHERE KNOW)

Category	Minor Projects	GHG savings
Transportation / Land use	Bus Rapid Transit (Vancouver) Bus Rapid Transit (Curitiba) Quality Bus Corridor (Dublin) MetroLink: Express Bus (Halifax) Bike Share (Paris) Bike Share (Barcelona) Bike Campaign (Whitehorse) Advanced Transit Pass (London) Realtime Information (Portland) Timed Transfer System (Edmonton) Clean Fuel Taxi (New York City) High Occupancy Vehicle Lanes (Seattle) High Occupancy Toll Lanes (Minneapolis) Carshare (Zipcar) Guaranteed Ride Home (Albaquerque) Pay As You Drive (Australia) Location Efficient Mortgages (Chicago) Parking Cash Out (California)	1.8 kt – – 1.125 kt 18 kt 1.92 kt 0.0045 kt – – – – – – – – – – 0.24 kt
Buildings	Green Roof (California) Heat Recovery in Restaurant (Toronto)	– 0.0075 kt
Energy	Small Hydro (Cordova Mines) Urban Wind Power (Toronto) Vertical Axis Wind (Liverpool)	0.06 kt 0.38 kt 0.0014 kt
Solid Waste	Methane Capture (Toronto) Automatic Vacuum Waste Collection (Hammarby)	– –
Water / Wastewater	Improved Water Distribution System (Tokyo) Rain Barrel Distribution (York Region)	– –
Carbon Sequestration and Offsets	CO_2 Sequestration using Bacteria (Berkeley) Algal Biodiesel (Cambridge & California) CO_2 as Feedstock for Plastics (Ithaca) Doubling Urban Canopy (Chicago)	– – – 170 kt

Note: Table 7.2 excludes community cases.

Medium Projects	GHG savings	Major Projects	GHG savings
Light Rail Transit (Calgary) Rubber-tired Streetcar (Caen) Low Emission Zone (London) Congestion Charging (London) Transit Buses-Hydrogen Highway (Port Coquitlam)	591 kt – – 120 kt 0.12 kt	Pedestrianization of City Centres (Freiburg) Major Subway Expansion (Madrid) New Single-line Subway (Rennes) Plug-in Hybrid (United States)	– – 18 kt –
Solar Air Heating (Montreal) Solar Hot Water Heating (Paris) Ground Source Heat Pump (Concord) Ground Source Heat Pump (Langen) Building Integrated Photovoltaic (Coney Island)	1.34 kt 0.214 kt 2.86 kt – 0.086 kt	Demolition / Reconstruction (Toronto)	31.4 kt
Tidal Stream System (Northern Ireland) Borehole Thermal Energy Storage (Okotoks) Photovoltaic Plant (Olmedilla de Alarcon) Wave Power Plant (Portugal) Lake Water District Air Conditioning (Toronto)	2 kt 0.26 kt 29 kt 1.8 kt 79 kt	Solar Central Receiver Station (Seville) Solar Thermal Electricity Plant (Mojave Desert) Geothermal Power (Northern California)	110 kt 270 kt 950 kt
Source-Separation & Methane Production (Sydney) Source-Separation & Methane Production (Guelph) Incineration-Based CHP (Gothenburg) Energy From Waste (Ottawa)	210 kt – 205 kt –	Greening Supply Chains (Worldwide)	–
		Energy Recovery (Malmo) Biogas from Sewage (Stockholm)	– 14 kt
CO_2 Sequestration in Greenhouse Operations (Sarnia)	–	Municipal Purchases of Carbon Offsets (San Francisco) Sustainable Industrial Agriculture (Utrecht)	– –

7.3 COST EFFECTIVENESS

At this point in the analysis, our purpose now is to use the data from the case studies to examine the cost effectiveness of strategies for reducing emissions. The case studies show projects ranging from $0.02 million to $730 million in investment (Canadian dollars are used throughout), with annual GHG savings between 45 tonnes of CO_2e and 950,000 tonnes of CO_2e. One measure of the cost effectiveness of the projects is given by the ratio of the annual GHG reductions to the capital costs.

From the 68 case studies for which information has been sought, data on annual GHG savings and/or capital costs was obtained for 42 cases. Of these, 34 have GHG savings, 30 have capital costs, and 22 have both (Table 7.3).

For the cases where the capital costs and GHG emissions are both known, there is a relatively consistent fit of increased emissions savings with higher investments (Figure 7.2). The data is, however, plotted on a log-log basis, since both the costs and GHG emissions vary over orders of magnitude. The log-log plot disguises the very large deviations in the data set. For example, the bike campaign in Whitehorse costing $2 million is estimated to save 45 tonnes of CO_2e per year; while the solar air heating system in Montreal costing $2.6 million has reported GHG savings of 1,342 tonnes of CO_2e per year. Another comparison can be made between the subway line in Rennes, France, saving 18,000 tonnes of CO_2e per year at a capital cost of $730 million, and Calgary's light rail transit, powered by wind-generated electricity, which saves 591,000 tonnes of CO_2e per year after a capital cost of $593 million. Clearly there are significant differences in cost effectiveness between the case studies, with respect to reducing GHG emissions.

While the line of best fit in Table 7.2 is of limited use as a predictor, it does help to distinguish the infrastructure investments achieving the most cost effective reductions in GHG emissions. Points that lie above the line, in the middle range of costs, include cases of solar hot water heating, urban wind power, tidal stream power, and biogas from sewage, as well as the Montreal solar air heating system.

Five cases at the top end of Table 7.2 are particularly noteworthy. These are cases which lie above the line of best fit, and exceed GHG savings of 100,000 tonnes of CO_2e per year:

- **Seville's Solar Central Receiver Station** with a peak power capacity of 11 MW, cost $55 million, and is estimated to save 110,000 tonnes of CO_2e per year.
- **London's Congestion Charging Scheme** is estimated to reduce emissions by 120,000 tonnes of CO_2e per year. It cost about $324 million to implement (and generates net revenue).
- **Gothenburg's Combined Heat and Power (CHP) System** fuelled by waste incineration reduces municipal solid waste disposal needs and displaces fossil fuel generated heat and electricity. The system cost $600 million, and saves about 205,000 tonnes of CO_2e per year.

- **Sydney's Source Separation and Energy Recovery System** achieves a 70 per cent diversion rate and produces enough electricity to power the separation facility. The estimated GHG savings are 210,000 tonnes of CO_2e per year, following a capital cost of $100 million.
- **Calgary's Light Rail Transit System** is essentially emissions-free as the train fleet is powered by wind-generated electricity. Following capital investment of $593 million (in the transit system and wind turbines), Calgary's C-train saves around 590,000 tonnes of CO_2e per year,

In addition to these five cases, our data set includes four other projects with annual GHG savings over 100,000 tonnes of CO_2e, but for which the capital costs are unknown to us. These are:

- a solar thermal electricity plant in the Mojave Desert (270,000 tonnes CO_2e per year)
- a series of over 20 geothermal power plants in Northern California (950,000 tonnes of CO_2e per year)
- Chicago's plan to double its tree canopy (170,000 tonnes CO_2e per year)

TABLE 7.3
CAPITAL COSTS & ANNUAL GHG SAVINGS FOR CASE STUDIES

Project	**Location**	**Capital cost** ($ million Can)	**Annual GHG saving** (kt CO_2e)
Transportation / Land Use			
Light rail transit	Calgary, AB	593	591(v)
Rubber-tired streetcar	Caen	370	
New single-line subway	Rennes	730	18
Quality bus corridor	Dublin	90	
Bus rapid transit	Vancouver, BC	52	1.8
MetroLink: express bus	Halifax, NS	12.3(v)	1.125(*)
Heavy-duty HCNG transit buses, Hydrogen Highway	Port Coquitlam, BC	3(v)	0.12(v)
Low emission zone	London	120(v)	
Congestion charging	London	324(v)	120(v)

Bike share	Paris	175(v)	18(*)
Bike share	Barcelona		1.92
Bike campaign	Whitehorse	2(v)	0.0045(v)
Real time information	Portland	8	
High occupancy vehicle lanes	Seattle	3.7 (v)	
Parking cash out	California		0.24(v)
Buildings			
Demolition / reconstruction	Toronto		31.4 (v)
Solar air heating	Montreal	2.6	1.34
Solar hot water heating	Paris	1.21 (v)	0.214 (v)
Ground source heat pump	Concord, ON		2.86
Building integrated photovoltaic	Coney Island, NY		0.086
Green roof	San Francisco	3.5	
Restaurant exhaust heat recovery	Toronto	0.02	0.0075
Energy			
Solar central receiver station	Seville	55	110(*)
Solar thermal electricity plant	Mojave Desert		270(*)
Tidal stream system	N. Ireland	7.2 (v)	2(v)
Borehole thermal energy storage	Okotoks, AB	5 (v)	0.26 (v)
Photovoltaic plant	Olmedilla de Alarcon, Spain	610	29(*)
Wave power plant	Portugal	14	1.8(*)
Geothermal power	California		950(*)
Lake water district air conditioning	Toronto		79
Small hydro	Cordova Mines, ON	1.8	0.06(*)

Urban wind power	Toronto	1.6	0.38
Vertical axis wind	Liverpool	0.607 (v)	0.0014(*)

TABLE 7.4
SOLID WASTE

Source separation & methane production	Sydney	100 (v)	210 (v)
Incineration-based CHP	Gothenburg	600 (v)	205 (v)
Methane capture	Toronto	32 (v)	
Water / Wastewater			
Biogas from sewage	Stockholm	20	14
Co-generation, wastewater treatment plant	Ottawa	4.5	
Wastewater heat recover	Sony City, Japan		3.5 (v)
Carbon Sequestration & Offsets			
Doubling urban canopy	Chicago	10/year (v)	170 (v)
Sustainable Community			
Vauban	Freiburg		2.1
Dockside Green	Victoria, B.C.	6 (v)	5.2 (v)

Notes: (v) indicates the data were verified; (*) means the GHG calculation was undertaken by the project team.

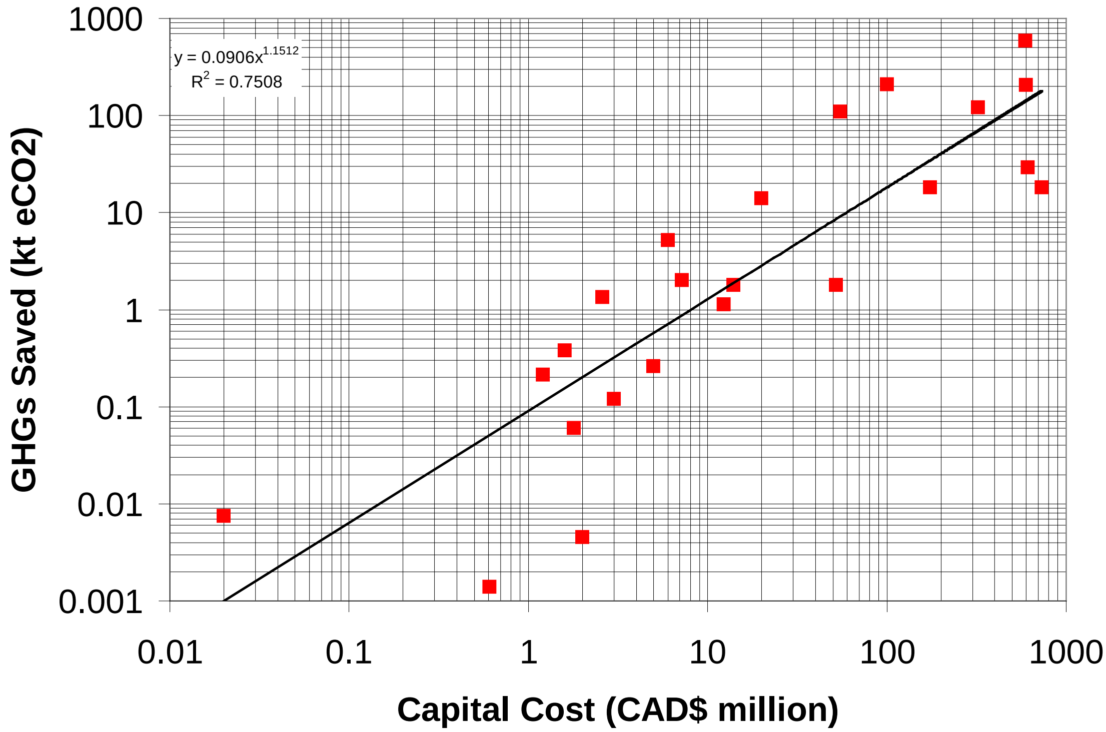

Figure 7.2 Annual GHG Savings versus Capital Costs for Infrastructure Case Studies

These nine cases with savings over 100,000 tonnes of CO_2e per year cover a variety of sectors: transportation, solid waste, energy and even urban forestry. This is encouraging, as it shows a diverse range of effective strategies can be taken to reduce emissions. For some of these nine, it is clear that the strategy exploits local conditions, such as high solar radiation, or suitable conditions for geothermal energy. In other cases, the strategy was a response to local stresses (e.g., traffic congestion in London, heat waves in Chicago). But for some cases, it is just a matter of being more creative and efficient with solid waste.

