GETTING TO CARBON NEUTRAL: A GUIDE FOR CANADIAN MUNICIPALITIES

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By

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CONTENTS

CHAPTER 1: INTRODUCTION

(C. Kennedy and E. Mohareb)

With the global urban population now exceeding fifty percent, cities are recognized as a major driver of global greenhouse gas (GHG) emissions. Moreover, as centres of wealth and creativity, with high population densities and economies of scale, cities must play a significant role in tackling global climate change. This is particularly clear in a political context where goals and 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 established inventories of GHG emissions, often using the simple pragmatic approach of ICLEI (International Coalition for Local Environmental Initiatives; see ICLEI, 2009). Within Canada, 157 municipalities are participating in the Partners for Climate Protection (PCP) program. Most of these municipalities have established inventories of GHG emissions, but many are struggling, however, to develop and implement strategies for substantially reducing GHGs.

Yet there are many examples of sustainable design practices both in Canada and elsewhere that have lead to lower GHG emissions for various neighbourhoods or infrastructure systems within cities. Canadian examples include: Calgary’s wind-powered C-train, Toronto’s deep-lake water cooling, and sustainable neighbourhood developments at Dockside Green, South East False Creek, and Okotoks. To these we can add international examples such as Malmo’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. Currently under development is the city of Dongtan, near Shanghai, China, which claims to be the world's first carbon neutral sustainable city.

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 purse a wide-range of such strategies, subject to their own unique conditions, then it is technically feasible for many to become carbon neutral.

The purpose of this guidebook is to assist medium to large Canadian municipalities 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.
- Rules of thumb for estimating the GHG emission reductions from a wide range of strategies that may be pursued by Canadian municipalities.
- An example of how integration of these strategies can be used to reduce a municipalities per capita GHG emissions by over 70%.

Climate Change and the Global Carbon Cycle

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

- environmental damage that would include the extinction of 20-30% 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 impacts are anticipated due, in part, to an imbalance in the global carbon cycle (Fig.1.1). As a consequence of fossil fuel combustion and land-use change, the atmospheric composition of carbon (shown in giga-tones of carbon, GtC) has increased relative to pre-industrial levels. This higher concentration of carbon-based molecules (such as carbon dioxide and methane) in the atmosphere is believed to be causing global climate change, via the greenhouse effect.

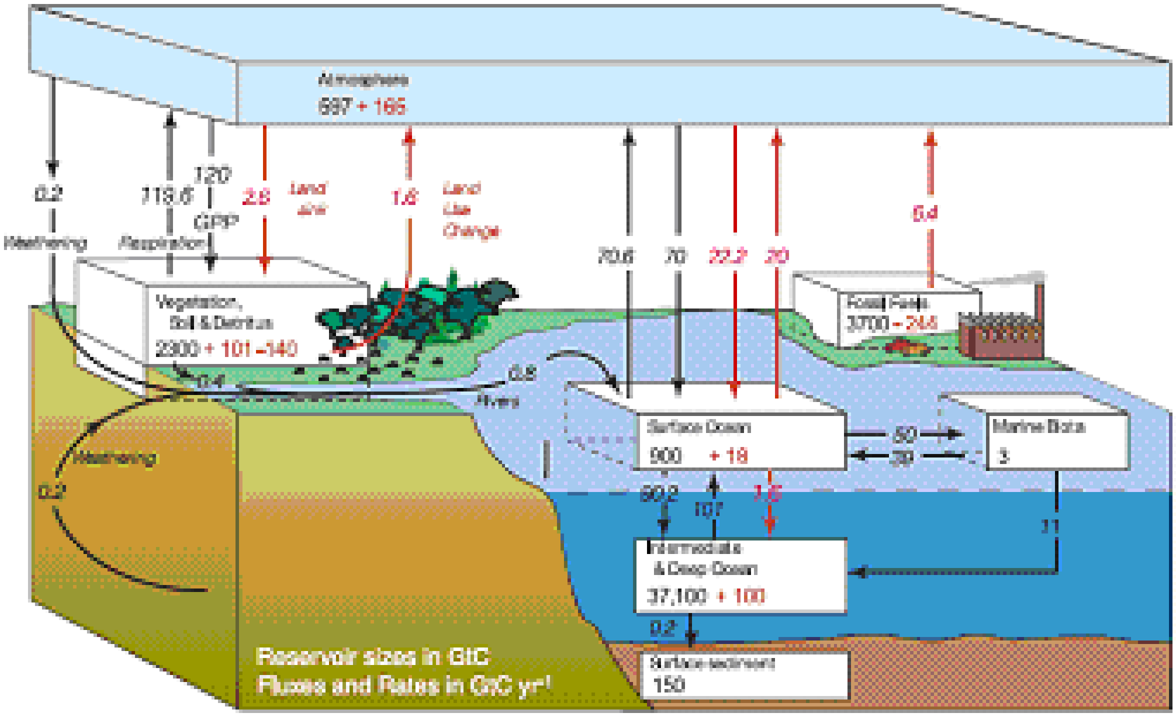

Figure 1.1 The global carbon cycle (Figure 7.3 from IPCC, 2007b)

There are additional compounds which are also considered to 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 impacts of greenhouse gases are typically expressed in terms of their global warming potential. This is a measure of how much a mass of greenhouse gas contributes 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 equivalents (t CO_2 e).

Common name	Chemical formulae	100-yr. Global Warming potential
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide	N_2O	310

Table 1.1 Examples of global warming potential for three common greenhouse gases. (For a full list of global warming potentials see Table 2.14 in the 2007 IPCC Fourth Assessment Report)

The current best estimates from the IPCC fourth assessment report suggest that climate sensitivity (the global average temperature increase related to a doubling of atmospheric CO_2 e concentrations to roughly 550 ppmv) is 3^oC (IPCC, 2007b). In order to achieve a stabilization concentration of 450 ppmv CO_2 e, the IPCC has proposed that Annex I countries (including Canada) must achieve an 80 – 95% GHG emissions reduction by 2050 (IPCC 2007c). The current estimate of global mean surface temperature increase for this concentration is 2.1^oC, which would reduce the likelihood and severity of the anticipated impacts.

How to Use This Guide

This book is primarily a quantitative guide, describing a variety of technological and urban planning strategies that can be used to substantially reduce community GHG emissions for a municipality. The guide also provides some information on the costs of strategies and ways in which barriers to implementation have been overcome. These are demonstrated by about 70 case studies included in this guidebook.

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. Essentially, the inventory is the starting point for a consistent and comprehensive set of calculations that lead through the guide. All reductions in GHG emissions that are determined in the guide can be deducted from the starting inventory.

This may sound straightforward, but some measures taken to reduce GHG emissions from municipalities do not necessarily apply to emissions that are included in most inventories, e.g., greening supply chains, growing local food and some aspects of waste management. A municipality should not get a credit for reducing GHG emissions if the emissions are not recognized in its inventory in the first place.

Part 2 of the guide (Chapters 3-7) 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 carbon sequestration/offsets). For each strategy the guide provides simple, generic rules of thumb for approximately quantifying the reductions in GHG emissions that can be achieved. For example, the formulae can be used to estimate the GHG reductions from: installing X km 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 rules of thumb 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 range of case studies, which are included as *boxed examples* throughout the guidebook. The case studies provide leading edge examples of initiatives that cities/municipalities are taking to reduce GHG emissions, both in Canada and worldwide. The case studies provide information on costs, benefits, implementation, and GHG savings. Thus, the case studies also provide empirical data to support/verify the “rules of thumb” developed in this guide.

The criteria for selection of case studies were:

- strategies that reduce, or prevent growth of, greenhouse gas emissions
- coverage of both Canadian and non-Canadian best practices
- examples from both medium and large municipalities
- primarily focussed 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 analysed 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 shows how the integration of a range of strategies can substantially reduce a municipality’s overall emissions. The inventory process, rules of thumb and other data tables in this guide have been developed in a consistent fashion, so that they can be used together 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.

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CHAPTER 2: INVENTORYING MUNICIPAL GHG EMISSIONS

(C. Kennedy)

Many Canadian cities have already determined their inventories of greenhouse gas emissions under the Partners for Climate Protection (PCP) program. This chapter reviews the inventorying process, however, since it is a necessary starting point to put reduction strategies in context. Here, we review the calculation of GHG emissions from major sources: electricity, heating fuels, and transportation fuels, as well as typically secondary sources such as industrial process emissions, and waste. (Emissions from agriculture, forestry and land-use change are excluded.) We also discuss emissions that can be attributed to cities, such as aviation, marine and upstream emissions, but 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_2 e. From a practical perspective, emissions of CO_2 itself dominate the urban inventory, with methane of significance for landfilled waste, and other gases mainly of significance for industrial emissions where they occur.

Electricity

GHG emissions (t CO_2 e) attributable to total electricity consumption in a municipality are determined by:

$$GHG_{electricity} = C_{electricity} \cdot L \cdot I_{electricity} \qquad (2.1)$$

The electricity consumption, $C_{electricty}$ (GWh), may exclude that from combined heat and power (CHP) plants within the municipality and electricity derived from the combustion of waste. From a data collection perspective it is often easier to use a convention of including emissions from CHP and waste combustion under heating fuels and waste, respectively.

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

The GHG emission intensity, $I_{electricity}$ (t eCO_2/GWh), is typically taken as that for 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 is often changing 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.

There is considerable variation in the GHG intensities of electricity supply between Canadian provinces. Alberta and Saskatchewan rely heavily upon coal combustion for power generation, and hence have emission intensities above 800 t CO_2 e/ 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. 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.

	NL	**PEI**	**NS**	**NB**	**QU**	**ON**	**MB**	**SK**	**AL**	**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

Table 2.1 Provincial electricity generation by source, and GHG emission intensity of electricity generated for 2006 (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 (t CO_2 e) for each fuel used, GHG_{fuel}, are determined by:

$$GHG_{fuel} = C_{fuel} \cdot I_{fuel} \quad (2.2)$$

where C_{fuel} (TJ) is the amount of fuel consumed, expressed in terms of its energy content. Table 2 gives the default IPCC (2006a) GHG emissions factors for fuels, I_{fuel} (t CO_2 / TJ) which can be used for calculating direct emissions.

	Energy content (TJ/ML)	**Direct Emissions** (t CO_2 e / TJ) IPCC[1]	**Lifecycle Emissions** (t CO_2 e / TJ) GHGenius (Canada)
Gasoline (Low Sulphur)	34.8	72.2	94.9
Diesel	37.8	75.2	92.3
Jet Kerosene	35.1	72.0	92.5 [2]
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[3]
Fuel Oil	Varies	77.8	91.6
Coal:	N/A		
Anthracite		98.1	100.8
Coking/Bituminous		94.4	107.1

Table 2.2 Direct and Lifecycle GHG Emissions Factors for Fuels (t eCO_2 /TJ).

Note1: Includes average tier 1 emission factors for CO_2, CH_4 and N_2O.
Note 2: The lifecycle emission factor for Jet Kerosene of 92.5 t eCO_2 /TJ was determined by assuming the same upstream contribution as diesel fuel.
Note 3: The lifecycle emission factor for natural gas was determined from processing data from GaBi4 and distribution losses reported by TransCanada pipelines.

Ground Transportation Fuels

The fuels used for ground transportation within cities are primarily gasoline and diesel, with small amounts of LPG and natural gas used in some cases. Emissions due to use of electrified modes of transportation, e.g., subways and streetcars, should be 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% 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: i) local fuel sales data; ii) scaling from provincial data using motor vehicle registrations; or iii) estimation from vehicle kilometres travelled (VKT) within cities determined using a computer model, or vehicle counting approach. The differences between these techniques can be less than 5% (Kennedy et al., 2009a).

Industrial Process Emissions

Direct industrial emissions include those from processes such as cement manufacturing and limestone consumption. They do not include emissions from industrial combustion of fossil fuels for heating. Data for this category of emissions can be difficult to determine for some municipalities. Industrial facilities with emissions greater than 100,000 t CO_2 e are, however, required to report to Environment Canada. Data for specific facilities are available at: http://www.ec.gc.ca/pdb/ghg/onlinedata/DataAndReports_e.cfm

Waste

A simplified version of the IPCC recommended approach for estimating the GHG emissions from landfill waste is given here. The ideal aim would be to calculate the methane emissions for a given year due to the decay of waste placed in the landfill during that year and previous years. The IPCC (2006) recommends an approach called *First Order Decay* for estimating such emissions based on the Scholl Canyon model. The data requirements are, however, cumbersome, requiring ideally twenty or more years of data for each facility within each city, and good estimates of decay coefficients. The method below is a pragmatic adaptation of the IPCC (1997) approach called *Total Yield Gas* and is based on the amount of waste landfilled in the inventory year.

The long-term GHG emissions from landfill waste (t CO_2 e) are given by:

$$\hat{GHG}_{\text{landfill}} = 21 \cdot M_{\text{landfill}} \cdot L_0 \left(1 - f_{\text{rec}}\right)\left(1 - OX\right) \tag{2.3}$$

where 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, in equation (2.5) is typically no higher than 0.1.

The methane generation potential, L_0 (t CH_4 / t waste), is determined using the IPCC (2006) approach as follows:

$$L_0 = {}^{16}\!/_{12}\, MCF \cdot DOC \cdot DOC_F \cdot F \tag{2.4}$$

where:
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 equal to 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.

The degradable organic carbon, DOC, is estimated from waste fractions, f_i, as follows

$$\mathrm{DOC} = \sum_{i} \mathrm{W_i} \cdot \mathrm{f_i} \quad (2.5)$$

where the weightings W_i are as shown in Table2. 3.

Waste fraction	$\mathbf{W_i}$
Food	0.15
Garden	0.2
Paper	0.4
Wood	0.43
Textiles	0.24
Industrial	0.15

Table 2.3 Weight fraction of DOC (degradable organic carbon) of particular waste streams (Source: IPCC waste model spreadsheet, available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html).

Aviation and Marine Transportation

GHG emissions from air and marine transportation are often not recorded in the inventories of Canadian municipalities, although some large global cities, notably London and New York City do report them as additional items. There is currently no standard approach for quantifying these emissions. Perhaps it might be appropriate to include only those emissions associated with travel by residents of a city, or movements of goods consumed only by residents of a city. On the other hand, if a city is a major gateway, or an attractor for visitors and conventions, then that gateway function is part of what the city does – and contributes to its economy. From a practical perspective, perhaps the only consistent means to determine GHG emissions from aviation and marine transportation is from the volumes of fuels loaded onto planes and ships in cities respective airports and marine transport terminals. Emissions can then be determined from equation 2.2 using the appropriate emissions factor from Table 2.2.

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 inventorying 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 t CO_2 e / GWh that year. (The intensity decreased to 180 t CO_2 e / GWh by 2006, as shown in Table 2.1, due to reduced use of coal generation). Allowing for line losses of 12% (i.e., L = 1.12 in equation 2.1), the GHG emissions produced in providing electricity to Toronto were 6,208 kt CO_2 e.

Heating and industrial fuel use in Toronto is predominantly by natural gas, although small amounts of fuel oils and other fossil fuels may be used. Consumption of natural gas in 2004, was 165,182 TJ (Table 2.4). Using the IPCC's emissions factor of 56.1 t CO_2 e /TJ (Table 2.2), the GHG emissions from Toronto's natural gas use were 8,672 t CO_2 e (using equation 2.2)

	Residential	**Commercial and Small Industrial**	**Large Commercial and 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_2 e)				
Natural Gas	4,700	2,475	1,497	8,672
Electricity	1,295	4,409	504	6,208

Table 2.4 GHG emissions from electricity and natural gas consumption for Toronto in 2004 (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 ML and 0.779 ML (million litres) respectively. GHG emissions from ground transportation were thus determined to be 8,772 kt CO_2 e.

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 kt CO_2 e (Kennedy et al. 2009a,b). These are facilities that have emissions in excess of 100 kt CO_2 e, and are required to report to Environment Canada. There could possibly be facilities with smaller emissions within the City of Toronto, but these are unknown.

Toronto Pearson Airport also lies outside of the City of Toronto. (It is located in 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 kt CO_2 e. None of this fuel is actually combusted in Toronto, and moreover, 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 kt CO_2 e was 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 years 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 kt CO2 e (The is based on a total landfill tonnage of 4,091,465 tons, with composition as given in Table 2.5; Kennedy et al., 2009a,b).

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

Table 2.5 Composition of land filled waste (residential and commercial) for the Greater Toronto Area in 2005 (Toronto City Summit Alliance, 2008).

The City of Toronto's total GHG emissions from major sources for 2004 were 24,600 kt CO_2 e (Table 2.6). This value excludes emissions from (non-energy) industrial processes, aviation, marine and commercial waste, as well as minor source and sinks such as agriculture. (Note that the City of Toronto (2007) reports emissions of 24,400 kt eCO_2 for 2004; the minor difference with Table 2.6 lies in the emissions factors used for ground transportation.)

	GHG emissions (kt eCO_2)
Natural Gas	8,672
Electricity	6,208
Gasoline	6,558
Diesel	2,214
Landfill Waste	978
Total	24,630

Table 2.6 Summary of direct GHG emissions from major sources for the City of Toronto in 2004.

Upstream Emissions

Beyond the seven categories of GHG emissions described above, there are further emissions that can be attributed to cities, but are 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.

These upstream emissions can be substantial. To demonstrate this, the life-cycle emission factors from Table 2.2 can be used to recalculate the GHG emissions from transportation fuel combustion that could be attributed to the City of Toronto. GHG emissions from gasoline increase by 31% from 6,558 to 8,620 kt CO_2 e; and diesel emissions increase by 23% from 2,214 to 2,717 kt CO_2 e.

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CHAPTER 3: BUILDINGS

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

As major consumers of heating fuels and electricity, buildings account for considerable proportions of GHG emissions in Canadian cities today. Three broad strategies for reducing these emissions are presented in this chapter: reduce demands; utilize solar energy; and exploit waste heat through ground source heat pumps. Other strategies involving changes to neighbourhood or local energy supply systems are covered later in Chapter 5. The strategies considered in this chapter are all at the building scale.

Strategy 1: Reduce Energy Demand

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

As a basis for understanding the potential to reduce building energy demands we start with the energy intensity of the current building stock. Table 3.1 provides energy use per gross floor area for residential and commercial buildings in each Canadian province (for more detailed data see Appendix A). There is clearly variation between provinces depending on factors such as 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 then Table 3.1 can be used as a starting point.

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

Table 3.1 Energy intensity (GJ/m^2) of the Canadian building stock, by province, as of 2006. Note Atlantic provinces treated as one region for commercial / institutional data (Source: NRCan NEUD tables). Note: excludes industrial buildings.

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 a 240 m^2 (2583 ft^2) detached house in Toronto designed using typical building standards of different eras. The 1930s version of the house consumes 2.7 times more energy than the same house built to R2000 standards.

Era	Description	Annual energy use per gross floor area (GJ/ m^2)	Annual energy use per gross floor area after basement and air leakage retrofits (GJ/ m^2)
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

Table 3.2 Impact of building era and retrofitting on the energy demand of a 240 m^2 (gross floor area) detached Toronto home. 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% reduction in air infiltration rates). (adapted from Tables 1, 3 and 5 of Dong et al., 2005)

a) Building Retrofits

The example in Table 3.2 also shows the effect 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%.

A wider study of 3,116 potential retrofits to Toronto region homes found possible energy savings of up to 74%. The average energy saving of Toronto homes in the EnerGuide for Houses Database was 22.4%, as simulated by CREEDAC. The standard deviation was 15%.

Only a few studies of energy savings from retrofitting high-rise buildings were found in our review. The rule of thumb below 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.

Rules of Thumb – Building Retrofits

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

b) New Energy Efficient Buildings

Newer buildings are already typically more energy efficient than older ones, but there is potential to increase efficiency yet further by designing residential homes that exceed R-2000 standards, and commercial buildings that surpass the Model National Energy Code of Canada for Buildings (MNECB).

Rules of Thumb – New Energy Efficient Buildings

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

Case 3.1: Regent Park Redevelopment, Toronto, Ontario

Regent Park is a 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% less energy intensive than similar conventionally designed buildings. Some of the energy saving measures include:

i) Advanced building envelope systems including shading as well as stringent insulation and windows

ii) 50% higher insulation standards for walls, roofs, and below grade

iii) Efficient HVAC with heat recovery and radiant heating systems

iv) 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%, from 39,300 to 7,900 t 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.

c) Energy Efficient Appliances and Lighting

There are a number of efforts to promote the energy improvement of appliances and some of them have already proven successful. The ENERGY STAR labeling program is a voluntary labeling program started by the US Environmental Protection Agency (EPA) in 1992 and now jointly operated with the US Department of Energy (DOE). The total energy saving obtained during the first four years (1996-1999) of the ENERGY STAR labeling campaign for appliances was 64 petajoules (Webber et al. 2000). The EnerGuide label, initiated by Natural Resources Canada, shows annual energy consumption for major home appliances in 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, EnerGuide and ENERGY STAR programs cooperated for labeling, and 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 3.3 (Kikuchi et al., 2009). Data for this comparison are from the US EPA/DOE (2006) and NRCan.

(2005). A 30% saving in electricity use is achieved using the energy-efficient appliances, which is in the middle of the range given in the rule of thumb below.

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**

Table 3.3 Energy use by conventional and energy-efficient appliances and lighting in a four-person home (Kikuchi et al., 2009).

Rules of Thumb – Energy Efficient Appliances

- Typical ENERGY STAR labeled appliances can save 10-50% 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.

d) Vegetation – Green Roofs and Urban Forestry

Here we consider the impacts of vegetation on reducing building energy use, rather than the sequestration of CO_2 through photosynthesis. The primary two vegetation strategies for reducing building energy use are the installation of green roofs (Case 3.2), and the planting of urban trees close to buildings. (Planting of vertical gardens – vegetation on the side of buildings - is a further possible 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 evapotranspiration. 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: Green Roof at the California Academy of Sciences, San Francisco, California

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
(2) 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/cooling energy demands through shading, reducing wind speeds, and related microclimatic effects. (McPherson et al., 1994; Engel-Yan, 2005).

Rules of Thumb – Vegetation

- Savings in peak summer cooling loads of 25% in rooms immediately below green roofs. (Saiz et al 2006)
- Green roofs typically reduce annual building energy demand by about 5% (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% (McPherson et al., 1994)

Strategy 2: Utilize Solar Energy

Except for in very dense financial centres, the solar radiation that strikes urban neighbourhoods by 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.

a) Photovoltaics

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 lead the market in the early 1990s, we focus on grid-connected systems, which are now predominant. 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 2003a). Therefore, they do not need battery units and are less expensive than off-grid system.

Although photovoltaic systems are currently not cost-effective compared with conventional electricity supply, the market for photovoltaics has significantly expanded all over the world, especially in the US, 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 30-45% 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; and 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 (tilt = latitude). The typical efficiency at which this radiation is converted into electricity can vary between 7 and 13% depending on the type of cells installed (Table 3.3).

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

Table 3.3: Photovoltaic Cell Type Efficiency and Output Comparison (adapted from RETScreen; see also Prasad and Snow, 2005)

Rules of Thumb – Photovoltaics

Annual Energy Output ≈ 70 + 310 • average daily radiation

where: 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, New York

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 3809 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%, 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

b) Solar Water Heating

Solar water heaters are a relatively inexpensive technology which even in simple applications may be used to provide the energy for 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 3.4), through which a flowing fluid (water, glycol, or other) 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, e.g., through the use of under-floor heating, or in combination with underground energy storage (see Case 5.8).

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, okay for service water heating
Evacuated Tube	Most expensive, best performance under varying climatic conditions

Table 3.4: Solar Water Heating Collector Types

Rules of Thumb – Solar Water Heating

Solar water heaters can provide 25% to 49% energy savings for service hot water needs (NRCan, 2003b). See Fig. 3.1

Figure 3.1 Potential contributions of solar water heaters to energy for water heating in different Canadian cities. (Assumes a freeze-protected system with 6 m^2 single-glazed flat plate solar collectors and two 270 litre hot water tanks; NRCan, 2003b)

Case 3.4: Solar Water Heating, Citè Jean Moulin – Plantes, Paris, France

This 759,000 Euro project encompassing 13 buildings, aids in providing 637 dwellings with domestic hot water. The dwellings consume 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 t CO2e.

Reference:

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

c) 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 and a circulation and control system. Solar collectors are generally one of three types: transpired plate, glazed panels and 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 draws outside air into the system while the 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.