The results from the case studies can be compared to those from projects under the Federation of Canadian Municipalities (FCM) Green Municipal Fund. The FCM records the expected savings in GHG emissions from some projects supported by the Green Municipal Funds. These funds, which were endowed by the Canadian Government, provide grants and below-market loans to directly support municipal initiatives in Canada.

The majority (14) of projects in the FCM database for which both GHG savings and capital costs are reported are in the solid waste sector, although there are six transportation projects, and four energy supply projects. There is also data for one community development project – an eco-industrial park in Hinton, Alberta.

Generally speaking, the eleven FCM data points for the non-waste sectors are more dispersed than our case study data (again on a log-log plot). The line of best fit of our data, from Figure 7.2, is shown with the FCM data in Figure 7.3 for comparison. The cost effectiveness of the eleven non-waste sector projects (1,541 tonnes of CO_2e/yr/$million) is on average better than for our case studies (414 tonnes of CO_2e/yr/$million); nine of the eleven points lie above the regression line of our data.

Furthermore, it is quite apparent that the solid waste projects in the FCM dataset substantially out-perform the data from our case studies. The average cost effectiveness of the FCM solid waste projects is 28,200 tonnes of CO_2e per year per $million.

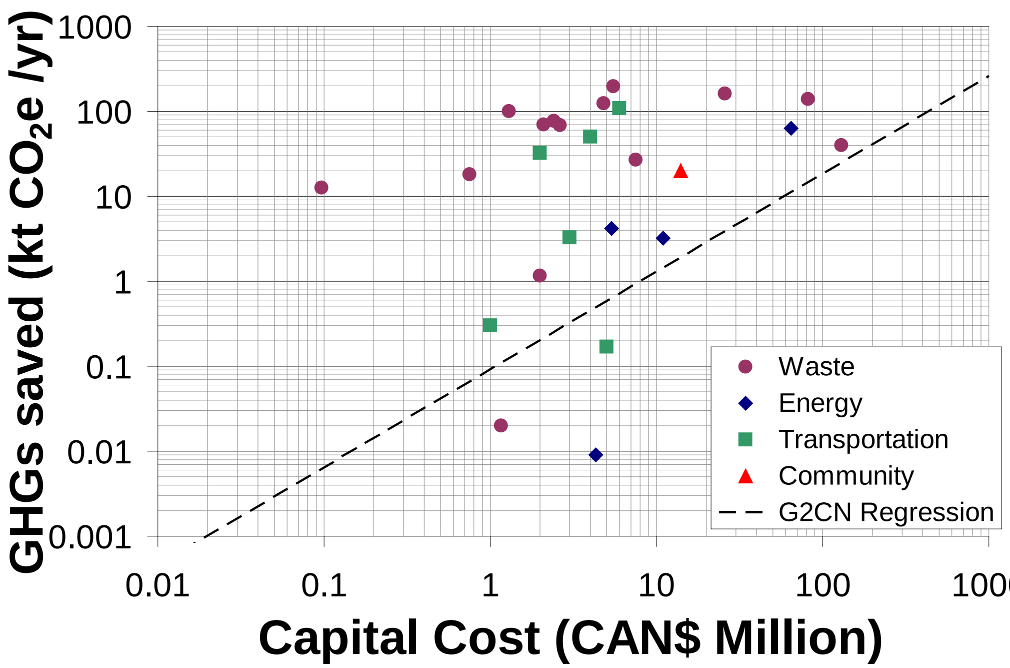

Figure 7.3 Annual GHG Savings versus Capital Costs for FCM-funded Projects

Notes: infrastructure projects funded under the Federation of Canadian Municipalities "Green Municipal Fund" (FCM, 2009). The dashed line is from the regression of data shown in Figure 7.2.

Several caveats have to be made in the interpretation of the results and comparison with the FCM data set. First, the determination of GHG emissions for projects in our data set has not necessarily been undertaken with consistent methodology. Other than the few cases where we calculated the GHG savings ourselves, the quality of the dataset depends on the calculations undertaken individually for each project.

Furthermore, we have undertaken a broad scan of infrastructure strategies for reducing GHG emissions. Generally, only one or two cases of a particular type of strategy are included in our dataset – and these may not necessarily be representative of the average performance of such a strategy. Where there is multiple data for a particular strategy, such as landfill gas to energy in the FCM dataset, then a high degree of variation in cost effectiveness is apparent.

Part of the variation in costs and GHG savings between projects can be attributed to differences in local conditions. Costs of projects vary due to factors, such as costs of labour, access to resources, access to technology, economies of scale, etc. GHG emissions saved when generating electricity from renewable sources depend on the GHG intensity of the local power grid. So even if costs are the same, the cost effectiveness is higher in regions that currently have greater dependence on coal for power generation. GHG reduction strategies that are cost effective in one region may not be so in another.

Several of the projects considered in the dataset are cutting edge applications of new or developing technologies. As such the costs of these projects, which may be considered trials or experiments, can be expected to come down as the technology develops.

A further important caveat is that while cost effectiveness has some merit as an economic measure, it is of limited use from an investment perspective. The private sector, in particular, must expect to achieve satisfactory rates of return if it is to invest in infrastructure that reduces GHG emissions. The OECD/IEA (2008) have identified a number of energy efficiency initiatives in a few example cities, such as building retrofits, LED traffic signals, and pool heat recovery, for which rates of return of over 100 per cent are achieved. Kikuchi et al. (2009) have also shown that investments in alternative energy technologies in Ontario can offer investors reasonable rates of return at relatively low risk, depending on the sector. The investments considered in both of the above studies are, however, relatively small scale. Further studies of returns on investment are perhaps warranted for infrastructure that substantially reduces GHG emissions.

Finally, few, if any, of the infrastructure projects considered in our dataset were designed solely for the purpose of reducing GHG emissions. Reducing emissions is only one goal. Transportation systems are designed to move people and goods; energy infrastructure is designed to provide heating, lighting and electrical service etc. By virtue of differences in their functionality, various types of infrastructure can be expected to differ in terms of cost effectiveness for reducing GHGs.

7.4 OTHER BENEFITS

For many of the case studies, we were able to document other benefits beyond the reduction in GHG emissions. These benefits can be broadly categorized in environmental, social and economic terms.

In some cases, the reduction of GHG emissions was just a part of a broader, more ecological approach to urban design. This was particularly apparent for the sustainable neighbourhood developments (Chapter 8). The buildings at Dockside Green in Victoria use 55 to 60 per cent less water than typical condominiums through use of grey water systems, on-site water treatment, and low flow facets. The BedZED development in London, UK, has rainwater capture and on-site water treatment; local and recycled building materials were also used. A further example is at the Bromma and Henriksdal biogas plants in Stockholm, Sweden, where the sewage sludge from wastewater is biologically treated under anaerobic conditions. The de-watered digestion residue is then used as a soil material to remediate mine wastes at the Aitik mine near Gällivare.

Other environmental benefits are apparent from projects involving vegetation. As well as helping to cool the interior of the building, the green roof on the California Academy of Sciences reduces stormwater runoff by up to 2 million gallons of water per year (70 per cent). The doubling of Chicago's tree canopy provides other ecosystem services such as: pollutant removal, urban heat island reduction, stormwater runoff reduction, habitat and forage. This large urban forestry project also provides quality of life benefits such as: increasing real estate value, retail/commercial improvements, and provision of parks and open space amenities.

Indeed, the social benefits were prominent in many of the cases. The development of Vauban as an environmentally sustainable city district of Freiburg, Germany, had strong social dimensions. Community involvement and participation in the planning process was fostered. Social balance was promoted through co-operative housing that allows lower income families to become homeowners. The Guaranteed Ride Home (GRH) program organized by the City of Albuquerque Transit Department not only supports residents who commute by transit, carpool, vanpool, bike or walk, but is also recognized as protecting public safety. Other transportation initiatives such as the Rennes subway, also saw safety (i.e., the reduction of traffic accidents) as a strong motivator.

For many of the transportation projects, increased social accessibility and system reliability were considered important benefits. These were reported for several cases: Calgary's LRT; the intelligent transportation systems on Vancouver's BRT; Halifax's MetroLink; Edmonton's timed transfer system; and the bike share program in Paris. Opening high occupancy vehicle lanes in Seattle was also seen as a means to increase the reliability of bus services.

In some cases, the increased reliability clearly provided economic benefits, such as through the system efficiencies achieved with Vancouver's intelligent BRT system.

Similarly, the Oyster transit card readers developed in London, UK, use a solid state low emission radio frequency to operate devices, such as ticket machines, gates, etc. The reduced use of mechanical moving parts of gates and ticket vending machines has seen considerable reduction in the number of breakdowns caused by parts, such as magnetic ticket handling units. This efficiency has lead to lower power consumption and lower requirements for system maintenance.

In many cases the sale of recycled materials or energy generated provide clear economic benefits. Compost from the organic stream of Sydney's source separation system, for example, is sold at for $20-30 (US) per tonne.

Broader economic benefits were also recognized. The use of wind turbines to power Calgary's C-train enhanced the capacity and market for wind-generated electricity in Alberta. The development of the SeaGen tidal power system in Northern Ireland was recognized as creating jobs for a new industry. The new technology improves offshore engineering capabilities with possible economic spin-offs.

Finally, San Francisco's municipal GHG offset program was seen as having particularly important local economic impacts. The program works by offsetting air travel emissions of municipal employees through financial contributions to emission reduction projects within the city. Spending offset dollars within the municipality, stimulates local economic activity and boosts expertise in green technologies. There is the further added benefit of reducing energy consumption by underprivileged communities in San Francisco.

7.5 BARRIERS OVERCOME

Many of the case studies in this guide are leading edge examples of new technologies or new planning initiatives, and such projects do not succeed without overcoming technical, social, organizational and, in some cases, legal barriers (Table 7.4). For about fifteen of the cases, in particular for transportation projects, we obtained details on the key hurdles that were overcome in implementation.

TABLE 7.5
BARRIERS OVERCOME BY MUNICIPALITIES IN REDUCING GHG EMISSIONS

Technical	› Capacity constraints › Engineering challenges › Risks / uncertainty
Social	› Working with operators, tradespersons and other stakeholders › Understanding behavioural change
Organizational	› Public versus private sector issues › Coordination and integration across departments
Legal	› Encouraging changes to provincial or federal laws

For some cases, the main barriers were technical. Edmonton Transit introduced a new timed-transfer system, where suburban feeder routes run to a transit centre and passengers can transfer to a route to the city centre or the university. Transit ridership in Edmonton increased by 45 per cent over five years. As the transit ridership grew, the capacity of some of the existing transit centres was not adequate to handle bus volumes, creating operational issues. The pedestrianization of Freiburg's city centre caused a spill over of cars onto immediately adjacent streets. This issue was tackled by narrowing streets and implementing parking restrictions. Many of the challenges in designing new electric cars are also technical. For example, the first concept vehicle behind the Chevrolet Volt experienced excessive aerodynamic drag that needed to be reduced. The challenge was to design a comfortable interior accounting for drag and the large battery.