Rules of Thumb – Solar Air Heating

Solar Air Heaters can provide 25% to 47% 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 which 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 CAD therefore the incremental cost of the solarwall was $285,000 CAD. The system delivers 23,000 GJ annually, and after comparing the differences in electricity use between the conventional and solarwall system, if fuel cost is taken at 0.25/m^3 CAD the system has a simple payback time of only 1.7 years.

Monitoring results show the combined effects from the solarwall, reduced heat loss, and destratification of indoor air results in a contribution of approximately 2.63 GJ/m2 of collector area based on an 8 month heating season. Hence, the solarwall saves 720,400 m^3 of natural gas/yr, reducing GHG emissions by 1,342 t CO2e /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.

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 and so are addressed later 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 in 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 which enables investors to pay back capital expenditures from savings derived from the use of GSHPs (Lund et al. 2005).

Rules of Thumb – 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% to 70% in the heating mode and 20% to 50% in the cooling mode can be obtained. Energy savings are even higher when compared with combustion or electrical resistance heating systems." (RETScreen)

Case 3.6: GSHP at the Metrus Commercial Building, Concord, Ontario

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 (35,000 sq. ft.). 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 m deep boreholes are spaced 4.6 m apart. Water is pumped through these boreholes via a closed pipe system to pick up 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, last updated June 9 2006, NRCan, http://www.canren.gc.ca/renew_ene/index.asp?CaId=48&PgId=1013, accessed November 4, 2008.

Case 3.7: GSHP at the 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 1200 employees while maintaining a target value for electricity and heat/cold demand of 100 kWh/m^2/yr (35% below conventional offices). To accomplish this, the heated/cooled area of 44,500 m^2 is served by 154 boreholes, each 70 m deep, arranged in two configurations. The boreholes are spaced at 5 m 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% of annual cooling and 70% of annual heating). The boreholes are arranged in 2 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 300,000 DM in annual energy costs.

Reference:
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CHAPTER 4: TRANSPORTATION AND LAND-USE

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

Arguably the most challenging area for reducing GHG emissions is that of transportation and land-use. As Kennedy *et al.* (2006) put 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.

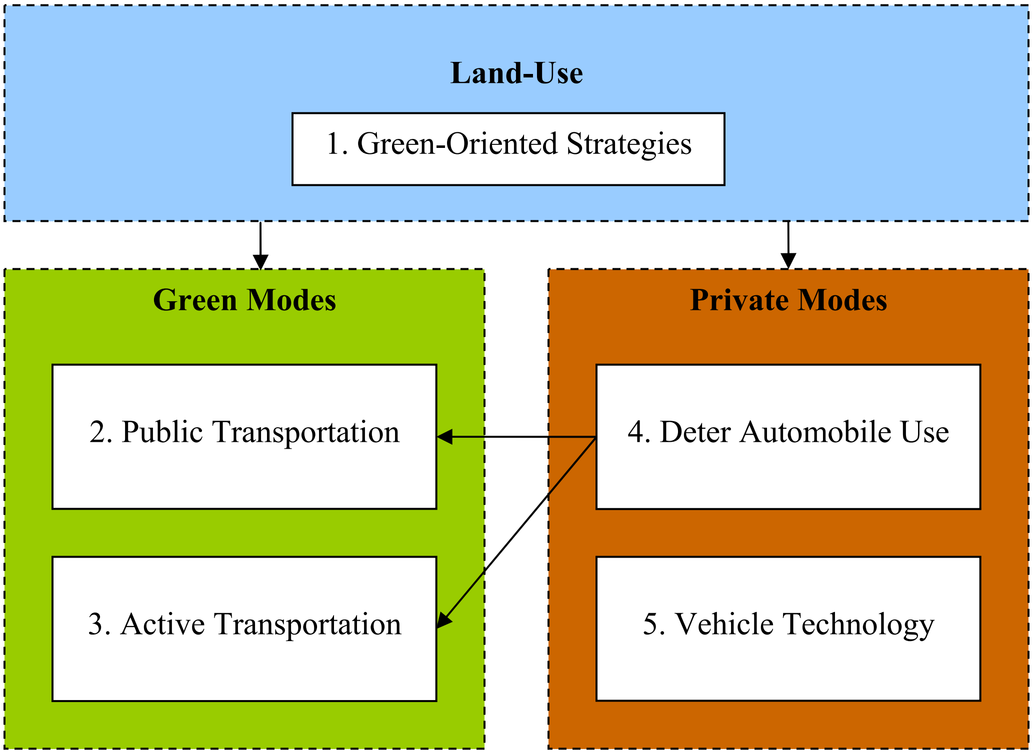

Figure 4.1: Interactions between five strategies developed in this guidebook

Figure 4.1 offers an illustration of the interactions between the five different strategies addressed in this guidebook. The first four strategies considered here all aim at reducing automobile use, either through changes to land-use, investment in public transportation, encouraging active transportation modes (walking and cycling) or deterring automobile use by financial or other means. The separation of these strategies is somewhat artificial since to substantially reduce automobile use requires an integrated approach with actions in all four areas. Strategy 5 is to change vehicle technology.

The extent to which GHG emissions are reduced by using electric transit (strategy 2) or electric automobiles (strategy 5) does depend on the electrical supply mix servicing a municipality. The GHG intensity of electricity supply in Canada varies from 6 t CO_2 e / GWh in Quebec to 800 t CO_2 e / 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 between jobs, residences and amenities are more conducive for non-auto modes; the percentage of auto-trips is 63% compared to an average of 80% for all zones (Table 4.1). An even lower automobile mode share of 56% 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%. Clearly appropriate land-use and attention to detail in neighbourhood design are important for supporting public transportation.

	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

Table 4.1: Mode split for Transportation Tomorrow Survey (TTS) zones in the Greater Toronto Area for 2001. Mixed land-use is defined as that with >30% residential area and >18% commercial area within 1 km of the zone centroid. A zone with a TTC subway stop and/or a Spadina LRT stop within 1 km of the zone centroid is considered to be well served (Green 2006).

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 found by Kennedy et al. (2009). Increasing population density through intensification of land-use is the first strategy for reducing GHG emissions from urban transportation.

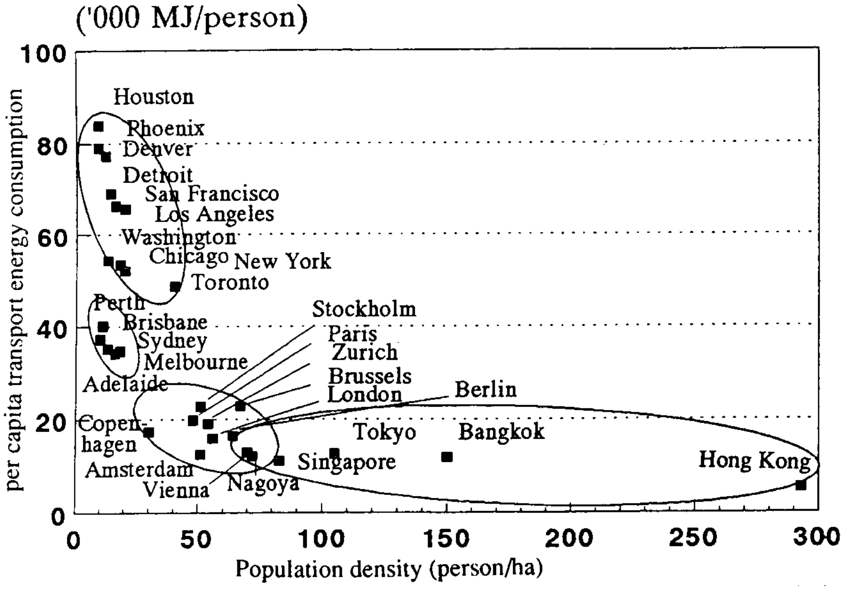

Figure 4.2: Variation in annual transportation energy consumption and population density between several global cities (Newman and Kenworthy 1991)

Rather than using a relationship between population density and energy use, we start at a more fundamental level by developing a rule of thumb 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 ridden by a person; we use the year as our reference (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.

Rules of Thumb – Motorized Passenger Kilometres Travelled (PKT)

$$\text{Motorised PKT per capita} \approx 2.78 \bullet (\text{GDP per capita} / \text{population density}) + 4747$$

$(R^2=0.80)$

where: motorized PKT per capita includes trips by both public and private transportation; GDP is urban gross domestic product in 2002 $CA; population and population density is 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 from 93 cities worldwide (Millennium cities database)

The rule of thumb 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 hence calculated by subtracting the public transportation PKT from the total motorized PKT as computed here. These relationships have been incorporated into a new empirical model of GHG emissions from urban transportation developed for this guidebook. The structure or the model, called MUNTAG (MUNicipal Transportation And Greenhouse-gases), is detailed further in Appendix B; it notably includes a method to translate these PKT per capita into GHG emissions. In this chapter, only the relevant rules of thumb are given.

Strategy 2: Public Transportation

Improving public transportation is seen as a key strategy towards reducing GHG emissions for the transportation sector. Cities with high-quality and reliable transit infrastructure and service typically show high transit mode-share and a lower transportation carbon footprint per capita. Public transportation is partially reliant on population density. This is true in some European and Asian cities where density has built-up and the auto mode is simply not an option due to congestion-related problems. However, there are other factors that are determining to develop and design a highly-used transit system; such factors include 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 build up density and hence 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.

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

Table 4.2 Relationship between Land Use Density and Transit Potential, studies for the Greater Toronto Area, taken from Metrolinx (2008)

Travel demand, in terms of trips per hour, may, however, 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, Table 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 therefore 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.

Characteristics Mode Category	ROW category	Mode	Wagons per Transit Unit	Line Capacity (sps/h)	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

Table 4.3 Transit Characteristics for each mode, adapted from Vuchic (2005a). 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.

In this section, we have therefore developed a rule of thumb for each public transport mode, i.e., conventional bus, light rail transit (LRT), subway and commuter rail; we have not been able to develop one for Bus Rapid Transit (BRT) although we illustrate an example. These rules of thumb can be applied to existing and planned infrastructure. The data required is track-km 'L' in 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.[1]

Before looking at each transit mode specifically and developing rules of thumb, 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 shows 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, it seems the Montreal subway is more efficient than the Toronto subway, and the opposite is true for their respective commuter rail systems.

	PKT per track-km			
	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 Avg		3,383,406	26,339,997	5,875,131
North-American Avg		7,935,681	16,166,881	1,817,752

Table 4.4 Passenger kilometres travelled (PKT) per kilometre of track for five Canadian cities, plus European and North American averages. (Source: Millennium cities database and Canadian Urban Transit Association)

Consequently we can review the energy efficiency of each mode. Table 4.5 shows the energy consumed in MJ for each transit mode per PKT for five Canadian cities in comparison to the European and North American averages. Notably, the Toronto streetcars, Montreal subway, Calgary LRT, and Vancouver Skytrain (shown as subway) perform better than European and North American averages. We see, however, that a similar observation can be made between the Montreal and Toronto subways and commuter rail systems, i.e., a higher PKT per km of track requires less energy.

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[1] Note that the PKT values rendered by the rules of thumb 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 linked to public transportation.

Nevertheless, it should be noted that these values are also dependent on the specific technology chosen for each mode.

Energy-use per PKT (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 Avg	0.58	0.69	0.48	0.87
North-American Avg	0.65	0.60	0.60	1.37

Table 4.5 Energy use per passenger kilometres travelled (PKT) for five Canadian cities, plus European and North American averages. (Source: Millennium cities database)

a) Conventional Bus

The conventional bus constitutes one of the largest portions of the public transportation infrastructure currently in place. Its history and popularity, however, remains anecdotal when we consider that it first thrived in the 1950's whereas the horse-drawn omnibus was invented in the early 1820's, the subway was first introduced in the 1860's and the streetcar arrived at the end of the 19th century. Since it does not have to be wired-up, be on rails and has a shared right-of-way, it is considered to be "flexible", hence its attractiveness for low demand corridors and also, as feeder to higher-grade transit modes. Capital costs requirements are also significantly lower compared to rail modes. Nevertheless, it is a large emitter of GHG due to its fuel type (i.e. diesel); a cleaner type of fuel would be biodiesel. Moreover, recent technological advances have made it possible to develop hybrid-electric buses and hydrogen powered buses. Furthermore, it is also possible to have them fully electric by using an overhead cable similar to streetcars; they are then called trolleybuses.

Rules of Thumb – 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 from 34 US cities (American Public Transit Association database)

The rule of thumb only considers the number of vehicles per million people under maximum service; a value of track-km in m/ha could not be collected since this mode shares its right-of-way with the auto traffic.

b) Bus Rapid Transit (BRT)

The Bus Rapid Transit (BRT) has become a strong candidate for the future of public transportation. Indeed, it combines the flexibility of a conventional bus while having the reliability of a light rail system. In other words, it enjoys a semi-exclusive right-of-way and does not require a separate depot to store the vehicles. Moreover, capital costs needed are smaller than those for LRT projects. It is mostly applied on low to medium demand corridors. One famous BRT system is in Curitiba, Brazil (Case 4.1); however, it remains an on-going topic of debate in the transportation community. Indeed, although being attractive, BRT does not carry the same image and feeling of permanence that rail-based transit modes have. In addition, past a certain capacity, BRT actually 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 then be fairly easily converted to a LRT line in the future; one method is outlined in Wood (2006). In terms of GHG emissions, although BRT uses the same technology as conventional buses, it can be thought of being more efficient since it carries more passengers and makes less frequent stops; it can also be powered with biodiesel, hydrogen or be hybrid-electric.

Case 4.1: Curitiba Bus Rapid Transit, Brazil

Since the 1965 Master Plan for the city of Curitiba limited uncontrolled growth by directing development along linear corridors, 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 km of exclusive bus lanes. Although the city of Curitiba has one of the highest automobile ownership rates in Brazil, about 70% 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 reduced. This has resulted in reductions 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 is also emerging as a potential hybrid between the BRT and the LRT. It is the rubber-tired tram; one example is the Tram-on-Tyre in Caen, France (Case 4.2).

This technology is electrically powered, and the vehicles are guided by a central rail while having rubber tires. Like the BRT, it does not require a special depot to store the vehicles, and yet, the presence of a guiding rail gives this technology the same image a typical light rail does. Capital costs are also significantly reduced compared to light rail systems.

Case 4.2: Caen Tram-on-Tyre, France

Caen (114,000 inhabitants in city and 395,000 in urban area) has one tramway (segregated streetcar) line with two branches at both ends; it follows a North-South axis. The line is 15.7km long, has 34 stations and a typical headway of 4-5min (9min on each branch). Every day, 40,000 trips are registered on the line. Its particularity lies in the technology used. Instead of running on two rails, rubber-tyred vehicles are used; one rail, each way at the centre, guides the tramway (Bombardier vehicles). It offers more comfort and braking is safer. The technology also allows the vehicles to be stored in any bus terminals; hence a reduction in capital costs. In fact, it can be viewed as a hybrid between electric BRT and LRT *(1, 2)*. While capital costs are lower than for a standard LRT, the image of the Caen tram is as effective as an LRT. A second line is presently 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/, November 8, 2008

c) Light Rail Transit (LRT)

The Light Rail Transit (LRT) technology is relatively "old" since it was first introduced in the late 1800's (essentially the streetcar technology). The trend, however, faded in the subsequent years, before being resurrected at the end of the 1970's and beginning of the 1980's. There are now many light rail systems throughout North America and around the world. This 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 then becomes semi-exclusive once it enters the core area. There are a few different 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 are linked to the type of electricity generation since this mode is fully electric. Furthermore, it seems to be always more environmentally-friendly than the BRT (Puchalsky, 2005).

Rules of Thumb – Light Rail Transit (LRT)

$$\text{PKT per capita} \approx 140.34 \bullet L + 1.49 \bullet v - 15.12$$

(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 m/ha.; and v is the number of vehicles (wagons) per million people under maximum service.

Data for the regression is from 22 US 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 (2007 data). The program, branded as Ride the Wind, powers the C-Train using 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 from the mountain passes. The city is purchasing wind power from ENMAX Energy Corporation, the city's electrical distribution system It is the first public Light Rail Transit system in North America to power its train fleet with wind-generated electricity

The C-Train is now 100% emissions free. The annual GHG emissions saved, in comparison to equivalent automobile ridership is:590 kt CO_2 e.

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

d) Subway

The subway is also an “old” transit mode since it was first introduced in London, UK, in 1863. It is considered the highest-grade of urban transit since it offers high to very-high capacity and can accommodate short headways 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. This technology is normally implemented on high-demand corridors. Nevertheless, 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. It is also a generator of wealth for a city, land use also tends to develop heavily along the subway lines, and it can also strengthen the core of a city (Cervero, 1998). However, its implementation must be done carefully in order to maximize transit usage; for instance, long lines reaching the suburbs may be only used 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 guideline to plan new projects or extend existing systems. In terms of GHG emissions, it is linked to the electricity generation source.

Rules of Thumb – Subway

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

where: PKT per capita is the total passenger kilometres travelled per year divided by the population; L is track length in m/ha.; and v is the number of vehicles (wagons) per million people under maximum service.

Data for the regression is from 11 US 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 *(1)*, which is impressive given the relatively small population of approximately 3 million (5 million in the metropolitan area) compared to other major cities. The system is also one of the fastest growing in the world, with 75 km of new subway lines built between 1999 and 2003 *(2)* and 36 new stations between 2003 and 2007 *(3)*. In addition to the extensive metro network, Madrid also has a dense network of suburban trains. The Metro network has 285 stations on 12 lines, totalling 283 km, 92% 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 2003-200, 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

e) Commuter Rail

Commuter rail lines are regional transportation systems rather than urban transit systems. They offer high capacity and speeds. They normally link the CBD of a city to its surrounding communities and run mainly during rush hours. They can be operated by the regional or national transportation authority or a combination of both; for instance, in Paris, France, the 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 attributed along a zonal system, where shorter distances are 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 rule of thumb (statistical indicators also prove not to be significant), which explains why only the number of vehicles per million people v is included here.

Rules of Thumb – 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; v is the number of vehicles (wagons) per million people under maximum service.

Data for the regression is from 13 US cities (American Public Transit Association database)

Strategy 3: Active Transportation

More than a quarter of trips in the US are to destinations less than a mile away (Pucher & Renne, 2003), and 75% of such trips are made using the automobile (Killingsworth et al., 2003). Similar values are anticipated for Canadian cities and towns since 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% of bus trips and 30 to 40% 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.

Build 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 build 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 provides 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).

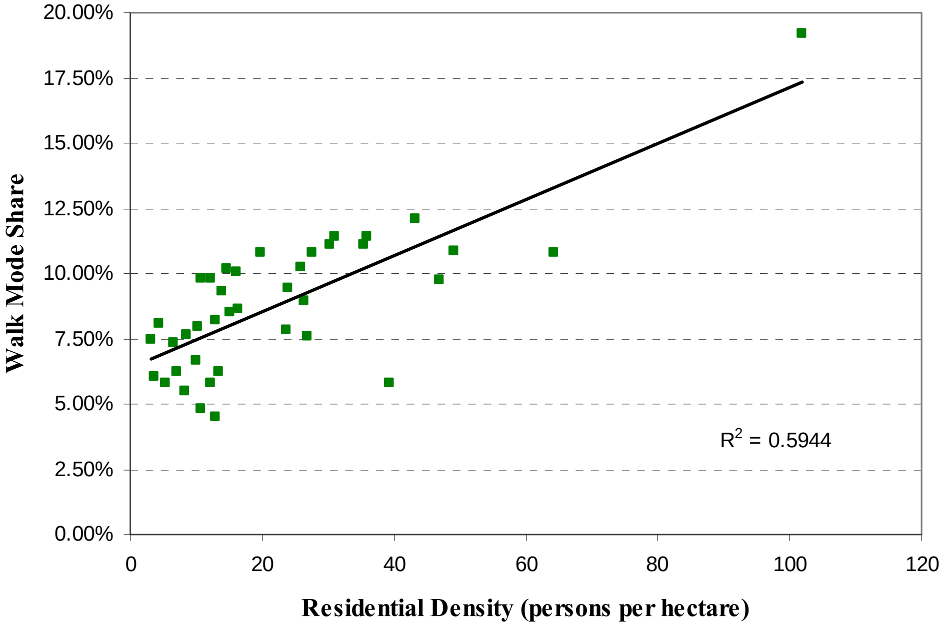

Figure 4.3: The effect of residential density on walk mode share as a percentage of all trips. Data plotted for 39 US cities; source Alliance for Biking & Walking (2007).

Relative cost of other available transportation options is also known to be a significant factor in the decision to walk and cycle. Strategy 4 introduces potential costing strategies to steer mode choice towards less carbon intensive alternatives.

Connectivity of the street network is another important determinant of active transportation mode share. The intertwined roads and dead-end of modern day subdivision developments provide little direct routes for pedestrians and cyclists. In contrast, the traditional grid-iron street pattern make active transportation options much more attractive. Intersection density (ID) can be used as a measure in quantifying connectivity of the road network. Analysis of 24 cities in California reveals that those with high IDs (about 40 intersections/km^2) have about 4% higher walking and cycling mode shares compared to cities with lower IDs (about 25 intersections/ km^2) (Garrick, 2008). It is evident that changing the road network for existing development is not an easy task and would mostly be in the form of 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 (CMHC, 2004).

Stated preference surveys have revealed that convenient and safe travel routes and crossings are important factors in choosing to walk and cycle. High vehicle traffic volumes are commonly associated with low willingness to walk and cycle since they reduce the sense of safety. Therefore, 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 success of Bicycle share programs such as Paris's Vélib' (Case 4.5) or Barcelona's Bicing Provision of bicycle lockers and bicycle parking posts, at frequent locations including transit stops significantly increase the level of convenience associated with this mode of travel. Our analysis of 17 US cities shows that addition of 100 bicycle parking posts per 10,000 residents can increase bicycle mode share by more than 1.5%.

It is argued that individual and social attitude, such as auto drivers' attitudes toward cyclists and bicycle culture in a community are equally important factor 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, BC, 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.

Influencing Factor	**Controll-ability**	**Impact on ridership**	**Potential Strategies**	**Examples**	
				Location	**References**
Social and individual attitude	Medium	High	Promotional programs aimed at improving individual attitude and drivers attitude towards pedestrian and cyclists	Wheels 2 Work Campaign, Whitehorse, BC Driver education, Netherlands and Germany	Case study 4.6 (Pucher & Buehler, 2008)
Network connectivity	Low - High	High	Increased intersection density by designing shorter blocks, fewer dead-end. Applying Fuse Grid community design schemes. Pedestrian and cyclist priority at crossings	Fused Grid scheme, Stratford, Ontario	(CMHC, 2004)
Cost of other transportation alternatives	High	High	Parking costs, tolls, taxes, and area pricing (See Strategy 5 for details)	See Strategy 4b and 4c	See Strategy 5b and 5c
land-use mix and density	Low-High	Medium	Appropriate zoning for existing and new development 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	Traffic calming measures such as lower speed limits, chicanes, and the Fused Grid scheme Car-free zones	Numerous Dutch cities Freiburg, Germany	(Pucher & Buehler, 2008) Case study 4.7
Convenience	High	High	Bikeshare Programs Provision of bicycle parking posts and lockers and racks on transit busses.	Vélib' bikeshare, Paris Bicing,bikeshare, Barcelona Metrolink, Halifax	Case study 4.5 (C40 Cities, 2008) (HRM, 2007)

Table 4.6: Built environment factors influencing active transportation mode share

It is evident that there are numerous strategies that can be implemented in order to reduce GHG emissions through replacing auto trips with active modes and supporting transit trips. It is also evident that there are a number of uncontrollable variables that should be taken into consideration when evaluating the impact of such strategy 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.

Similar to the approach taken for public transit, a rule of thumb is established by a regression analysis, here using data from a sample of 24 US 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 variable 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.

Rules of Thumb – Bicycle Facility

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

($R^2=0.74$)

where L is the total length of bicycle facilities per area of influence in m/ha and P is the number of bicycle parking spaces at transit stations per one million people.