With any new technology there is uncertainty. This was particularly acute for the development of the 1.2 MW SeaGen Tidal System – the first installation of a truly commercial scale tidal stream electricity generator – installed 400 metres off the coast of Northern Ireland. The engineering challenges for offshore renewable energy systems are formidable: the technology needs to be large enough scale to be cost effective, it needs to be accessible for maintenance and repair, and it needs to be reliable and long lasting. The technology risks of the project were perceived to be severe and one of the main barriers was difficulty in raising finances rapidly enough and sufficiently to cover costs. The financier's perceptions can easily be self-fulfilling in slowing a project and making it cost more as a result. The approvals process also became more difficult as a result of sometimes unsubstantiated controversies surrounding a new technology to be applied in the seas. It is always difficult to be the first-mover and have to push through the barriers ahead of everyone else.

Uncertainty about the future price of energy was a major issue to be overcome in the energy supply cases. This proved to be a challenge for the Calgary C-train, as it was powered by electricity from wind turbines. The biggest challenge for planners was trying to get a feel for energy price forecasts; a great deal of time was spent coming to grips with the different projections in the market. For building scale alternative energy, Bristow and Kennedy (2009) show how the type of building owner (i.e., residential, commercial, institutional) and size of government subsidy can make the difference in overcoming uncertainty in future energy prices.

Three notable transportation cases from London, England, had technical barriers with particular social dimensions. One was the development of a low emission zone, which aims to deter specific polluting vehicles from driving within most of Greater London. In implementing this scheme, Transport for London had to build a robust database of compliant and non-complaint vehicles and work with third parties to develop vehicle certification services. Then, they had to work with abatement equipment manufacturers and certification authorities to help vehicle operators make their vehicles compliant. Lorry and bus operators had to accept the scheme.

Another initiative was London's Oyster Card – a "smart" card that stores period tickets (travelcards), cash (for pay as you go) or concession tickets for use on London buses, underground, trams, light rail, overground services, and some National Rail lines within Greater London. Developing these ticketing products and media to meet the needs of the various stakeholders in such a complex multi-modal and multi-operator environment was challenging. Transport for London wanted to roll out the benefits of the Oyster system rapidly from launch in the year 2000. This involved upgrading the existing system infrastructure, upgrading off system retailers, improving processing, as well as rolling out ticket products onto the new Oyster platform. In parallel, the new smart ticket medium needed to be explained and promoted to a large customer base.

The third, well-known, transportation initiative was the congestion charging scheme introduced in Central London in February 2003. To implement such a radical change it was important to understand likely customer behaviour (i.e., choosing the correct payment channel mix and establishing whether infrastructure, such as the call centre, was able to cope with the projected demand). Projecting the modal shift from cars onto public transport was challenging. Plus there was the need to maintain the integrity of the system (i.e., correct verification of documents for the registration process). The system was also implemented within significant time constraints.

Many of the case studies involved organizational challenges – and this was highlighted in particular by the implementation of the Vélib' public bicycle rental programme in Paris. Close to 1,500 automated rental bike stations with 35,000 bike racks have been created in the city for over 20,600 bikes. In addition to the legal complexities of using a private company to operate the program, there were many organizational challenges. As bike stations were often created in already crowded locations, the City of Paris had to manage the process of removing automobile parking spaces – a sensitive issue for local residents and businesses. The City also had to obtain technical authorizations from underground network providers, such as electricity, water and heating providers; each single station requiring separate studies. Then there was authorization from the Central Police Head Quarters, to ascertain that each station was accessible in the safest possible manner for users. Moreover, the City of Paris had to obtain authorization from the French Public Buildings' Architects which assessed the potential aesthetic issues and integration of bike parks into the Parisian landscape. Implementation of the program required many teams within the City of Paris (Departments of Roads, Finance, Legal Affairs, Communication, Urban Planning and the Central Piloting Team of the General Secretary) to work in a concerted fashion throughout the project phase to make it a success.

The challenge of coordination across multiple agencies was also identified as the main barrier in implementing Chicago's plan to double its tree canopy. Part of Chicago's plan to combat climate change involves planting 1,000,000 new trees by 2020. A public-private partnership is coordinating the planting efforts with the assistance of residents and corporate sponsors.

The involvement of the private sector caused some challenges in establishing Curitiba's bus rapid transit scheme. Initially, the private bus operators were paid based on the number of passengers carried, which created competition for main road services, but left parts of the city unserved. To solve this issue, operators are now paid based on distance travelled.

In the case of Halifax's new bus rapid transit scheme, MetroLink, some aspects of the project required changes to provincial legislation. In particular, installation of significant transit priority measures, such as queue-jump lanes and priority transit signals required legal action at the provincial level. Participation from the provincial and federal governments was also required to provide part of the capital costs.

The establishment of high occupancy vehicle (HOV) lanes in Seattle, Washington, also required bills to be introduced in the legislature to establish HOV policy. A ballot initiative was recently defeated that would have converted HOV lanes to peak hour lanes only.

The main barrier to the opening of the Rennes subway was also political. Rennes is one of the smallest cities with its own subway, having a city population of 210,000 and urban area population of 405,000. The 9.4 km line serviced by light automatic vehicle technology was opened in March 2002. Political opposition from a number of elected councillors and from some of the population had, however, blocked the implementation of the subway from 1989 until 1995. Construction was then slow due to civil engineering constraints (tunnels and underground stations).

Overall, we see that Canadian cities aiming to become carbon neutral will have to overcome a range of challenges:

- developing new technology
- managing project risks
- understanding the social response to new urban systems
- organizing complex projects
- designing new legislation
- fighting for political turf.

7.6 TEN ACTIONS FOR MUNICIPALITIES

The research presented in this guide concludes that achieving carbon neutrality at the municipal level is technically feasible, despite the risks and costs associated with strategies to pursue such a goal. The climate change imperative has inspired these authors to craft a list of specific actions that, in combination, would be highly effective at bringing a city toward carbon neutrality. These recommendations are aligned with the key areas explored in this report as having the greatest potential to reduce GHG emissions: buildings; land use; transportation; energy supply; and efficiency. Due to the layered nature of policy making in Canada, full implementation of several of the below strategies would require cooperation between municipal, provincial and federal governments, however this reality should not delay action at a municipal level.

1. Develop bold, ambitious building codes

The state-of-the art in green or sustainable building design is already capable of producing carbon neutral buildings. By reducing energy demand, utilizing solar energy and tapping waste heat sources, buildings have been constructed in Canada that are (or are close to) carbon neutral. Chapter 3 provides a series of Estimation Guidelines for determining the savings that may be obtained by incorporating energy efficient envelopes, photovoltaics, solar water heaters, solar air heaters, passive solar design and ground source heat pumps.

Building codes are not under the direct purview of municipalities in Canada. However, Canadian municipalities could be very influential in the provincial update of building codes to reflect the positive impact buildings can have on emission mitigation. By independently encouraging the widespread adoption of these technologies through the promulgation of municipal by-laws and building standards, municipalities could develop serious evidence that the market is capable of incorporating clean energy generation capacity and strict efficiency measures in both new and existing buildings.

2. Accelerate the retrofitting of the existing building stock

The greatest challenge for reducing building-related GHG emissions comes from the energy-related inefficiencies of the existing building stock. There is a checklist in Chapter 3 for a comprehensive building or facility energy audit, as well as Estimation Guidelines for savings from retrofits to low rise and high rise residential buildings. The expanded example application in Chapter 8 suggests that savings of 2.7 megatonnes of carbon dioxide equivalent (Mt CO_2e) per year could be achieved in Toronto by retrofitting all pre-2012 buildings to the 2012 building code standards. Particular opportunities lie in retrofitting high rise buildings through programs such as the Mayor's Tower Renewal project in Toronto. Municipalities need to accelerate the retrofitting of buildings – both their own and those of the wider community. This may require the establishment of revolving capital funds or other financial incentives.

3. Build transit systems supported by appropriate land use and financing mechanisms

Chapter 4 presents the MUNicipal Transportation And Greenhouse gases (MUNTAG) model. The model integrates a series of guidelines on land use, public transportation, active transportation, financial policies and vehicle technologies to provide a powerful tool for assessing potential reductions in urban transportation-related emissions.

Encouraging the public to shift from automobiles to low emissions public transit is a huge challenge. Developing transit supportive communities is necessary, but not sufficient; municipalities also have to find ways of actually building the transit systems. Ultimately, the development of sustainable urban transportation requires a new financial model through which revenues from road tolls, area pricing, parking and other sources are re-invested in substantial transit infrastructure.

4. Design neighbourhoods to facilitate active transportation

Sustainable urban transportation requires supporting major transit infrastructure through local neighbourhood design. Essentially, this means creating attractive, relatively dense, mixed use neighbourhoods where people find it convenient and safe to walk and cycle. Factors such as density, the relative cost of alternative forms of transportation, and the street layout of a city (grid versus intertwined roads and dead ends) all strongly influence the decision to walk or cycle. Retrofitting the road layout of a community is prohibitively expensive and therefore more appropriate for consideration in new developments; however, increasing density and imposing a greater diversity of land uses are possibilities for existing municipalities to capture the emissions reduction potential of active transport. Chapter 4 provides Estimation Guidelines for the mode share impacts of providing bicycle facilities, along with case studies of cycling and pedestrian initiatives.

5. Encourage the adoption of electric or low-emissions vehicles

Changing vehicle technology is another strategy for reducing transportation sector GHG emissions. Chapter 4 provides data and information on the emission factors for biofuel, fuel cell, plug-in hybrid and hybrid-electric vehicles, which are incorporated into the MUNTAG model. The widespread adoption of these vehicles depends largely on the incentives provided by federal, state and provincial governments in North America. Municipal governments can help catalyze the change by greening their own fleets, regulating taxi fleets and providing reduced parking fees or other advantages for green vehicles.

6. Green the electricity supply

Greening the electricity supply not only reduces emissions from current demands, but also provides low carbon electricity supply to replace fossil fuel use in other sectors (e.g. to provide power for electric vehicles and ground source heat pumps). A review of GHG inventorying procedures in Chapter 2 shows there are stark differences in the GHG intensity of electricity supply between Canadian provinces. Municipalities in Alberta and Saskatchewan have GHG intensities of over 800 tonnes CO_2e per gigawatt hour (GWh), while those in British Columbia, Newfoundland, and Quebec are at or below 20 tonnes of CO_2e/GWh. Reaching carbon neutral will be particularly challenging for those municipalities that depend on high carbon intensity electricity; they will need to consider investing in larger scale green electricity supply systems.

7. Undertake integrated community energy planning

A new model of local energy planning is emerging, which enables municipalities to harness energy from a variety of community sources. As well as the building scale sources of Chapter 3, technologies such as aquifer and borehole thermal energy storage may be developed. These may be combined with district energy systems, combined heat and power facilities, or other energy technologies that tap waste streams, as described in Chapter 5. This evolving model suggests that communities can provide a sufficient economy of scale for integrated resource recovery and levelling of energy demand profiles, while maintaining system reliability. To exploit such opportunities, municipalities will need to change fundamentally the way they undertake energy planning and management, however the long-term impact on emissions reductions can be tremendous.

8. Continue harvesting the solid waste streams

While GHG emissions resulting from solid waste stream management and disposal are modest relative to other sources in most Canadian municipalities, waste management strategies continue to be the 'low hanging fruit' in terms of GHG reduction. A comparison of projects funded by the Federation of Canadian Municipalities shows that waste projects have generally been the most cost effective in cutting GHG emissions. Waste diversion through implementation of the 3Rs (waste reduction, reuse and recycling) is also effective in lowering GHG emissions. Chapter 6 includes Estimation Guidelines for GHG emission reductions for solid waste management options, including for recycling, waste incineration and methane capture and Chapter 7 provides calculations of the cost effectiveness (i.e., annual GHG savings per dollar of capital expenditure) for over 20 of the case studies, lending insight to municipalities considering employing similar strategies on how to balance costs with emission savings.