Data for regression is from 25 cities in the USA (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 t CO_2 e per year. The entire scheme originated from the Vélo'v programme in Lyon. Automated rental bike stations are present throughout the city; there are 1,451 stations for over 20,600 bikes (300m apart) and 35,000 bike racks. It is available 24-hours a day, every day. The first half-hour is free, the second is €1, the third is €2, and every subsequent half-four 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 1280 advertising spaces of $2m^2$ and 348 spaces of $8m^2$. 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 Campain – Whitehorse, Yukon

The “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 at many levels. Examples of these investments include: 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 therefore implemented to promote bicycle-use. It 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 putting effort to orient new development towards a more pedestrian and bicycle-designed style. An estimated 4.5 tonnes of greenhouse gases 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

Strategy 4: Deter Automobile use

Internal combustion engine (ICE) automobiles have ascended exceptionally fast since the 1930’s. They now make up the largest portion of transportation trips in most developed countries around the world, and this does not come without problems. Not only are they the largest emitters of GHGs in the transportation sector, they also challenge the very fundamentals of sustainability. Indeed, although they usually provide more convenient transportation means, they are also the 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 crowded streets (pedestrians, horse-drawn vehicles, etc). Nevertheless, the current circumstances have become so dramatic that they carry with them environmental, health-related, even financial issues and many more. It is therefore broadly accepted that actions have to be taken in order to face these problems, and the first one to tackle is to reduce automobile usage, i.e., VKT. This section outlines several solutions that address this issue in a direct, full-frontal manner.

The costs of an average car can be divided into two distinct groups: external and internal. The external costs are not paid directly by auto-users such as road facilities, municipal services or water pollution. The internal costs, on the other hand, are paid directly by auto-users. We further partition these internal costs in two categories: fixed and variable. The fixed internal costs are related to costs such as vehicle ownership, license plates and also, to some extent, insurance. Finally, the variable internal costs are day-to-day costs such as gasoline price, irregular parking, tolls, etc. Figure 4.4 shows a breakdown of these three types of costs for an average car. About a third of the costs are external (35%), and therefore not experienced by auto-users. Another significant portion is fixed internal (28%); these costs do not affect frequency of auto-use. Hence, only 37% of the entire costs of a car are actually felt by auto-drivers regularly and thus have an impact on their daily travel behaviours.

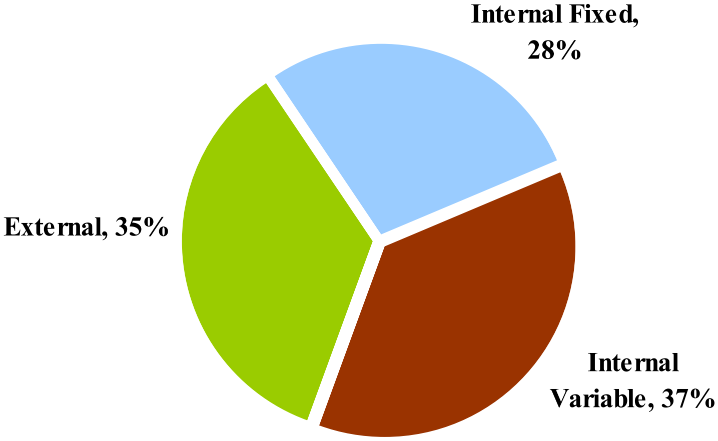

Figure 4.4: Distribution of average car cost, taken from Litman (2009)

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 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 guidebook, 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 normally unpopular with the different levels of authorities involved. Instead we focus on practises 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, although impacts on overall VKT are difficult to establish. It is the first strategy addressed in this section.

Mathematically, to quantify the impacts of a strategy on travel behaviour, transportation economists usually use the concept of *elasticity*, usually reported as a percentage change per 1% increase in price. For transportation, a strategy is said to be elastic if an increase in price influences the VKT.

Before looking at the various strategies, it should be underlined that increase in gasoline price has a significant and effective impact on total VKT (Table 4.7). To illustrate the concept of elasticity, in the long-term, an increase of 1% 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.

Total VKT elasticity of gasoline price

	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

Table 4.7: Total VKT elasticity of gasoline price on auto-drivers, auto-passengers, public transportation and active transportation. Values are reported for short-term and long-term. Table was adapted from TRACE (1999)

a) Pedestrianization

Pedestrianization consists in secluding a geographical area of a city from cars and therefore making it accessible solely by active and public transportation. It is relatively common in some parts of the world such as Europe (e.g., Freiburg, see case study 4.7) and even North-America (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 most often become highly popular and enjoy true economic success (Clarke and Dornfeld, 1994) as well as having many other social and environmental benefits, from air pollution and 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 to real impact at the city scale (i.e. total VKT). Moreover, we have not found any specific studies in the literature to produce a rule of thumb. Nevertheless, 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, area-wide traffic calming schemes, and difficult and expensive parking. The city has an extensive downtown car-free network, covering an area of 0.5 km^2. 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:

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

b) 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, parking prices have the particularity to deter entire auto trips (e.g., home-work trip) as opposed to reducing the length or the number of trips for gasoline price. As a result, strong parking policies can have a more significant impact on GHG emissions.

In the literature, elasticity of parking prices varies greatly. For instance, Miller (1993) shows that in Toronto, parking pricing has an elasticity greater than 1.0. The context is also important. For instance, parking prices in the CBD are usually higher than parking prices elsewhere; therefore a 1% increase in each will not have the same impact. For this guidebook, we chose to use elasticities reported in TRACE (1999) as for gasoline prices. Although the values are significantly lower, we assume it represents 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; the elasticities also refer to VKT.

Rules of Thumb – 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)

c) Tolls, taxes, area pricing and other strategies

There are several other strategies that have been implemented in order to reduce the level of congestion (i.e. deter automobile use). These can be recognized as methods of "internalising externalities". All these strategies can have a low to high 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. Furthermore, results vary according to location, present conditions and context. As a result, in this section, we outline the main strategies that have been implemented around the globe (Table 4.8), but it is not possible to establish rules of thumb. Nonetheless, we highlight two major studies that have been carried out in Auckland, New-Zealand, and Washington DC, US, where the responses to several travel demand management strategies in terms of VKT reductions were modelled.

Name	Description	Examples of Application	References
Area pricing	Daily toll to enter and travel within one specific area	London, UK Singapore	Litman (2006) TCRP (2003)
Cordon tolls	Daily toll to solely enter one 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, Canada National highways: France	TCRP (2003) Bousquet (2001)
High Occupancy Vehicle (HOV)	Lane(s) on highways or major arteries reserved to 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 km 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)

Table 4.8: List of popular strategies to reduce traffic congestion. List of reference is not exhaustive but can be referred to for further information.

A study was produced for the city of Auckland, New-Zealand (MoT, 2006), where the impacts of five different strategies on VKT reductions were analysed. Table 4.9 shows the results; note that the reductions in auto are in VKT whereas the increases in public and active transportation are in mode share (i.e., PKT). The first two strategies introduce 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; it is called strategic network. The fifth strategy imposes a parking levy to all auto-users (public and private properties) in the regional CBDs. It seems the double cordon pricing was the most effective in this study to reduced auto VKT and hence to reduce GHG emissions.

	Single Cordon ($2)	Double Cordon ($2)	Area Pricing ($3.40)	Strategic Network ($4.10)	Parking levy ($6.85)
Total Auto VKT	-6.50%	-10.70%	-9.30%	-6.00%	-3.00%
Public Transportation Mode Shift	+1.90%	+3.2%	+3.2%	+1.00%	+2.30%
Active Transportation Mode Shift	0.00%	+0.34%	+2.03%	+0.18%	+0.49%

Table 4.9: Study of responses to travel demand management strategies for Auckland, New-Zealand. The project was commissioned by the Ministry of Transport of New-Zealand and carried out by a consortium of consultants led by Deloitte. Total Auto VKT reports percentage difference in total VKT; Public Transportation and Active Transportation report additional mode share in response to these strategies. Monetary values are reported in CA$. Table was adapted from MoT (2006)

Another comprehensive study was produced by Harrington et al. (2008) for Washington DC. In this case, six second-best studies were studied. Table 4.10 shows the results. The study considered three different cordon tolls strategies: downtown cordon (small area), beltway cordon (larger area) and double cordon (including the two formre). Harrington et al. also analysed the impacts of a freeway toll, a comprehensive toll (charging all vehicles on every roads) 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 14.60%; hence this is the most effective technique to reduce GHG emissions.

	VMT tax	Comprehensive toll	Freeway toll	Double cordon	Beltway cordon	Downtown cordon
Percent of VMT affected	100%	100%	26%	7%[a]	7%[a]	1.1%[a]
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	-14.60%	-7.10%	-2.10%	-1.30%	-0.90%	-0.80%

[a]: Percent trips, not VMT.

Table 4.10: Study of responses to travel demand management strategies for Washington DC, US. “VMT % change” row reports changes to total vehicle-miles travelled VMT; this value can be taken as is for VKT due its dimensionless characteristic. All currencies were kept in US$. Table was adapted from Harrington et al (2008).

Case 4.8: Congestion Charging, London, UK

Vehicles which drive within a clearly defined zone of central London between the hours of 7am and 6pm, 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 of £5 per day to travel between 7am and 6.30pm. 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 are spent on improving transport in London. Traffic levels & congestion immediately decreased after the implementation. However, five years later, it seems congestion came back to pre-charging levels. In 2007/08, the scheme generated a net revenue of £137m.

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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(1) Transport for London, *Congestion Charging*, Transport for London, http://www.tfl.gov.uk/roadusers/congestioncharging/, accessed November 8, 2008

(2) 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

Strategy 5: Changing Vehicle Technology

Changing vehicle technology is another strategy to address GHG reduction requirements from the transportation sector. Nevertheless, it takes a rather different approach to what has been 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 the current use of fossil fuels to power automobiles to greener technologies. Although this strategy could in fact 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% of transportation energy consumption in the US came from petroleum-based fuels (Source: 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 guidebook, we have looked at three specific potential alternative fuels: biomass, fuel cells, and electricity. But before, Table 4.11 shows the current emissions factors for four types of vehicles as a matter of comparison to the three alternatives.

	Passenger Car	**Light Truck**	**Truck**	**Diesel Bus**
Fuel	Gasoline	Gasoline	Diesel	Diesel
App. L / 100 km	9.1	16.7	-	62.5
g CO2e/km	297	472	1,393	1,670

Table 4.11: Average emissions factor for four types of vehicles. Data was adapted from GREET 1.8c model (Argonne National Laboratory, 2009), Beer et al. (2000) and Lenzen (1999). The "L / 100km" are approximated values; 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 rules of thumb since the figures presented were mostly taken from individual sources and their applicability is not straight-forward. Indeed, assessments of different fuels are highly dependent upon their origins. As a result, 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. Nevertheless, in this section, we offer a general perspective of the different fuels; the figures quoted could serve as a guideline to calculate GHG reductions linked to changing vehicle technology.

a) Biomass

In this guidebook, biomass essentially 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. They are more environmentally-friendly than fossil fuels since plants require carbon dioxide to grow (photosynthesis). Although 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 c).

Table 4.12 shows the effect of using different blends of biomass from different sources relative to gasoline consumption and carbon emissions. Llow blends (10%) have little impact on both consumption and emissions. Nevertheless, 85% blends can have a significant impact; in particular E85 from cellulosics reduces emissions by 69%.

	E10 Corn	**E85 Corn**	**E10 Cellulosics**	**E85 Cellulosics**
% Reduction of Gasoline Consumption	6%	73%	6%	71%
% Reduction of Carbon Emissions	1%	6%	6%	69%

Table 4.12: Effects of using biomass as a fuel to reduce gasoline consumption and carbon emission for a passenger car. E10 and E85 refer to a 10% and 85% blend respectively. Reductions given are tank-to-wheel values. Table was adapted from West (2008).

Biomass can also be a fuel for diesel-powered vehicles such as public transportation buses and trucks. In this case, biodiesel is produced. For a 20% blend of biodiesel, carbon emissions from buses would be reduced from 1670 gCO_2 e/km to 1400 gCO_2 e/km, a 16% reduction (adapted from Beer, 2000). Table 4.13 shows the reduction of diesel consumption and carbon emissions from BD 20 (20% blend of biodiesel) 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 since GHGenius is a Canadian model while Beer (2000) considers the Australian environment.

	BD 20	
	Combined Truck and Buses	**Buses**
% Reduction of Diesel Consumption	**19.20%**	**-**
% Reduction of Carbon Emissions	**3.55%**	**16%**

Table 4.13: Effects of using 20% biodiesel blend to reduce diesel consumption and carbon emissions for buses and combined truck and buses. Table adapted from Beer (2000) and GHGenius (2009)

b) Fuel Cells Vehicles

Fuel cell vehicles (FCV) use the chemical reaction between oxygen and typically hydrogen to create electricity that then powers an electric engine. Although they use electric engines, their fuel is different to electric-vehicles (EV), 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. However, the future of fuel cells has been challenged this past decade due to technological constraints in producing the hydrogen fuel to begin with. Nonetheless, 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 shows 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.

	Gasoline	Natural Gas FC	Gasoline FC	Hydrogen FC
g CO2e / km	280.3	90.7	169.3	99.7
% difference with Gasoline	-	67.6%	39.6%	64.4%

Table 4.14: Average GHG emissions of Fuel Cell powered passenger cars (Table adapted from Bauen and Hart, 2000)

Public transportation buses can also be powered with fuel cells and therefore reduce the carbon footprint of the public transportation sector at the same time. Figure 4.4 shows the average emissions of transit buses in Vancouver, BC, when powered with different fuels.

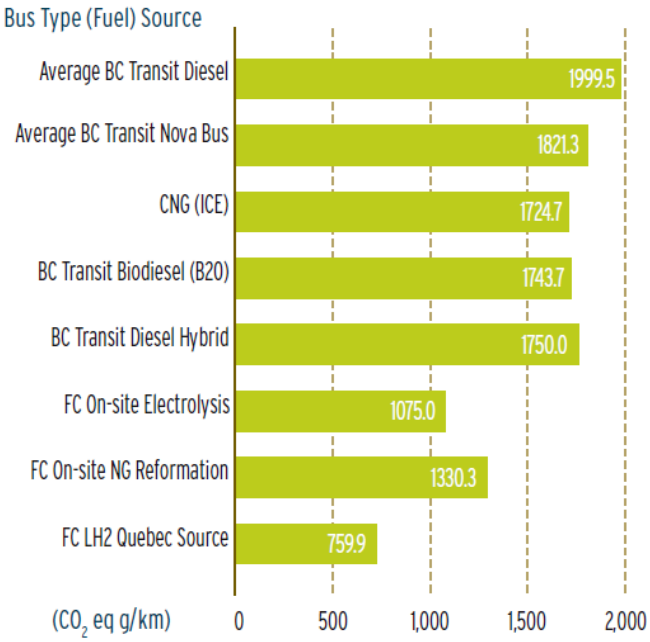

Figure 4.4: Average GHG emissions of buses in Canada according to different technologies. CNG stands for Compressed Natural Gas; B20 is equivalent to BD 20; FC stands for fuel cells. (From Wise, 2008).

c) Plug-in Hybrid and Hybrid Electric Vehicles

Electric vehicles are possibly the best alternative for the long-term. At the moment, there are mainly hybrid gas-electric vehicles (HEV) commercialised; HEVs switch between gasoline and electricity to power the engine (e.g., Toyota Prius). Plug-in-hybrid electric vehicles (PHEV) should be available in the near future; there are essentially similar to HEVs with the possibility to "plug-in" and recharge the batteries from a typical 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 21. and chapter 5). Some countries have already started to regulate their automobile fleet such as Australia and Israel (Case 4.9). A review of existing PHEV 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. Gasoline refers to a conventional gasoline-powered mid-size car; the numbers "30" and "20" stand for 30 mile and 20 mile electric-only ranges. The table shows that HEV and PHEV are much more efficient than ICE vehicles even by 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 are used as the fuel; carbon emissions are reduced by 93%. Similar to biomass, fuel cells could be used to power HEV and PHEV. However, we have not been able to acquire data on the matter; see Suppes (2006) for more information.

	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%

Table 4.15: Effects of HEV and PHEV on reduction of gasoline consumption and carbon emission, using five different types of fuels. E10 and E85 refer to a 10% and 85% blend respectively. HEV 30 stands for 30 mile electric-only range; PHEV20 and PHEV30 stand for 20 mile and 30 mile electric-only range respectively. Reductions given are tank-to-wheel values. Table was adapted from West (2008).

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

	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
Percent reduction from ICE	-	65%	37%

Table 4.16: Comparison of energy use between an ICE, a BEV and a FCV in MJ/100km. Table was adapted from Gilbert (2007).

Case 4.9: Better Place Electric Vehicle Network, Israel (all cities)

In addition to future 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.

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CHAPTER 5: ENERGY SUPPLY

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

Municipalities can reduce their GHG emissions through building and transportation strategies (discussed in chapters 3 and 4), but 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 carbon free energy supply through their financial power and planning controls.

The strategies considered in this chapter are 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.

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 t CO_2 e 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 the rule of thumb below.

Case 5.1: TREC WindShare, Toronto, Ontario

The Toronto Renewable Energy Cooperative (TREC) WindShare was 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 750kW 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.

Rules of Thumb – 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]

Assumes the average annual wind speed entered represents the average annual wind speed at the hub height of the installed turbine(s). Uses the following characteristics 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, but municipalities with access to suitable rivers may encourage development of smaller hydroelectric facility, 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, Ontario

This example of a small hydroelectric facility has a rated capacity of 800kW and is approximately 88% 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.

Rules of Thumb – Hydro Power

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

where P = power (kW); Q = flow (m^3/s); H = Head (m)

"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 quite location specific. Rules of thumb for wind power, hydropower and photovoltaics have been given above, and in Chapter 3. For the more location-specific strategies we provide case examples 5.3 to 5.8, rather than further rules of thumb. 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. Given the variety in sources of renewable energy, many Canadian municipalities may find new sources of electricity.

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 came online in September 2008 with a peak capacity of 2.25MW and consists of three generators. When the remainder of the project is completed 21MW will be installed. The generators are tethered three miles off of 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 1.2MW tidal stream generator installed 400m off the coast of Northern Ireland is the first of its kind. The generator consists of two turbines, each 16m 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, and hence are unlikely to pose a threat to wildlife. The system operates around eighteen to twenty hours per day and does not pose a visual distraction as the bulk of the system is mostly under water.

The SeaGen system installed at Strangford has the capability of generating approximately 4500MWh/year (allowing for 10% downtime with a new technology). The UK figure for displaced carbon is based on an average 0.45 $kgCO_2/kWh$ (DEFRA 2005). On this basis SeaGen at Strangford will displace emissions of 2025 tonne 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 depends on the size of project, and site conditions. Costs were initially in the order of $6million/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 operations 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 2600 and 4500MWh/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.

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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 11MW. The project consists of 624 120m^2 heliostats that reflect sunlight onto a receiver at the top of a 100m tall tower, which produces steam to drive a turbine. The station cost 35 million Euros to construct and produces 24.3 GWh of electricity per year (12-15% of this is provided by natural gas) There are plans to expand the system to 300MW by 2013 which would be enough to power 180,000 homes - approximately the size of Seville.

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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, California

This 354 MW solar thermal electricity plant consists of over 900,000 curved concentrating solar collectors covering 1,600 acres. The curved mirrors focus the suns rays on an absorber pipe that runs parallel to the mirrors. The heated fluid in the pipes runs the turbines that generate electricity. The system was constructed in phases, the first was started in the mid 1980s.

Reference:

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

Case 5.7: Parque Fotovoltaico Olmedilla de Alarcón, Spain

This 60MW 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, produces approximately 85,000MWh/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, California

The Geysers is the largest geothermal power project in the world. The project consists of 22 plants and currently has a total capacity of 750MW. The project provides around 60% 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.

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, and 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.

a) Aquifer Thermal Energy Storage

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 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 therefore can only be utilized in areas of specific geologic deposits. The most common geology used for ATES is the sandstone aquifer with high porosity and permeability. Igneous rock formations (bedrock) can also be used in areas with a significant degree of fractures. 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 m per day (20 m/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 changes 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).

Rules of Thumb – Aquifer Thermal Energy Storage

ATES systems typically achieve:

60-80% reduction in cooling electricity requirements; and
20-30% reduction in heating primary energy. (Snijders 2008)

b) Borehole Thermal Energy Storage

BTES systems comprise of long boreholes, anywhere from 20 to 400 m 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 conditions 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, consists of 400 boreholes with a depth of 135 m, and is located at Richard Stockton State College, Pomona, NJ, USA (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, then 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% reduction in primary energy use relative to conventional systems. Due to the significant cost associated with drilling multiple deep boreholes, BTES is the most expensive of the natural UTES options (Wong et al., 2007). Nevertheless, BTES systems are feasible for a significant range of project types and settings.

Rules of Thumb – Borehole Thermal Energy Storage

BTES systems can provide up to 90% 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 increased resource at a later time.

Case 5.8: Drake Landing Solar Community, Okotoks, Alberta

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 m deep, 150 mm diameter, 2.25 m spacing. The system contains 24 parallel circuits, each having 6 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% more efficient than conventional homes. Overall, 90% 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

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). 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 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.

Heat sources such as geoexchange 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. District energy also provides a greater economy of scale for technologies making then more cost effective to implement. 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).

Rules of Thumb – Energy Sharing From Industrial Processes

GHG savings of 26.4 kg CO_2 e per GJ of shared energy were estimated for a study in Calgary by the Canadian Urban Institute (2008)

Rules of Thumb – District Space and Water Heating

GHG savings of 24.2 kg CO_2 e per GJ energy produced by a district system were estimated for a study in Calgary by the Canadian Urban Institute (2008)

Case 5.9: Enwave Deep Lake Water District Air Conditioning, Toronto, Ontario

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 t CO2 e of GHGs per year, reduces electricity demand by 90% compared to conventional systems, and reduces power demand by 61MW.

Reference:

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

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 biofuel efficiencies from the power generated typically range between 25 and 55 percent with the remaining energy lost to mechanical energy to drive the generator and heat. In a CHP system the heat energy is recovered increasing the overall efficiency to between 60 and 90 percent depending on the application (RETScreen International, 2009). 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 percent or 57 million tonnes of CO2 and 11 percent of Canada’s total energy consumption could be avoided annually (Gilmour and Warren, 2008).

The waste heat delivered in the form of either steam or hot water can either be utilised 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 minimised 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 systems means that they 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.

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 and other project administration	10% - 15% of capital cost

Table 5.1 Construction costs for components of community energy system (Wilson, 2007).

Rules of Thumb – Building Integrated Combined Heat and Power

For CHP fuelled by natural gas:

$$\text{Annual GHGs saved} \approx (0.00262 \,.\, \text{Grid Emissions Factor} - 0.765) \,.\, P \,.\, f$$

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 2080 and 8760). The grid emissions rate of the given jurisdiction (province) is represented in t CO_2 e / GWh and needs to be greater than 292 t CO_2 e /GWh to provide GHG savings.

US EPA, 2009. CHP Emissions Calculator. Accessed April 2009 . <http://www.epa.gov/chp/basic/calculator.html>

Based on typical performance parameters of microturbine CHP (Table 5.2) the cost of reducing one ton of CO2 e by this technology is between \$2,400 and \$12,900 (US).