9. Seek efficiency in municipal services

To provide leadership to the community, municipal governments should aggressively pursue reductions in GHG emissions generated by their municipal buildings and services. The energy required to provide municipal water and wastewater supplies can be a significant source of emissions. There are energy conservation opportunities and strategies for increasing the efficiency of water and wastewater systems; water demand management instruments and elimination of leaks are especially powerful ways of reducing emissions from municipal services. Chapter 6 provides Estimation Guidelines for energy savings from water, wastewater and other municipal services.

10. Green the city

While the primary focus of this guide is the mitigation of urban GHG emissions, municipalities also need to adapt to the imminent environmental and economic implications of climate change. Greening the city with green roofs and urban forestry provides both mitigative and adaptive benefits. Urban agriculture and CO_2 enriched greenhouses also have potential to help cities manage the transition to living under the conditions of an altered climate. Estimation Guidelines for the GHG savings of these practices can be found in Chapters 3 and 6.

The preceding ten recommendations reflect the breadth of strategies available to municipalities striving to reduce emissions. In a practical sense, a city would balance emission reduction targets with feasibility in order to select the combination of these options most logical for its individual circumstances.

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CHAPTER 8: INTEGRATION OF STRATEGIES: TORONTO CASE STUDY

(L. Sugar)

As described in the boxed case studies throughout this guide, there are many examples of sustainable design practices that have reduced the GHG emissions from cities in Canada and abroad. While each case details the success of a specific project, achieving carbon neutrality, or near-neutrality, requires a synergistic approach where a variety of GHG reduction strategies are employed. This is currently demonstrated at the community scale in three notable projects:

- Dockside Green in Victoria, B.C.
- Beddington Zero-Energy Development (BedZED) in London, U.K.
- Vauban District in Freiburg, Germany

All three have advanced energy efficient homes and combined heat and power facilities. Dockside Green has online smart-metering and energy controls, BedZED homes are heated and ventilated using passive solar techniques, and Vauban is parking-free and pedestrian focused. The combination of numerous GHG reduction strategies has made these developments near-carbon neutral.

CASE 8.1
DOCKSIDE GREEN, VICTORIA, BRITISH COLUMBIA

Dockside Green is a six-hectare mixed use community developed on a brownfield site near downtown Victoria, BC, featuring a range of low carbon strategies. Buildings are designed to be LEED® Platinum certified and 45 to 55 per cent more efficient than buildings designed to current national codes. This is achieved by heavy insulation, double-glazed low-e windows, heat recovery ventilators, and external shading on south and west windows to minimize heat gains. Electricity demands are reduced through use of ENERGY STAR appliances, low-energy lighting with occupancy sensors, and day-lighting techniques. Energy use will be smart-metered with digital controls accessible over the Internet. Heat and some electricity will be provided by a biomass energy cogeneration facility with peak heating needs met with backup natural gas boilers. The community is designed to be pedestrian friendly with abundant green spaces and walkways. In addition, a mini-transit system and car share program will help reduce transport emissions. Compared to a traditional development, 5,215 tonnes of CO_2e per year are avoided through biomass use, space heating efficiency, and electricity efficiency.

Reference: Dockside Green: Annual Sustainability Report 2007. http://docksidegreen.com/images/stories/bottom/itn/SustainabilityReport2007.pdf. Accessed February 2009.

CASE 8.2
BEDDINGTON ZERO-ENERGY DEVELOPMENT, LONDON, UK

The Beddington Zero-Energy Development, or BedZED, is a high density, mixed use, carbon-neutral community developed on an urban brownfield site in Southwest London and completed in 2002. The community is designed to maximize social amenity and environmental sustainability, while maintaining financial effectiveness. All buildings have advanced envelope insulation and air tightness, and all heating, cooling and ventilation is achieved using passive techniques (including terraced blocks, building orientation that best utilizes solar gains, and heat recovery wind cowls). The absence of mechanical systems reduces electricity demand, as do smart meters, low energy appliances and light bulbs. Electricity and additional heat is supplied from a bio-fuelled combined heat and power plant (CHP), which runs on wood chips from local urban tree trimmings. Photovoltaic cells on southern facades also generate electricity.

Residents of BedZED have eco-footprints of 3.0 ha/person, compared to 5.4 ha/person for a typical UK resident. Efficient appliances and water systems reduce energy demand compared to current UK use by: 86 per cent for heating and water heating, 40 per cent for home electricity, and 50 per cent less water consumption. The energy sources for space heating, cooling and electricity generation are carbon-neutral.

References:

1. Twinn, Chris. (2003). BedZED. Arup Journal, 38(1), p10-16.
2. BioRegional. (2009). BedZED. http://www.bioregional.com/what-we-do/our-work/bedzed/. Accessed July 2009.

CASE 8.3
VAUBAN DISTRICT OF FREIBURG, GERMANY

Vauban is an environmentally sustainable city district of Freiburg, Germany, developed using co-operative and participatory planning strategies. All buildings comply with low energy standards, some of which are passive houses or plus energy houses. A co-generation facility and over 450 m^2 of solar collectors provide 45 per cent of the community's electricity requirements, as well as district heating. The community is "parking-free" and close to 50 per cent of the households are car-free. Doorstep parking is replaced by a peripheral community car park, which also stores community car-sharing vehicles. Cars are permitted on residential streets for pick-up and delivery purposes only, where they must travel at "walking speed" (5 km/h). Businesses, schools, shopping and recreation facilities are all located within walking or cycling distance. Public buses and tram lines connect Vauban to the Freiburg city centre. The community design is estimated to save 28 GJ of energy, 2,100 tonnes of CO_2e and 4 tonnes of SO_2e per year.

References:

1. Vauban District, Freiburg. English Description of Vauban District. www.vauban.de/info/abstract.html. Accessed November 2008
2. Öko-Institut. Sustainable districts in urban conversion areas. www.oeko.de/service/cities, as described in Vauban District, Freiburg. English Description of Vauban District. www.vauban.de/info/abstract5.html. Accessed November 2008).

The GHG reduction strategies described in this guide have already proven effective in new community and city developments throughout the world. The strategies will also make significant impacts when applied to existing cities in Canada. In this chapter, example calculations are conducted for the City of Toronto, highlighting the potential of various combinations of reduction strategies, represented in the guide as Estimation Guidelines. By following the example calculation techniques, a municipality may create its own scenarios of reduction strategies towards the development, or assessment, of plans for emission reductions.

The Toronto Case Study is divided into three scenarios: a 2004 Base Case Scenario; a 2031 Planned Policies Scenario; and a 2031 Aggressive Alternatives Scenario. The 2004 Base Case Scenario provides a check of the Estimation Guidelines and data tables provided in the guide. This scenario is based on current municipal infrastructure and demographics, and it is verified with respect to values presented in the City of Toronto's 2004 GHG Inventory (ICF International, 2007). The 2031 scenarios are future projections of GHG emissions for the city. These scenarios consider reductions due to currently planned municipal and provincial policies (Planned Policies) and alternative actions that could be considered aggressive (Aggressive Alternatives). The GHG emissions and potential savings in all scenarios will focus on the sectors responsible for the largest amounts of emissions: Buildings and Transport.

8.1 BASE CASE SCENARIO FOR 2004

In 2004, the population of the City of Toronto was about 2.65 million, and the city's gross domestic product was about $101.7 billion (based on provincial GDP weighted by employment data). The total land area for the City, kept constant in all scenarios, is 63,000 hectares.

8.1.1 BUILDINGS

The gross-floor-area (GFA) of Toronto's building stock in 2004 was estimated using roof areas and building heights provided by the city for the following building categories: low rise residential; apartments; and commercial-institutional. The GFA was estimated based on assumptions of floor height. For low rise residential buildings and apartments, the estimated GFA was taken to be the average of the two total GFA values calculated assuming both 10 ft and 12 ft ceilings. For commercial buildings, 12 ft and 14 ft ceilings were assumed. The total GFA of the Toronto building stock in square kilometres for each building type is shown in Table 8.2.

The total energy consumption (in GJ) by each building type was calculated as the product of building stock (in m^2) and energy intensity (in GJ/m^2), using the energy intensity values for Ontario provided in Table 3.1 (shown again in Table 8.1). The total energy consumption was further divided according to end-uses: a portion of the total energy represents heat, and a portion represents electricity. In Toronto, heat is generally fuelled by natural gas. Heating energy end uses are space heating and water heating, and electrical energy end uses are lighting, appliances and space cooling. Toronto's split between natural gas and electricity, as well as the Canadian average split in end use consumption of natural gas and electricity, is shown in Table 8.1.

The total energy consumption of the 2004 Toronto building stock, as well as the energy associated with each end-use, is shown in Table 8.2. The total emissions shown in Table 8.2 were calculated according to Equations 2.1 and 2.2, taking the 2004 Ontario electrical emissions intensity (including line losses) to be 246 g CO2e/kWh (68.3 t CO2e/TJ) and the emissions intensity of natural gas to be 56.1 t CO2e/TJ (as shown in Table 2.2). In Toronto in 2004, buildings were responsible for about 14 megatonnes of GHG emissions.

TABLE 8.1
ENERGY, NATURAL GAS & ELECTRICITY BREAKDOWN BY END USE FOR DIFFERENT BUILDING CLASSIFICATIONS

		Low-Rise Residential	Apartments	Commercial
Energy Intensity (GJ/m^2)		0.83	0.68	1.65
Total Energy Breakdown				
Canadian Average	Non-electrical energy	62%	52%	56%
	Electricity (incl. Heating)	38%	48%	44%
Toronto	Natural gas	82%	82%	51%
	Electricity	18%	18%	49%
Total Natural Gas Breakdown				
Canadian Average	Space heating	72.5%	72.5%	85%
	Water heating	27.5%	27.5%	15%
Total Electricity Breakdown				
Canadian Average	Lighting	21.5%	21.5%	25%
	Appliances	60%	60%	58%
	Space cooling	18.5%	18.5%	17%

Source: NRCan NEUD tables

TABLE 8.2
ESTIMATED ENERGY USE % EMISSIONS FOR THE TORONTO BUILDING STOCK, 2004

	Low-Rise Residential	Apartments	Commercial	TOTAL
Building Stock (km^2)	93.04	53.37	72.12	218.5
Total Energy (TJ)	77,219	36,292	118,994	232,505
Heating (natural gas) (TJ)	63,648	29,914	60,796	154,357
Space heating (TJ)	46,145	21,687	51,676	119,508
Water Heating (TJ)	17,503	8,226	9,119	34,849
Electricity (TJ)	13,572	6,378	58,198	78,149
Lighting	2,918	1,371	14,666	18,955
Appliances (TJ)	8,143	3,827	33,755	45,725
Space Cooling (TJ)	2,511	1,180	9,836	13,526
Total Emissions ($ktCO_2e$)	4,498	2,114	7,386	13,997

8.1.2 TRANSPORT

GHG emissions associated with transport were calculated using the MUNTAG model (described in Chapter 4 and Appendix B) with inputs, such as Toronto's 2004 population, land area, GDP, and information about the transit and bicycle infrastructure. The 2007 transit infrastructure for Toronto was provided by the Toronto Transit Commission (Toronto Transit Commission, 2008); as there were no major infrastructure changes in the interim, it was assumed to be similar to the 2004 infrastructure:

- 1,545 buses
- 248 streetcars, 69.2 km of streetcar tracks
- 706 subway cars, 68.3 km of subway tracks

The resultant vehicle kilometres travelled (VKT) of each motorized mode – private automobiles, bus, streetcar, and subway – is shown in Table 8.3. The total length of Toronto's bicycle facilities was 403 km (City of Toronto, 2009), resulting in an estimated bicycle mode share of 0.88 per cent. This mode share fraction was subsequently subtracted from the GHG emissions of each motorized mode.

To calculate the per-kilometre emissions intensity (g CO_2e/VKT) of each public motorized mode, the North American average energy intensity from Table 4.4 (MJ/VKT) was multiplied by the per-unit-energy emissions intensity of the mode's fuel (gCO_2e/MJ). Buses operate on diesel fuel (per-unit-energy emissions intensity in Table 2.2), and streetcars and subways are powered by electricity (per-unit-energy emissions intensity of 68.3 gCO2e/MJ, as described above). For private automobiles, the average fuel mileage was taken to be 11.24 L/100km (Table 4.15). This mileage was combined with the energy content (MJ/L) and per-unit-energy emissions intensity of gasoline (g CO_2e/MJ) given in Table 2.2. The per-kilometre emissions intensity for each motorized mode is shown in Table 8.3.

The final results of the MUNTAG model, including the GHG savings due to the bicycle mode share, are shown in Table 8.3. The results indicate that in 2004 passenger transport contributed about 3.2 megatonnes to Toronto's GHG footprint.

TABLE 8.3
VKT, EMISSIONS & MODE SHARE SAVINGS FOR TORONTO'S TRANSPORT INFRASTRUCTURE, 2004

	Private Automobiles	Bus	Streetcar	LRT	Subway	TOTAL
VKT per capita (km)	4,077	29	12	-	39	4,157
Emission factor (kgCO_2e/km)	0.271	2.01	1.07	1.15	0.852	-
Per capita emissions before savings (kgCO_2e)	1,103	59	13	-	33	1,208
Emissions before savings (ktCO_2e)	2,920	155	33.8	-	87.5	3,197
MODE SHARE SAVINGS						
Active transport						
Biking (ktCO_2e)	26	1.4	0.3	-	0.8	28
Total Savings (ktCO_2e)	26	1.4	0.3	-	0.8	28
Total emissions (ktCO_2e)	2,895	154	33.5	-	86.7	3,169

Note: Values estimated using the MUNTAG model.

Emissions calculated using the Estimation Guidelines and tables presented in the guide were comparable to values presented in the 2004 Toronto GHG Inventory (Table 8.4). For the sources of emissions that were common to both methods – including low rise residential homes, apartments, and commercial buildings, as well as private automobiles and transit buses – there was only a 2 to 17 per cent difference in numerical values. Although the Estimation Guidelines in the Guide exclude emissions from industrial buildings, trucks, and waste, the calculations for other sources were shown to be verifiable.

TABLE 8.4
COMPARISON BETWEEN 2004 TORONTO GHG INVENTORY AND 2004 BASE CASE SCENARIO

	2004 Toronto GHG Inventory	2004 Base Case	% Difference
Population (millions)	2.65	2.65	-6%
BUILDINGS (ktCO_2e)			
Low-rise residential (kgCO_2e)	5,997	4,498	10%
Apartments (ktCO_2e)		2,114	
Commercial (ktCO_2e)*	8,887	7,386	-17%
PASSENGER TRANSPORT (ktCO_2e)	8,559	3,169	-
Private Automobiles ((ktCO_2e)	2,839	2,895	2%
Bus (ktCO_2e)	172	154	-11%
Streetcar (ktCO_2e)	-	34	-
LRT (ktCO_2e)	-	-	-
Subway (ktCO_2e)	-	87	-
Other vehicles (ktCO_2e)	5,549	-	-
WASTE (ktCO_2e)	978	-	-

*From 2004 Toronto GHG Inventory, included industrial emissions (“Commercial and small industrial” and “Large commercial and industrial”)

8.2 PLANNED POLICIES SCENARIO FOR 2031

The Province of Ontario and the City of Toronto are implementing numerous plans and initiatives to reduce GHG emissions. Using the Estimation Guidelines provided in this guide, the GHG impacts of a few of the policies are quantified in this scenario for the year 2031.

Following the linear population growth trend described in Ontario’s Growth Plan for the Greater Golden Horseshoe (Ministry of Public Infrastructure and Renewal, 2006), the population of Toronto in the year

2031 will be about 3.08 million. The city's GDP is projected to be $178 billion, and the land area will remain the same at 63,000 hectares.

8.2.1 BUILDINGS

To extrapolate the building stock into the year 2031, the Growth Plan's population trends, employment trends, and residential housing construction trends were followed. The total residential GFA (the sum of low rise residential and apartments) was assumed to grow at the same rate as population, which will increase 16 per cent by 2031. Ten per cent of the increase in residential GFA was assigned to low rise residential housing and the remaining 90 per cent was assigned to apartments. Commercial GFA was assumed to grow at the same rate as employment, which is projected to increase 10 per cent by 2031. The extrapolated building stock values are shown in Table 8.5.

Following the same method used in the 2004 Base Case Scenario, the total energy used by each building type was calculated according to the intensity and energy breakdown schemes in Table 8.1. The total emissions were also calculated according to Equations 2.1 and 2.2. The emissions intensity of natural gas remained at 56.1 t CO_2e/TJ, and the projected Integrated Systems Plan electrical emissions intensity (including line losses) was taken to be 37.8 g CO_2e/kWh (10.5 t CO2e/TJ) (Ontario Power Authority, 2006). The total energy and emissions before savings is shown in Table 8.5.

In addition to using the electricity emissions intensity of the Province's Integrated Systems Plan, which will promote small-scale urban renewable generation, five initiatives were quantified in this scenario:

- banning incandescent bulbs
- requiring ENERGY STAR appliances
- implementing the 2012 Ontario Building Code
- completing the Mayor's Tower Renewal project
- promoting commercial green roofs

Banning incandescent bulbs

The Estimation Guideline regarding CFL bulbs indicates a 75 per cent energy savings over incandescent bulbs. Assuming 70 per cent of residential lighting energy and 10 per cent of commercial lighting energy is currently from incandescent bulbs, the energy savings to lighting electricity is 52.5 per cent and 7.5 per cent respectively. This results in a total GHG savings of about 40.1 kilotonnes (Table 8.5).

Requiring ENERGY STAR Appliances

The ENERGY STAR Estimation Guideline offers a range of potential savings based on different appliances. The average savings was taken as 30 per cent for these calculations, and it was assumed 60 per cent of residential appliances and 30 per cent of commercial appliances are not already ENERGY STAR rated. The energy savings to appliance electricity is therefore 18 per cent for residential buildings and 9 per cent for commercial buildings, resulting in a total GHG savings of about 61.5 kilotonnes.

Implementing the 2012 *Ontario Building Code*

The planned 2012 Ontario Building Code will require that all new homes are built to a higher standard of efficiency, similar to R2000 standards (Love, 2009). The Energy Efficient Buildings Estimation Guideline states that R2000 homes use 30 per cent less energy than conventional homes. Implementing this standard for low rise residential buildings would reduce the increase in space heating energy between 2012 and 2031 by 30 per cent. This energy savings corresponds to a reduction of 14.8 kilotonnes of GHG emissions.

Completing the Mayor's Tower Renewal Project

The Mayor's Tower Renewal Project will aggressively retrofit existing 1960s-era high rise towers, as well as promote neighbourhood revitalization initiatives (Kesik et al., 2008). To simulate the effects of this, a 30 per cent savings on space heating energy will be applied to all Toronto Community Housing Corporation buildings, as per the Building Retrofits Estimation Guideline (this 30 per cent saving is conservative; much larger savings are projected for some buildings.). The 2004 Toronto GHG Inventory shows that Community Housing Corporation buildings currently require about 2.9 million GJ of space heating energy a year. Reducing space heating needs by 30 per cent saves 49.4 kilotonnes of GHG emissions.

Promoting commercial green roofs

The Vegetation Estimation Guideline describes green roofs as reducing peak summer cooling loads by 25 per cent in roofs immediately below the green roof. The green roof initiative targets to cover 10 per cent of commercial buildings with green roofs (City of Toronto, 2009b). Assuming the savings would apply to 10 per cent of the cooling energy used by commercial buildings, the total percentage savings to space cooling electricity would be 0.25%. This results in a GHG savings of 0.3 kilotonnes.

Based on the values presented in Table 8.5, the initiatives that will have the greatest impact to GHG emissions are the Mayor's Tower Renewal Project, requiring ENERGY STAR appliances, and banning incandescent bulbs. All five initiatives have a combined GHG savings of about 166 kilotonnes. These initiatives, combined with the lower electrical emissions intensity resulting from Ontario's Integrated Systems Plan, will cause Toronto's buildings to be responsible for 10.6 megatonnes of GHG emissions in 2031.

TABLE 8.5
COMPARISON BETWEEN 2004 TORONTO GHG INVENTORY AND 2004 BASE CASE SCENARIO

	Low-Rise Residential	Apartments	Commercial	TOTAL
Building Stock (km^2)	95.55	76.00	80.13	251.7
Total Energy Before Savings (TJ)	79,306	51,677	132,215	263,199
Heating (natural gas) (TJ)	65,368	42,595	67,551	175,514
Electricity (TJ)	13,938	9,083	64,665	87,686
Emissions Before Savings ($ktCO_2e$)	3,814	2,485	4,469	10,767
SAVINGS				
Incandescent bulbs to CFL Bulbs ($ktCO_2e$)	16.5	10.8	12.8	40.1
All appliances EnergyStar rated ($ktCO_2e$)	15.8	10.3	35.4	61.5
R2000 standards in 2012 OBC ($ktCO_2e$)	14.8	-	-	14.8
Mayor's Tower Renewal Retrofits ($ktCO_2e$)	-	49.5	-	49.5
Commercial roof space 10% green ($ktCO_2e$)	-	-	0.3	0.3
Total Savings ($ktCO_2e$)	47.1	70.6	48.5	166.2
Total Emissions ($ktCO_2e$)	3,767	2,414	4,421	10,601

8.2.2 TRANSPORT

The most significant transport-related government initiative currently planned for Toronto is the Greater Toronto Area's Metrolinx Plan (Metrolinx, 2008), which will increase the availability of public transport. The three other initiatives that were quantified in this scenario include: an increased adoption of electric vehicles; bicycle facility improvements (i.e., increased bicycle lanes and bicycle parking racks); and a 10 per cent increase in parking price to deter auto use.

Subway and LRT

The Metrolinx Plan will result in numerous upgrades to the current TTC infrastructure. The Plan will increase subway routes and construct new LRT lines. Assuming the same number of buses as in 2008, as well as a maintained ratio of transit carriages to track length, the new Metrolinx infrastructure in 2031 will consist of:

- 1,737 buses
- 248 streetcars, 65.6 km of streetcar tracks
- 1,063 subway cars, 102.85 km of subway tracks
- 452 LRT cars, 126 km of LRT tracks

The calculated VKT of each motorized mode in 2031 is shown in Table 8.6.

The per-kilometre emissions intensity (g CO_2e/VKT) of each motorized mode in 2031 (shown in Table 8.6) will be different from the 2004 Base Case due to the lower electrical emissions intensity associated with the Province's Integrated Systems Plan. For public modes, the North American average energy intensity from Table 4.4 (MJ/VKT) was again multiplied by the per-unit-energy emissions intensity (g CO_2e/MJ) of either diesel fuel (in Table 2.2 for buses) or Integrated Systems Plan electricity (10.5 t CO_2e/TJ for subways, streetcars and LRTs).

Increasing adoption of personal electric vehicles

Current provincial government initiatives aim to increase the market share of electric vehicles to five per cent by 2020 (Office of the Premier, 2009). Assuming an exponential increase in years following, the percentage of private automobile VKTs travelled by electric vehicles was taken to be 20 per cent in 2031. The remaining 80 per cent of VKTs were then assigned to internal combustion engines using gasoline that operate with an average fuel mileage of 11.24 L/100km (as in the 2004 Base Case Scenario). The engines of electric vehicles were taken to operate 65 per cent more efficiently than internal combustion engines. Therefore, the average energy intensity (MJ/VKT) was estimated to be 35 per cent of the 11.24 L/100km internal combustion automobiles. The reduced energy requirements would then be met using electricity with the per-unit-energy emissions intensity of the Integrated Systems Plan (10.5 t CO_2e/TJ). With these assumptions, the per-kilometre emissions intensity of electric vehicles was calculated to be 93.55 g CO_2e/VKT. Accordingly, GHG emissions savings associated with the 20 per cent adoption of electric vehicles in 2031 is 4.39 kilotonnes.