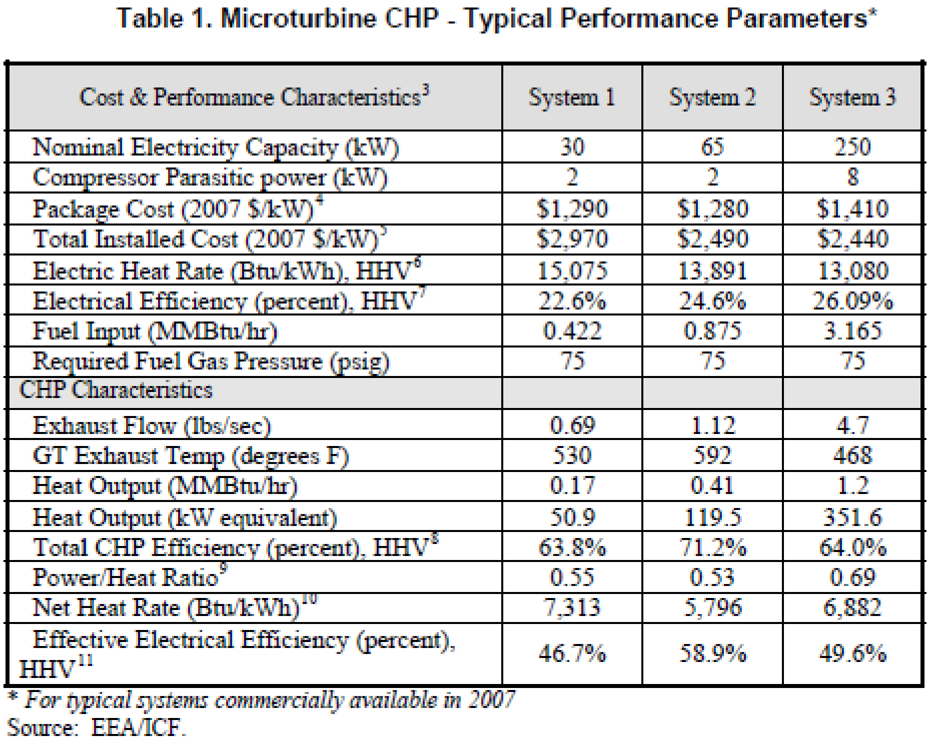

Table 1. Microturbine CHP - Typical Performance Parameters*

Cost & Performance Characteristics[3]	System 1	System 2	System 3
Nominal Electricity Capacity (kW)	30	65	250
Compressor Parasitic power (kW)	2	2	8
Package Cost (2007 $/kW)[4]	$1,290	$1,280	$1,410
Total Installed Cost (2007 $/kW)[5]	$2,970	$2,490	$2,440
Electric Heat Rate (Btu/kWh), HHV[6]	15,075	13,891	13,080
Electrical Efficiency (percent), HHV[7]	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
GT 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[8]	63.8%	71.2%	64.0%
Power/Heat Ratio[9]	0.55	0.53	0.69
Net Heat Rate (Btu/kWh)[10]	7,313	5,796	6,882
Effective Electrical Efficiency (percent), HHV[11]	46.7%	58.9%	49.6%

** For typical systems commercially available in 2007*

Source: EEA/ICF.

Table 5.2 Typical performance parameters of Microturbine CHP (Table 1 from the US EPA, 2008).

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CHAPTER 6: MUNICIPAL SERVICES

(E. Mohareb)

Municipal services provide energy and GHG savings opportunities that cities have direct control over. How cities manage their wastes, maintain their water infrastructure, plans their urban canopy, or light their streets can have an impact on their emissions inventories.

Material flows through our cities and towns are a key motivator 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 will result from the numerous stages of manufacture, from initial processing to final sale. From process and extraction residues, to packaging materials, to finished goods, proper disposal of waste is an ongoing concern for municipalities. 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 treatment and pumping of water / wastewater. By addressing demand and treatment energy efficiency, it is possible to lower these emissions.

From the sequestration perspective, it is possible to quantify the carbon capture benefits of urban green spaces. In addition to the energy services provided through evaporative cooling and shading, they utilize CO_2 through photosynthesis as they grow through time.

Waste Management

Waste management emissions are commonly perceived as the "low-hanging fruit" of reductions strategies. Many of the technologies are already 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 the disposal in sanitary landfills; methane gas, a potent GHG (with a global warming potential of 21), 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% of disposed waste in 2000 being deposited in landfills. Incineration is used to eliminate the remaining 5% (Statistics Canada, 2005).

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 wastes from biogenic 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 45-60% on a dry volume basis. While CO_2 is a component of LFG (40-60%), it is produced through the degradation of materials which 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 (based on the starting boundary being post-consumer waste production).

GHG emissions will result from waste collection and landfill operations as well as the release of methane. 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 (estimated that waste trucks travel roughly 30 km to landfill site). Even for the City of Toronto's 2004 emissions inventory, where waste is transported to landfill sites in Michigan (over 350 km away), GHG emissions from transporting waste are less than 10% of waste emissions[2] (ICF, 2007).

To understand what can be achieved through better management of solid waste, the components of waste streams must first be examined. Of greatest interest to municipalities is residential solid waste as it is managed using municipal funds. Statistics Canada (2005) provides national data for composition of residential waste, seen in Table 6.1, and notes total residential solid waste generated in 2002 was over 12 million tonnes. Degradable materials account for more than 66% of this waste, including organics, paper, lumber and animal wastes. Of this, 2.5 million tonnes was diverted, i.e., just over 20% of waste generated. As will be highlighted later, increased diversion will result in reductions in GHG emissions.

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

Table 6.1: Canadian Residential Waste Composition (Source: Statistics Canada, 2005)

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

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[2] Examining waste deposited in 2004, emissions from transport were 0.1% of community total while LFG commitment was 1% of total community emissions.

Sector	Percentage of 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 (incl textiles, lumber, animal wastes, tires, hazardous waste)	7%

Table 6.2: Greater Toronto Area Non-Residential Solid Waste (Source: Toronto City Summit Alliance, 2008)

A rule of thumb is presented below in order 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.

Rules of Thumb – 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 equal to 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 proportionally, non-residential waste diversion is far below that of residential (22% vs 40.5% diversion rate). This represents both a loss of valuable resources as well as an opportunity for GHG emissions reduction.

	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

Table 6.3: Comparison of Residential and Non-Residential Waste Generation and Diversion Data (Modified from Statistics Canada, 2006).

In cases where waste management related emissions are substantially reduced due to elimination of methane emissions from landfill operations (through capturing or alternative management strategies, such as incineration), then collection related emissions will rise proportionally. Case 6.1 below provides one solution presented by the Swedish firm Envac to address these 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.). The extent of waste collection vehicles operation is reduced, resulting in reduced transportation-related GHG emissions and ease of source separation, increasing landfill diversion. This increased waste diversion saves GHG emissions directly (by reducing degradable wastes deposited in landfills) and indirectly (through reduced material embodied energy requirements from recycling). Additionally, waste can be further sub-divided into an organic stream to be digested for biogas production (potential for Waste-To-Energy). An installation has recently been completed at Wembley City, London. Regarding costs, in one analysis provided by Envac, installations costs were comparable to traditional UK infrastructure, yet annually operating costs were reduced by nearly 45% The Wembley installation saves 360 t CO_2 e per year.

Figure 6.1: Visualisation of Envac Collection System (Source: Envac, 2009)

Reference:

(1) Envac (2008). Press – Quintain and Envac launch the UK's first underground vacuum waste system at Wembley City [Online]. Available HTTP: http://www.envac.net/frameset.asp (Accessed November 7, 2008)

(2) Tornblom J (2009). Personal Communication - May 6, 2009.

Strategy 1: Increased Sorting & Recycling

Though emissions savings from recycling may not register in many municipal GHG inventories, the reductions achieved are significant and should be recognized. By recycling materials, and offsetting the demand for virgin materials, energy savings are realised. A study by the EPA demonstrates that lifecycle emissions reductions are of the order 1 t CO_2 e per tonne of material recycled (Table 6.4).

Recycled Material	Emissions vs Virgin Materials (tonne CO_2 per tonne of material)
Aluminium 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

Table 6.4: Net GHG Emissions for Various Recycled Materials (Modified from EPA 2006)

In municipalities that source or process these materials locally, emissions reductions will be realized on their industrial inventory figures. Otherwise, lifecycle emissions are reduced and valuable materials are diverted and utilized.

Additionally, if organics are separated into a separate waste stream, controlled anaerobic digestion of these wastes can result in the creation of useful by-products: compost and biogas. Compost can displace artificial fertilizers (which are themselves highly GHG-intensive), in addition to reducing the potential for LFG production through the separation of degradable materials. Some municipalities have successfully implemented sophisticated waste separation systems, such as in Sydney, Australia (Case 6.2 below).

Case 6.2: Sydney Waste Diversion

Using a sophisticated source separation system, Sydney has achieved 70% diversion of municipal solid waste processed by its modern facility from landfill. In addition, an anaerobic digestion process produces methane from degradable organic carbon, which in turn is converted to organic fertilizer (30,000 t per annum). The methane is combusted to produce electricity to power the separation facility. The facility is able to extract all process water needs from the treated waste (1). Sydney's waste diversion system saves 210,000 t CO_2 e per year.

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

Finally, in place of organics processing at a central facility, residential composting units provide a less capital-intensive alternative. Though the option to produce and capture biogas from anaerobic digestion is lost, there are reductions in methane emissions due to the generally aerobic conditions in backyard composting. A study by Beck-Friis et al. (2000) showed methane emissions (mg/m^2) for a small (1m radius) compost heap to be roughly 25% of those for of a larger (2.5 - 3.0m) heap. This compost can 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 t CO_2e/t of organics.

Strategy 2: Waste Incineration & Gasification

As stated earlier, the second most common form of waste disposal in Canada is incineration, handling 5% of all waste (Statistics Canada, 2005). While concerns over air emissions (NO_x, SO_x, polychlorinated dioxins/furans, lead, mercury, etc) have been highlighted recently as a central argument against incineration, lifecycle CO_2 emissions reductions are achievable using incineration (Ruth 1998; EPA 2006).

Assuming a waste-to-energy (WTE) system is in place, there is potential for indirectly reducing GHGs in two ways: 1) Electricity generation from fossil sources (another assumption) is displaced by electricity produced from waste combustion; 2) Many WTE facilities recover metals for recycling, leading to reductions in process energy compared to the extraction of virgin materials. These two avenues work to reduce lifecycle GHGs.

Though CO_2 emissions result from the combustion process, only non-biogenic sources should be considered (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 emissions reductions achieved.

Table 6.5 shows net GHG emissions for various materials. The emissions reductions achieved by incineration are lower than from 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.

Combusted Material	Net Emissions from Incineration (tonne CO_2 per tonne of material)
Aluminium 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

Table 6.5: Net GHG emissions from Combustion (Mass Burn) of Various Materials (modified from EPA, 2006)

Combustion facilities are generally categorized 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, 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 their website, the electricity is generated producing nearly 60% fewer CO_2 emissions when compared to coal power generation (Plasco Energy Group, 2008).

Strategy 3: Methane Capture

As mentioned previously, generation of LFG produces methane, a powerful GHG. A solution which has been implemented in numerous municipalities is the installation of a LFG capture system. Through a network of piping, gases are collected and either flared or utilized for energy services (i.e. electricity generation). As of 2006, there are 52 LFG collection systems operating in Canada (Environment Canada, 2008). These collected roughly 314 kt of methane in that year, just 28% of the total generated (Table 6.6). Clearly LFG capture systems could be further implemented to reduce municipal/national GHG emissions.

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)

Table 6.6: National Methane Generation and Fate for Sanitary Landfills (EC, 2008)

Case 6.3: Landfill Gas Collection, Toronto, Ontario

The City of Toronto has taken 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. All electricity sales provide royalties to the City for providing exclusive rights to LFG produced at the sites, which have helped recover costs for the installation 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 in the explosion hazard from subsurface methane.

References:

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

The US EPA has conducted an analysis of three distinct landfill conditions which affect lifecycle GHG emissions. In addition to emissions being released from LFG generation, sinks are achieved (not all carbon captured by biogenic means are released into the atmosphere) and fossil electricity generation is displaced (in the case of energy production from LFG). The studies producing these data assumed ideal conditions for degradation (sufficient moisture and nutrients). These are presented in Table 6.7. Landfill gas recovery operations are estimated to have an average efficiency of 75% and 10% of methane is assumed to be oxidized (EPA 2006).

Landfill Material	**Emissions from Landfilling (tonne CO_2e per tonne of material)**		
	No LFG Collection	**LFG w/ Flare**	**LFG w/ 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

Table 6.7: Lifecycle GHG Emissions Resulting from Waste Disposal in Landfill with and without LFG Collection

From Table 6.7, benefits from LFG collection are apparent from a GHG perspective. As well, certain materials will always result in net emissions even with a collection system in place. These materials would be best kept out of landfills through source separation (food waste, office paper).

Strategy 4: Water Demand Management

Water services (drinking water and waste water) are a significant component of municipal GHG inventories. In powering pumping stations and treatment facilities, significant electricity use is incurred. 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/annum (City of Toronto, 2007).

Rules of Thumb – Urban Water Systems

Electricity required for:

water treatment and distribution = 580 kWh per ML.
wastewater pumping and treatment: = 550 kWh per ML

These values are for the City of Toronto (Sahely and Kennedy, 2007)

The principle strategies for reduction of these emissions are demand management and elimination of leaks. Case 6.4 provides one example of how good monitoring systems can save energy, GHG emissions and water. Water demand techniques can include provision of rain barrels for storm water collection (which also reduces issues associated with water run-off and storm water management) and local by-laws to curb usage.