Increasing length of bicycle facility to promote active transport

The bicycle facility in Toronto, which includes bicycle lanes and all bicycle supporting infrastructure such as lockers, shower facilities at work place, etc., is planned to increase from 403 km to 1,004 km by 2012 (City of Toronto, 2009a). Assuming this length of facility stays constant through to 2031, it will result in an active-transport mode share of 1.31%. This mode share, applied across all modes, results in a total GHG savings of about 25.1 kilotonnes.

Increasing parking price to deter auto use

While official plans to increase parking prices are not known, a conservative estimate of 10 per cent was made. According to the Parking Price Estimation Guideline, this would result in a mode share decrease of 0.70% for private automobiles and a mode share increase of 0.10% for public transit. The combined effects of these mode share changes resulted in a savings of about 11.7 kilotonnes of GHG emissions.

The final results of the MUNTAG model for the Metrolinx infrastructure, including the GHG emissions savings from each government initiative, are shown in Table 8.6. The most significant savings are associated with changing 20 per cent of personal vehicles to electric vehicles. When combined, the planned initiatives reduce transport-related GHG emissions to about 3.1 megatonnes in 2031.

TABLE 8.6
VKT, EMISSIONS & PLANNED MODE SHARE SAVINGS FOR TORONTO'S METROLINX INFRASTRUCTURE, 2031

	Private Automobiles	Bus	Streetcar	LRT	Subway	TOTAL
VKT per capita (km)	4,017	28	11	21	54	4,131
Emission factor (kgCO_2e/km)	0.271	2.01	0.163	0.175	0.130	
Per capita emissions before savings (kgCO_2e)	1,087	57	1.8	6.3	7.1	1,156
Emissions before savings (ktCO_2e)	3,348	176	5.4	11	22	3,562
TECHNOLOGY SAVINGS						
Vehicle technology						
20% Battery electric vehicles (emissions factor of 94 gCO_2e/km) (ktCO_2e)	439					439
ADDITIONAL MODE SHARE SAVINGS						
Active Transport						
Biking	22	2.3	0.07	0.15	0.28	25

Parking fees						
10% Increase in parking Price (ktCO_2e)	12	-0.2	-0.01	-0.01	-0.02	12
Total Mode Share Savings (ktCO_2e)	473	2.1	0.07	0.14	0.26	476
Total emissions (ktCO_2e)	2,875	174	5.4	11	21	3,086

Note: Values estimated using the MUNTAG model.

In 2031, assuming the currently planned policies and initiatives will be implemented, buildings and passenger transportation will account for 13.7 megatonnes of GHG emissions, or 4.44 tonnes per capita (Table 8.9). Compared to the 2004 Base Case Scenario, this represents a 31 per cent savings in GHG emissions per capita. A large portion of this is due to the reduced electrical emissions intensity associated with the Province's Integrated Systems Plan, as well as a reduction in internal combustion automobile use. The other initiatives outlined in this scenario provide relatively modest GHG savings, which opens potential opportunities for significant savings to be achieved through more aggressive actions.

8.3 ALTERNATIVE AGGRESSIVE SCENARIO FOR 2031

The Alternative Aggressive Scenario explores the GHG emissions in 2031 associated with making aggressive changes to Toronto's buildings and transport infrastructure. The changes draw from some of the most innovative case studies in this guide, and their impacts are quantified using the Estimation Guidelines provided. This scenario represents one aggressive plan that could help Toronto get closer to carbon neutral.

8.3.1 BUILDINGS

The 2031 building stock and associated emissions before savings are the same as in the Planned Policy Scenario; however, the savings in this scenario are more aggressive. In addition to expansion of the initiatives described above, changes involving buildings retrofits and innovative energy systems were applied. Several energy saving measures contributed to reducing emissions:

- replacing all light bulbs with LEDs and all appliances with ENERGY STAR rated appliances
- retrofitting all buildings built before 2012
- designing all buildings after 2012 to low-energy standards
- implementing BTES, solar water heating, and ground-source heat pumps in low rise residential homes

- outfitting half of all apartment buildings with ATES systems
- outfitting commercial buildings with solar air heating and 25 per cent green roof coverage

LED light bulbs and ENERGY STAR appliances

LED bulbs use less electricity than both incandescent and CFL bulbs. They are approximately 90 per cent more efficient than incandescent bulbs and 60 per cent more efficient than CFL bulbs. Assuming the same percentages of incandescent lighting as in the Planned Policy Scenario (70 per cent of residential lighting energy and 10 per cent of commercial lighting energy), and assuming the remaining lighting energy is currently met with CFL bulbs, implementing CFL bulbs would save 81 per cent of lighting electricity in residential buildings and 63 per cent of lighting electricity in commercial buildings. This corresponds to savings of about 150 kilotonnes of GHG emissions. Following the previous method for ENERGY STAR appliances, they will again save about 61.5 kilotonnes of GHG emissions.

Retrofitting pre-2012 buildings

The Building Retrofits Estimation Guideline states that retrofitting can reduce energy demand by 30 per cent for apartments and commercial buildings and can save up to 50 per cent for low rise residential homes. Taking the average energy savings to be 30 per cent for all building types, the GHG emissions savings associated with retrofitting all buildings constructed before 2012 was calculated to be about 2.7 megatonnes.

Designing post-2012 apartments and commercial buildings to low-energy standards

The emergence of accreditation for sustainable buildings has increased the popularity of low energy apartments and commercial buildings. According to the New Energy Efficient Buildings Estimation Guideline, these buildings can be designed to consume 60 per cent less energy than standard. When applied to all apartments and commercial buildings constructed after 2012, this resulted in a savings of about 425 kilotonnes.

Designing post-2012 low-rise residential homes to low energy standards with BTES systems

As demonstrated by the Drake Landing Solar Community in Alberta (Case 5.8), R2000 homes combined with a Borehole Thermal Energy Storage system use 90 per cent less space heating energy than a typical community. If all new low rise homes in Toronto built after 2012 were designed with the same specifications – R2000 energy standards combined with a BTES system – they would save 61.3 kilotonnes of GHG emissions in 2031.

Solar water heating and ground-source heat pumps in pre-2012 low-rise homes

Outfitting low rise residential homes built before 2012 with solar water heating and ground source heat pumps would also decrease fossil fuel based energy consumption. The Solar Water Heating Estimation

Guideline assigns 45 per cent savings to water heating energy needs with the addition of solar heaters in Toronto. If these savings were applied to all pre-2012 low rise residential homes in the city, 445 kilotonnes of GHG emissions would be avoided. Taking an average of the savings described in the Ground Source Heat Pumps Estimation Guideline, outfitting all pre 2012 low-rise residential homes with ground source heat pumps would save 30 per cent on both space heating and space cooling needs – equivalent to a GHG emissions savings of 791 kilotonnes.

ATES systems in half of all apartment buildings

Much of the geology in Toronto may be conducive to the use of Aquifer Thermal Energy Storage systems, which can provide 25 per cent savings to heating energy and 70 per cent savings to cooling energy needs. If half of all apartment buildings in Toronto were serviced with an ATES system, this would result in a total GHG emissions savings of about 223 kilotonnes.

Solar air heating and green roofs on commercial buildings

The Canadair Facility Solarwall (Case 3.5) is an example of an effective solar air heating strategy reducing emissions associated with space heating of commercial buildings. According to the Solar Air Heating Estimation Guideline, there is the potential for a 25 to 47 per cent saving in space heating energy. Using the conservative estimate that a 30 per cent energy savings is possible for commercial buildings in Toronto, solar air heating applied to all commercial buildings could save about 966 kilotonnes of GHG emissions. The green roof initiative described previously could be aggressively extended to cover 25 per cent of commercial buildings with green roofs. Assuming the Estimation Guideline's 25 per cent savings to peak cooling needs would again apply to 10 per cent of the cooling energy consumed, this would result in a savings of 0.7 kilotonnes of GHG emissions.

When combined, all the aggressive savings strategies would result in a reduction of about 5.8 megatonnes of GHG emissions from buildings, as shown in Table 8.7. The strategies with the most significant reductions are building retrofits, commercial solar air heating, and low rise residential ground source heat pumps. With the aggressive savings, buildings account for about 4.9 megatonnes of emissions in 2031 Toronto.

TABLE 8.7
ENERGY USE, EMISSIONS & AGGRESSIVE EMISSIONS SAVINGS FOR THE TORONTO BUILDING STOCK, 2031

	Low-Rise Residential	Apartments	Commercial	TOTAL
Building Stock (km^2)	95.55	76.00	80.13	251.7
Total Energy Before Savings (TJ)	79,306	51,677	132,215	263,199

	Heating (natural gas) (TJ)	65,368	42,595	67,551	175,514
	Electricity (TJ)	13,938	9,083	64,665	87,686
Emissions Before Savings ($ktCO_2e$)		3,814	2,485	4,469	10,767
SAVINGS					
	Incandescent and CFL bulbs to LEDs ($ktCO_2e$)	25.5	16.6	107.8	149.9
	All appliances EnergyStar rated ($ktCO_2e$)	15.8	10.3	35.4	61.5
	All pre-2012 buildings retrofitted ($ktCO_2e$)	1,079.7	566.2	1,074.9	2,720.8
	Post-2012 buildings follow energy efficiency standards ($ktCO_2e$)	-	301.3	124.0	425.3
	Post-2012 homes built to R2000 standards with BTES systems ($ktCO_2e$)	61.3	-	-	61.3
	Pre-2012 homes outfitted with solar water heating ($ktCO_2e$)	445.4	-	-	445.4
	Pre-2012 homes outfitted with ground source heat pumps($ktCO_2e$)	790.8	-	-	790.8
	Half of apartment buildings outfitted with an ATES system ($ktCO_2e$)	-	222.8	-	222.8
	Commercial solar air heating ($ktCO_2e$)	-	-	966.3	966.3
	Commercial roofs are 25% green ($ktCO_2e$)	-	-	0.7	0.7
Total Savings ($ktCO_2e$)		2,418.5	1,117.2	2,309.1	5,844.8
Total Emissions ($ktCO_2e$)		1,396	1,368	2,160	4,922

The transport-related emissions quantified in this scenario involve aggressive changes to transit infrastructure, vehicle technology, and bicycle infrastructure. In addition, aggressive auto use deterrents, such as increased parking fees, taxes and tolls, provide further emissions savings.

Improved transit infrastructure

The current Metrolinx plan will promote significant improvements to public transit by 2031. To examine an aggressive alternative to the current plan, GHG savings were quantified assuming all planned LRT lines would instead be constructed as subway lines. This would cause a significant shift away from automobile use to public transit, resulting in a total emissions savings of about 686 kilotonnes.

Complete shift to electric vehicles

Aggressive actions to completely shift vehicle technology from internal combustion engines using gasoline to electrically powered engines would cause a dramatic reduction in the overall GHG emissions intensity of automobiles. An advanced electric vehicle infrastructure network, such as Better Place's Electric Vehicle Network in Israel (Case 4.9), would promote this shift. Replacing all automobiles with electric vehicles by 2031 would save 1.7 megatonnes of GHG emissions.

Improved bicycle infrastructure

The current plan for the bicycle infrastructure in Toronto is to increase the length of the bicycle facility to 1,004 km by 2012. Continuing to increase linearly through to 2031 would result in a bicycle facility 2,431 km in length. With this aggressive increase, the active transport mode share would be 2.33 per cent applied across all modes, resulting in 26.7 kilotonnes of emissions saved.

Increased parking price

As in the Planned Policies Scenario, the conservative parking price increase of 10 per cent would result in a mode share decrease of 0.70% for private automobiles and a mode share increase of 0.10% for public transit. When applied to the alternative transit infrastructure proposed in this scenario, this would result in GHG savings of about 6.2 kilotonnes.

Introducing taxes and tolls

Results from a study of travel demand strategies for Washington, DC, shown in Table 4.10, outline the mode share changes caused by numerous strategies. Applied to Toronto in 2031, the mode share changes resulting from a VMT tax and a Freeway toll would save 133.6 and 19.2 kilotonnes of GHG emissions respectively. While not quantified in this scenario, since it would mostly impact commuters from surrounding areas, Toronto could effectively implement a Beltway Cordon along the city limits and charge vehicles entering the city to further deter auto use.

The aggressive methods in this scenario result in a total of 2.6 megatonnes of emissions saved (Table 8.8), with the most significant measures including shifting from internal combustion to electric vehicles and switching LRT to subway lines. With all aggressive savings employed, transport will contribute 0.96 megatonnes to Toronto's 2031 GHG footprint.

TABLE 8.8
VKT, EMISSIONS & MODE SHARE SAVINGS FOR TORONTO'S METROLINX INFRASTRUCTURE WITH AGGRESSIVE TRANSPORT CHANGES, 2031

	Private Automobiles	Bus	Streetcar	LRT	Subway	TOTAL
VKT per capita (km)	4,017	28	11	21	54	4,131
Emission factor (kgCO_2e/km)	0.271	2.01	0.163	0.175	0.130	
Per capita emissions before savings (kgCO_2e)	1,087	57	1.8	6.3	7.1	1,156
Emissions before savings (ktCO_2e)	3,348	176	5.4	11	22	3,562
INFRASTRUCTURE AND TECHNOLOGY SAVINGS						
Transit Infrastructure						
LRT infrastructure changes to subway infrastructure (ktCO_2e)	701			11	-27	686
Vehicle technology						
20% Battery electric vehicles (emissions factor of 94 gCO_2e/km) (ktCO_2e)	1,731					1,731
ADDITIONAL MODE SHARE SAVINGS						
Active transport						
Biking	21	4.1	0.1	0.0	1.1	27
Parking fees						
10% Increase in parking Price (ktCO_2e)	6.4	-0.2	0.0	0.0	0.0	6.2
Taxes and tolls						
VMT tax (CO_2e)	134					134
Freeway toll (CO_2e)	19					19

Total Savings (ktCO_2e)	2,613	3.9	0.1	11	-26	2,603
Total emissions (ktCO_2e)	735	172	5.3	0	47	959

Note: Values estimated using the MUNTAG model.

With more aggressive action, building and transport-related GHG emissions could be reduced to 5.9 megatonnes, or 1.91 tonnes per capita, in 2031 Toronto. In addition to the province's Integrated Systems Plan, the most significant contributors to savings involve retrofitting all existing buildings, utilizing renewable heating and cooling systems, and the complete proliferation of electric automobiles. Compared to the 2004 Base Case Scenario, the aggressive actions suggested in this scenario could reduce GHG emissions per capita by 71 per cent.

TABLE 8.9
COMPARISON OF FINAL EMISSION VALUES FOR ALL SCENARIOS AND 2004 TORONTO GHG INVENTORY (ALL VALUES IN TCO2E)

	2004 Base Case	**2031 Planned Policies**	**2031 Aggressive Alternatives**
Population (millions)	2.65	3.08	3.08
BUILDINGS (ktCO_2e)	13,997	10,601	4,922
Low-rise residential (kgCO_2e)	4,498	3,767	1,396
Apartments (ktCO_2e)	2,114	2,414	1,368
Commercial (ktCO_2e)	7,386	4,421	2,160
PASSENGER TRANSPORT (ktCO_2e)	3,169	3,086	959
Private Automobiles ((ktCO_2e)	2,895	2,875	735
Bus (ktCO_2e)	154	174	172
Streetcar (ktCO_2e)	34	5.4	5.3
LRT (ktCO_2e)	-	11	-
Subway (ktCO_2e)	87	21	47
TOTAL (ktCO_2e)	17,166	13,687	5,881
TOTAL per capita (tCO_2e)	6.48	4.44	1.91

The aggressive actions applied to Toronto in this scenario could be successfully applied in any municipality in Canada. Individually, projects invoking these strategies are demonstrating success in cities throughout the world, as described in the previous boxed case studies in this guide. When treated as systems working together, these strategies have allowed for the creation of near-carbon neutral communities, such as Dockside Green and BedZED. Innovative actions that challenge and renew the existing infrastructure in our municipalities is a critical component of Getting to Carbon Neutral.

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APPENDIX A: BUILDING ENERGY USE IN CANADA, BY PROVINCE

		Canada		Ontario		Quebec		British Columbia		Alberta		Manitoba	
		2006		2006		2002		2006		2006		2006	
Single Detached	Energy Intensity (GJ/m2)	0.87		0.83		1.03		0.69		1.22		0.82	
	Stock (million m2)	1,078		442		188		155		110		38	
		Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)
Table 34	Electricity	37.7	19.9	30.2	-	56.3	-	40.0	-	16.0	-	50.4	-
Table 39 for "Canada"	Natural Gas	47.1	22.0	59.9	10.9	7.9	0.8	52.2	2.8	83.2	5.6	43.1	0.7
	Heating Oil	5.7	3.9	3.9	1.1	12.4	1.7	0.6	0	0.0	0	0.2	0
	Other (coal, propane)	1.1	0.6	1.5	0.3	0.4	0	0.7	0.1	0.6	0.1	0.7	0
	Wood	8.4	1.5	4.4	0.3	23.0	0.8	6.4	0.1	0.2	0	5.5	0
Single Attached	Energy Intensity (GJ/m2)	0.8		0.83		0.87		0.64		0.92		0.76	
	Stock (million m2)	168		85		28		23		16		3	
		Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)
Table 35	Electricity	40.2	3.1	32.1	-	65.9	-	42.8	-	19.8	-	51.9	-
Table 40 for "Canada"	Natural Gas	49.1	3.3	60.2	2.1	8.6	0.1	52.2	0.4	79.4	0.6	44.2	0
	Heating Oil	5.6	0.8	3.8	0.2	15.3	0.3	0.5	0	0.0	0	0.2	0
	Other (coal, propane)	1.0	0.1	1.4	0.1	0.3	0	0.7	0	0.5	0	0.7	0
	Wood	4.1	0.1	2.5	0.0	9.8	0	3.8	0	0.2	0	3.0	0
Low Rise	Detached	86.5%		83.9%		86.9%		87.1%		87.3%		92.9%	
Weighted ave of Detached and Attached	Attached	13.5%		16.1%		13.1%		12.9%		12.7%		7.1%	
	Stock (million m2)	1,244		527		214		178		126		42	
Table 36	Energy Intensity (GJ/m2)	0.861		0.830		1.009		0.684		1.182		0.816	
Table 42 for "Canada"		Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)
	Electricity	38.0	17.6	30.5	-	57.6	-	40.4	-	16.5	-	50.5	-
	Natural Gas	47.4	19.5	59.9	9.5	8.0	0.7	52.2	2.5	82.7	5.0	43.2	0.7
	Heating Oil	5.7	3.5	3.9	1.0	12.8	1.5	0.6	0.0	0.0	0.0	0.2	0.0
	Other (coal, propane)	1.1	0.5	1.5	0.3	0.4	0.0	0.7	0.1	0.6	0.1	0.7	0.0
	Wood	7.8	1.3	4.1	0.3	21.3	0.7	6.1	0.1	0.2	0.0	5.3	0.0
Apartment	Energy Intensity (GJ/m2)	0.72		0.68		0.81		0.65		0.92		0.58	
	Stock (million m2)	338		120		117		43		22		9	
		Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)
Table 38	Electricity	47.8	6.5	29.8	0	67.7	-	43.8	-	17.6	-	51	-
Table 45 for "Canada"	Natural Gas	39.4	4.8	63.2	2.6	8.7	0.4	52.5	0.7	81.6	0.8	45.5	0.1
	Heating Oil	8.0	1.4	3.7	0.2	16.8	1.2	0.4	0	0	0	0.2	0
	Other (coal, propane)	0.7	0.1	1.3	0.1	0.3	0	0.6	0	0.5	0	0.6	0
	Wood	4.0	0.2	2.3	0.0	6.6	0.1	2.7	0	0.2	0	2.7	0
Commercial/Institutional	Energy Intensity (GJ/m2)	1.62		1.65		1.8				1.6		1.6	
Table 1	Stock (million m2)	667.7		255.9		126.7				95.8		26.5	
		Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)			Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)
*Quebec data - 2006	Electricity	43.5	26.8	44	-	54.6	-			32.7	-	40.1	-
	Natural Gas	42.9	23.3	47	10	29	3.3			63.4	4.9	55.1	1.2
	Light Fuel Oil and Kerosene	6.9	5.5	4.8	1.4	9.5	1.8			0.1	0	0.8	0
	Heavy Fuel Oil	3.9	3.1	1.8	0.6	5	0.8			1.2	0.1	1.2	0
	Steam	0.2	0	0.1	0	0	0			0	0	0	0
	Other (coal, propane)	2.5	1.7	2.6	0.7	1.8	0.3			2.6	0.2	2.9	0.1
High Rise	Apartment	33.6%		31.9%		48.0%		31.6%		18.7%		25.4%	
Weighted ave of Apartment and Commercial/Institutional	Commercial/Institutional	66.4%		68.1%		52.0%		68.4%		81.3%		74.6%	
	Stock (million m2)	1,006		376		244		136		118		36	
Table 38	Energy Intensity (GJ/m2)	1.318		1.340		1.325		1.067		1.473		1.341	
Table 42 for "Canada"		Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)
	Electricity	44.9	20.0	39.4	-	60.8	-	43.9	-	29.9	-	42.9	-
	Natural Gas	41.7	17.1	52.2	7.6	19.3	1.9	48.4	2.1	66.8	4.1	52.7	0.9

Source NRCan NEUD tables

Saskatchewan		Newfoundland		PEI		Nova Scotia		New Brunswick		Territories		Atlantic		BC and Territories	
2006		2006		2006		2006		2006		2006		2006		2006	
1		0.75		0.59		0.68		0.92		0.7					
38		20		5		35		27		3					
Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)				
23.8	-	64.4	-	15.1	-	45.8	-	61.1	-	33.6	-				
71.5	1.3	0.0	0	0.0	0	0.0	0	2.2	0	6.2	0				
1.4	0	17.8	0.2	70.4	0.2	37.9	0.7	18.2	0.3	40.7	0.1				
1.1	0	1.3	0	5.0	0	3.5	0.1	0.8	0	7.1	0				
2.3	0	16.6	0	9.4	0	12.8	0.1	17.8	0.1	12.4	0				
0.94		0.72		0.6		0.63		0.89		0.66					
2		2		0		3		1		1					
Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)				
22.9	-	65.2	-	15.7	-	45.0	-	64.5	-	38.7	-				
72.7	0.1	0.0	0	0.0	0	0.0	0	2.0	0	5.8	0				
1.6	0	16.4	0	63.1	0	36.9	0	17.7	0	39.1	0				
1.0	0	1.2	0	4.4	0	3.4	0	0.7	0	6.7	0				
1.9	0	17.1	0	16.8	0	14.7	0	15.1	0	11.7	0				
94.7%		90.9%		100.0%		92.1%		96.4%		75.0%					
5.3%		9.1%		0.0%		7.9%		3.6%		25.0%					
38		22		5		38		28		4					
0.997		0.747		0.590		0.676		0.919		0.690					
Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)				
23.8	-	64.5	-	15.1	-	45.7	-	61.2	-	34.4	-				
71.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	6.1	0.0				
1.4	0.0	17.7	0.2	70.4	0.2	37.8	0.6	18.2	0.3	40.3	0.1				
1.1	0.0	1.3	0.0	5.0	0.0	3.5	0.1	0.8	0.0	7.0	0.0				
2.3	0.0	16.6	0.0	9.4	0.0	13.0	0.1	17.7	0.1	12.2	0.0				
0.75		0.59		0.46		0.56		0.68		0.58					
6		2		1		7		5		0					
Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)				
27.4	-	67.4	-	17.2	-	49.8	-	64.2	-	45.2	-				
69	0.2	0	0	0	0	0	0	2.3	0	5.1	0				
1.3	0	15.8	0	63	0	35.7	0.1	18.2	0	34.6	0				
0.9	0	1.1	0	4.1	0	2.7	0	0.7	0	5.5	0				
1.5	0	15.7	0	15.7	0	11.8	0	14.6	0	9.6	0				
2.12												1.56		1.26	
23.4												46.3		93.1	
Shares %	GHG (Mt of CO2e)											Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)
30.9	-											39.1	-	43.9	-
49.5	1.2											2	0.1	46.5	2.7
0.4	0											36.8	1.9	5.8	0.5
13.2	0.5											16.5	0.9	2	0.2
4.4	0											0	0	0	0
1.5	0											5.7	0.3	1.8	0.1
20.4%		4.1%		2.1%		13.1%		9.7%		0.0%					
79.6%		95.9%		97.9%		86.9%		90.3%		100.0%					
29		48		47		53		51		93					
1.040		1.520		1.537		1.429		1.474		1.260					
Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)				
30.2	-	40.3	-	38.6	-	40.5	-	41.5	-	43.9	-				
53.5	1.0	1.9	0.1	2.0	0.1	1.7	0.1	2.0	0.1	46.5	2.7				

APPENDIX B: MUNICIPAL TRANSPORTATION AND GREENHOUSE-GASES (MUNTAG) MODEL

In this appendix, we illustrate a method to translate PKT per capita into GHG emissions for the entire transportation section. Figure B.1 illustrates the MUNTAG (MUNicipal Transportation And Greenhouse-gases) model, which is an empirical model developed for this purpose.

In Figure B.1, the expression "(i)" refers to "input", which means external data is required, whether it can be calculated using some of the methods enlisted below or not.

Note that the standard is "per capita", not "per passenger". In others words, we assume all inhabitants drive, take public transit and walk/bike. The values calculated are averaged over the entire population.

a) Land Use

<u>GDP pc/Pop D</u>

For this component, the desired GDP per capita value in 2002 CAN$ reflects the level of infrastructure considered. For instance, if the commuter rail is included, then the urban area GDP is preferred to the city GDP. GHG emissions from a particular city can then be accounted by using city population only in a later stage. To calculate the GDP of an area, one method is to consider the GDP of a supra-area (e.g., province) by industrial sectors and then scale it down using the ratio of employment of the area relative to the supra-area by sectors.

<u>Motorized PKT/p</u>

This should be calculated by using the estimation guideline present in chapter 4.

b) Private Mode

<u>Private PKT/p</u>

Private PKT per capita is calculated by subtracting transit PKT per capita from the total motorized PKT per capita.

<u>Private VKT/p</u>

Private VKT per capita is calculated based on the values of PKT/p found. The relationship is of the sort:

$$\text{Private: VKT per capita} \approx 0.7 \cdot \text{PKT per capita} + 96.43 \tag{B.1}$$

where VKT per capita is the total annual vehicle kilometres travelled divided by the population for the private mode; PKT per capita is the total annual passenger kilometres travelled divided by the population for the private mode. Data for the regression was calculated from the Millennium Cities Database.

Alternatively, if the average vehicle occupancy "v_occ" of the studied area is known, simply use this equation:

Private: VKT per capita ≈ PKT per capita / v_occ (B.2)

<u>Private GHG/p</u>

Private GHG per capita is based on auto and fuel type. See tables with emission factors in Strategy 5 of the Transportation chapter.

c) Public Transport

<u>Transit-km of transit in m/ha</u>

Transit-km in m should be readily available or estimated for new transit lines; note that it is not needed for the conventional bus mode. For area in ha, use the area of service, i.e., urban area for commuter rail. The same areas should be used for all different public transit modes.

<u>Number of vehicles per million people operating under maximum service</u>

For existing lines, this should be readily available. For new projects, computing the maximum number of vehicles 'v' needed to run a transit line is not evident; here is one possible approximation of 'v':

$$\mathrm{v} = w \cdot \frac{T_c}{h} \times \frac{1{,}000{,}000}{population} \qquad \text{(B.2)}$$

where, 'w' is the number of wagons per transit unit (see Table 4.3), 'T_c' is the cycle time (in mins) and 'h' is the minimum headway (under maximum service operation, in mins).

Furthermore, the cycle time 'T_c' can be estimated using:

$$T_c = 2 \cdot T_o + T_t = 2 \cdot \theta \quad \cdot \frac{V_o}{L} + T_t \qquad \text{(B.3)}$$

where, 'T_o' is the one-way operating time (in mins), calculated as the ratio of operating speed 'V_o' (in km/h, see Table 4.3 for typical values) by the distance 'L' (km). The terminal times 'T_t' (in mins) can be estimated to be approximately 15 per cent of the two-way operating times.

<u>Public PKT/p</u>

Public PKT per capita should be calculated using the estimation guidelines available from the Transportation chapter.

<u>Public VKT/p</u>

Public VKT per capita is calculated based on the values of PKT per capita found. Table B1 shows the relation for each transit mode.

Transit Mode	Relationship	R^2
Conventional Bus	0.0573• PKT per capita + 8.03	0.74
Light Rail Transit	0.0426• PKT per capita + 0.12	0.86
Subway	0.0396• PKT per capita + 0.91	0.98
Commuter Rail	0.0281• PKT per capita – 0.10	0.99

Table B.1: PKT per capita to VKT per capita relationships for transit. VKT per capita is the total annual vehicle kilometres travelled divided by the population for each mode; PKT per capita is the total annual passenger kilometres travelled divided by the population for each mode. Data for the regression was taken from the respective sources for each estimation guideline.

Public GHG/p

Public GHG/p should be calculated based on VKT/p. For the rail modes, the energy consumed in MJ per VKT should be taken from Table B.2. Since conventional buses are not reliant on the electricity grid, emission factors according to fuel type and fuel consumptions present in Strategy 5 should be used. Canadian and US cities should use the North-American averages. The GHG can be then computed by using the emission factor presented in Chapter 5.

	Energy per VKT[1] (MJ/VKT)				
	Bus	**Streetcar**	**LRT**	**Subway**	**Commuter Rail**
Toronto	21.17	12.11		13.22	55.91
Montreal	26.92			9.57	47.24
Ottawa	30.82				
Calgary	21.41		13.06		
Vancouver	20.00			8.86	43.23
European Avg	16.19	13.05	15.19	11.18	12.21
North-American Avg	27.22	15.59	16.77	12.47	47.63

[1]VKT is per wagon-kilometer

Table B.2 Energy use per vehicle kilometres travelled (VKT) for five Canadian cities, plus European and North American averages. (Source: Millennium cities database)

d) Active Transport

Length of Bicycle lanes in m/ha

The length of bicycle lanes in m should be readily available or estimated for new projects. For the area, the same area as for public transportation should be used. This step does not require VKT per se since cyclists and walkers do not produce any GHG emissions no matter the length of the journey. Nevertheless, they save GHG from what they would emit if they had used another mode of transport.

e) Financial Policies

Gasoline or Parking price increase as a percentage and/or Tolls, taxes, area pricing

The tables and estimation guidelines present in Strategy 4 of transportation chapter should be used. If the elasticity is given in total VKT, multiply previous "VKT/p" calculated by population and use this number. If it is given as a percentage reduction, use VKT/p directly.

f) Vehicle Technology

This strategy can be applied anytime since it affects the GHG/p directly. To calculate the benefits of switching vehicle technology, follow steps a) to e), record the number, and then change the GHG/p values.

g) Running the MUNTAG model

This six-step sequential procedure can be followed to run MUNTAG.

1. Land-use; to calculate motorized PKT pc
2. Public transport; to calculate PKT pc, VKT pc and GHG pc
3. Private mode; by subtracting transit PKT pc to motorized PKT pc, and then calculating VKT pc and GHG pc
4. Active transport; to calculate total GHG saved from bicycle infrastructure
5. Financial Policies; use previously calculated private mode and public transport VKT pc to calculate the potential impacts of new strategies; save all results before carrying out step 6
6. Vehicle Technology; apply new emissions factor, re-run steps 2 to 4, and compare values to base case

After steps 1 to 4, the black box at the bottom right, "Total GHG emitted w/o Financial Policies (kt)", can be calculated by summing private and public transit GHG emissions and subtracting the GHG saved from active transportation; this is essentially the base case scenario. Then, step 5 calculates the "Total GHG emitted from transportation (kt)" (blue box at bottom right). Step 6 is rather different since it affects emission factors directly. The base case scenario (steps 2 to 4) should inevitably be compiled first.

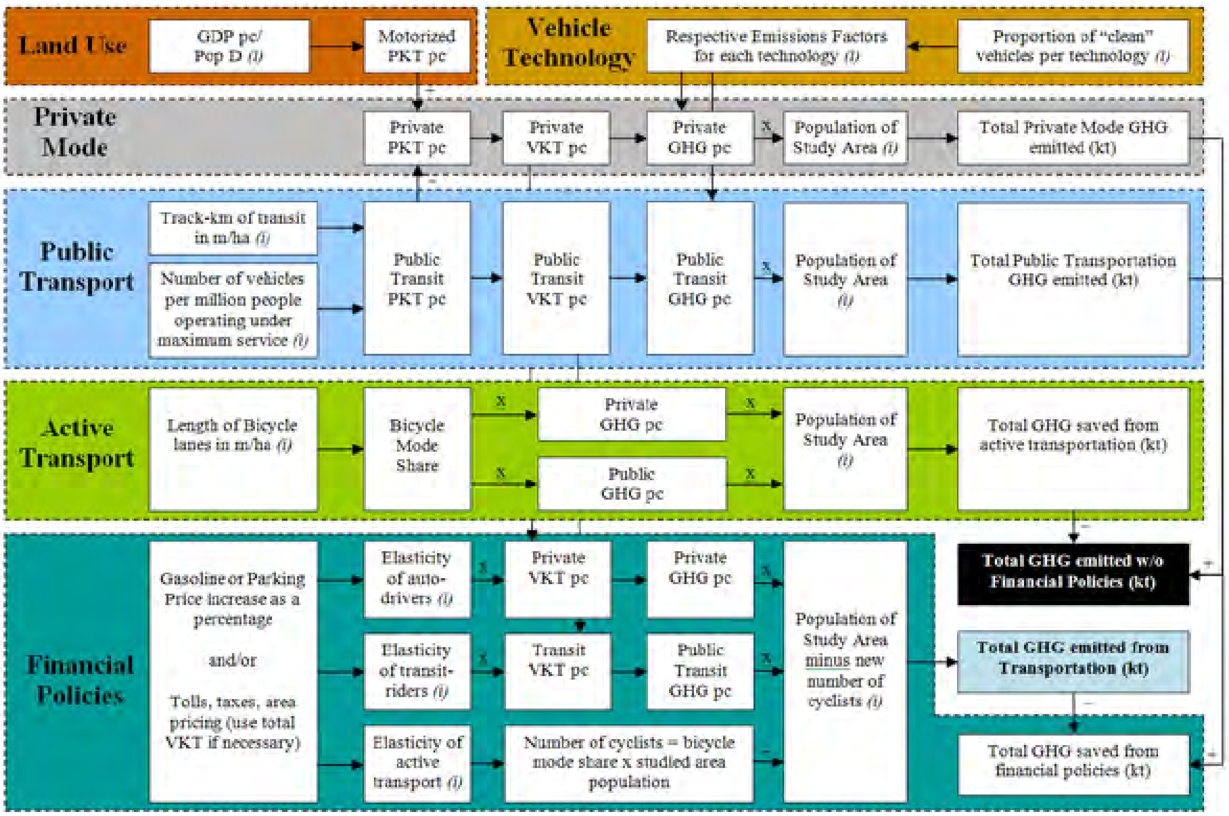

Figure B.1: MUNTAG: MUNicipal Transportation And Greenhouse-gases

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