Case 6.4: Improved Water Distribution Systems, Tokyo, Japan

In addressing the reduction of water demand, Tokyo has implemented a sophisticated leak detection system which has resulted in a 50% reduction in water wastage in one decade (1). Through a focus on same-day-repair, a reduction in CO_2 emissions 73,000 t annually has also been realised by reduced energy requirements for water distribution.

References:

1 Climate Leadership Group (2008). *Best Practices*, Tokyo, Japan: C40 Cities. [Online]. Available HTTP: http://www.c40cities.org/bestpractices/ (Accessed November 7, 2008)

Strategy 5: Urban Greenery

Urban greenery provide a diverse range of community benefits, from aesthetics to cooling services, and its existence serves both mental and physical needs. A municipality can set policy 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 lend the benefit of sequestering CO_2 during growth. Pataki et al. (2006) estimates gross sequestration due to urban trees in the US at 22.8 Mt of carbon / year. Assuming a ratio of carbon to CO_2 of 1:3.67 (mass of C : mass of CO_2), this offset is roughly 1.3% of American emissions (EPA 2008). Pataki et al. provide a figure of 0.2×10^{-9} Mt Carbon / m^2 for a median value of carbon sequestration by urban trees. A rule of thumb is thus provided below, based on this median value.

Rules of Thumb – Urban Forest Carbon Sequestration

$$GHG_{sequestered}\ (\text{tonnes } CO_2) = 700 \text{ t } CO_2 / km^2 * A_{UF}$$

where A_{UF} = Area of urban forest (km^2) (Pataki et al. 2006, 2092-2102)

Additionally, green roofs can 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).

Certain urban centres have begun 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.

Strategy 6: Urban Agriculture & CO_2-enriched Greenhouses

Of recent concern to both the sustainability and food security of cities is the source of food products. Generally speaking, cities are not self sufficient for food due to the limited arable land within their boundaries, so produce and other groceries 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 but 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 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 dominate the life-cycle emissions associated with food; Weber and Matthews (2008) found that 83% of the average Americans food carbon footprint were attributable to production. Transportation emissions, however, contributed just 0.36 t CO_2e/year per household of the 8.1 t CO_2e total, or 4%. Their research suggests that agricultural practices and diet will lead to much greater reductions in GHG emissions associated with food. As Table 6.8 shows, there is significant variation in the carbon intensity of different food products.

Food Product	Carbon Intensity (kg CO_2 / kg)
Red Meat	22
Cereals / Carbs	3
Chicken / Fish / Eggs	6
Diary	4
Fruit / Vegetables	2

Table 6.8: Life-Cycle Carbon Intensity of Various Food Categories (Estimated from Weber & Matthews, 2008)

While organic agriculture (and other low-impact techniques) and reduced-meat diets can reduce emissions, the question of emissions from urban greenhouse vegetables also can be addressed. Since many greenhouse operations required 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 gasses from the combustion of animal wastes to fertilize crops. This system resulted in offsetting 320 t / year for a 1000 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. Rather than a linear food system which leaves waste and food production disconnected, Innovatie Network's concepts reuse wastes from compatible industries for food manufacturing (similar to the biodynamic agriculture discussed earlier). One such example is the Happy Shrimp Farm, which will use waste heat from a power plant in a shrimp aquaculture operation.

Strategy 7: 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, total reservoir potential in 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 suggest CO_2 emissions from suitable emissions sources for CCS could reach 600 Mt / annum nationally by 2050 (40% 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 and cryogenic separation).
2) Compression/liquefaction of separated CO_2 is performed to facilitate transportation
3) Transportation (by pipeline or ship) to its final reservoir
4) Pumping of CO_2 into reservoir

All of these processes require energy and hence have a energy penalty and, assuming processes are fossil fuel driven, a carbon penalty. Electricity generation is of particular concern for all municipalities; Energy efficiency penalties for electricity generation stations range from 6 – 19 (natural gas plants) or 5-13% (coal-fired plants) (Damen et al. 2006). When considering the global average efficiency of natural gas and coal are 34% and 40% respectively (IEA, 2008), these reductions can severely limit 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, where a Saskatchewan-based Integrated Gasification Combined-Cycle power generation development was abandoned after its capital costs rose from $3778/kW to $8444/kw. Compared to the best currently available natural gas combined cycle power plant at less than $1000/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.

Strategy 8: Purchasing Carbon Offsets

One final strategy for reducing carbon footprints of municipal services is to purchase emissions offsets. By purchasing offsets, a municipality simply funds a project which 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 emissions reductions. The offset purchaser can then claim the GHG reduction against their own carbon balance, moving it towards net zero. Case 6.5 illustrates this concept further.

Case 6.5: Carbon Offsets, Toronto, Canada

An emerging climate change strategy has been the offsetting air travel and other energy consumption-related emissions by contributing financially to a renewable energy or other CO_2 offsetting project. Typically, these offset initiatives have a calculated $ / CO_2 emission avoided in a project that will benefit an external community in lowering their emissions (depending on carbon market prices). These emissions reductions projects are quantified using international standards and are independently audited. Zero Footprint provides clients with the means to quantify and purchase offsets in accordance their policies and current finances.

Reference:
Zero Footprint, 2009. Blue Chip Offsets. [Online] Available HTTP:
http://corporate.zerofootprint.net/blue-chip-offsets/ Accessed May 24, 2009

One final innovative example being considered 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 emissions 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 (San Francisco Government, 2008). Residents have the opportunity to purchase offsets as well, benefiting projects within their own community.

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CHAPTER 7: COMPARISON OF STRATEGIES

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In developing this guidebook for reducing municipal GHG emissions, we have analysed 68 case studies, many of which have been presented as boxed examples in previous chapters. As well as supporting the *rules of thumb* developed in the guide, the case studies provide a substantial dataset for comparing the different strategies for reducing GHGs. Here we primarily 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 implementation.

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 experience of research and teaching on 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 neighborhoods (Engel-Yan et al. 2005; Codoban and Kennedy 2008) and 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 first towards Canada, and second towards 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; adapted from the project website: www.utoronto.ca/sig

In some cases we were only able to obtain information 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 OPA (2007) or US 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.

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 to 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.

	Scale of Engagement		
Category	**Minor**	**Medium**	**Major**
Transportation / Land-use	High occupancy vehicle lanes; smart commute; car-pool networks; car share	Financial penalties to auto use (e.g., tolls, congestion charging)	Pedestrianization of city centres
	Natural gas vehicles (e.g. municipal buses)	Incentives for use of low-emission vehicles.	Infrastructure for plug-in-hybrid electric vehicles
	Bus rapid transit	Light rail transit	Subways
	On-road bike lanes Bike share	Segregated bike lanes	Bicycle highways
Buildings	Building energy retrofits Green roofs Energy star buildings	Improved building operations Photovoltaics Solar water/ air heaters Ground source heat pumps	Demolition and 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 waste water treatment plants
Carbon Sequestration	Planting of urban forestry Algae	Residential scale urban agriculture in CO_2-enriched greenhouses	Industrial scale urban agriculture in CO_2 -enriched greenhouses Carbon offsets

Table 7.1. Preliminary classification of GHG reduction strategies by scale of engagement.

Information on GHG savings from the case studies generally supports the classification of strategies shown in Table 7.1, although there are exceptions. All of the case studies investigated in this work, except 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 was obtained, it generally supports the minor classification. The main exception is Paris' bike share scheme, which is large enough in scope to save 18 kt CO_2 e per year, which can be 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 hence would be more appropriate in the minor category

The main disparity in the transportation projects is with the light rail and subway projects. The classification scheme in Table 7.1 recognizes that the subway mode is 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 just covers one single line in a relatively small city. The Calgary case includes the whole LRT system, which, moreover, is a quasi-regional rail system in 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 kt CO_2 e 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 for all projects, and again were generally close to expectations (Table 7.2). The Okotoks BTES system is relatively small, serving only 50 houses, so perhaps 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. A few of the projects may be out of place. The methane capture in 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 kt CO_2 e/ yr. (this needs to be verified; it may include building energy savings)

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

Category	Minor	Medium	Major
Transportation / Land-use	Bus Rapid Transit (Vancouver) **1.8 kt** Bus Rapid Transit (Curitiba) Quality Bus Corridor (Dublin) Metrolink: Express Bus (Halifax) **1.125 kt** Bike Share (Paris) **18 kt** Bike Share (Barcelona) **1.92 kt** Bike Campaign (Whitehorse) **0.0045 kt** 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) **0.24 kt**	Light Rail Transit (Calgary) **591 kt** Rubber-tired streetcar (Caen) Low Emission Zone (London) Congestion Charging (London) **120 kt** Transit Buses-Hydrogen Highway (Port Coquitlam) **0.12 kt**	Pedestrianization of city centres (Freiburg) Major Subway Expansion (Madrid) New Single-line Subway (Rennes) **18 kt** Plug-in Hybrid (United States)
Buildings	Green Roof (California) Heat Recovery in Restaurant (Toronto) **0.0075 kt**	Solar Air Heating (Montreal) **1.34 kt** Solar Hot Water Heating (Paris) **0.214 kt** Ground Source Heat Pump (Concord) **2.86 kt** Ground Source Heat Pump (Langen) Building Integrated Photovoltaic (Coney Island) **0.086 kt**	Demolition / Reconstruction (Toronto) **31.4 kt**
Energy	Small Hydro (Cordova Mines) **0.06 kt** Urban Wind Power (Toronto) **0.38 kt** Vertical Axis Wind (Liverpool) **0.0014 kt**	Tidal Stream System (Northern Ireland) **2 kt** Borehole Thermal Energy Storage (Okotoks) **0.26 kt** Photovoltaic Plant (Olmedilla de Alarcon) **29 kt** Wave Power Plant (Portugal) **1.8 kt** Lake Water District Air Conditioning (Toronto) **79 kt**	Solar Central Receiver Station (Seville) **110 kt** Solar Thermal Electricity Plant (Mojave Desert) **270 kt** Geothermal Power (Northern California) **950 kt**
Solid Waste	Methane Capture (Toronto) Automatic vacuum waste collection (Hammarby)	Source-Separation & Methane Production (Sydney) **210 kt** Source-Separation & Methane Production (Guelph) Incineration-Based CHP (Gothenburg) **205 kt** Energy From Waste (Ottawa)	Greening Supply Chains (Worldwide)
Water / Wastewater	Improved Water Distribution System (Tokyo) Rain Barrel Distribution (York Region)		Energy Recovery (Malmo) Biogas from sewage (Stockholm) **14 kt**
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 (?)**	CO_2 Sequestration in Greenhouse Operations (Sarnia)	Municipal Purchases of Carbon Offsets (San Francisco) Sustainable Industrial Agriculture (Utrecht)

Table 7.2 Case studies investigated in developing this guidebook, including annual GHG savings (kt CO_2 e) where know. (Excludes community cases)

Cost Effectiveness

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 t CO_2 e and 950,000 t CO_2 e. 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 (Fig. 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 t CO_2 e per year; while the solar air heating system in Montreal costing \$2.6 million has reported GHG savings of 1,342 t CO_2 e per year. Another comparison can be made between the subway line in Rennes, France, saving 18,000 t CO_2 e per year at a capital cost of \$730 million; and Calgary's light rail transit, powered by wind-generated electricity, which saves 591,000 t CO_2 e 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 Figure 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 Figure 7.2 are particularly noteworthy. These are cases which lie above the line of best fit, and exceed GHG savings of 100,000 t CO_2 e per year:

- **Seville's Solar Central Receiver Station** with a peak power capacity of 11MW, cost \$55 million; and we estimate that it saves 110,000 t CO_2 e per year.
- **London's Congestion Charging Scheme** is estimated to reduce emissions by 120,000 t CO_2 e 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 t CO_2 e per year.

PROJECT	**LOCATION**	**CAPITAL COST ($ million CAN)**	**ANNUAL GHG SAVING (kt CO_2 e)**
TRANSPORTATION / LAND USE			
Light Rail Transit	Calgary. Alb.	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, Ont.		2.86
Building Integrated Photovoltaic	Coney Island, New York City		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, Alb.	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, Ontario	1.8	0.06(*)
Urban Wind Power	Toronto	1.6	0.38
Vertical Axis Wind	Liverpool	0.607 (v)	0.0014(*)

continued

PROJECT	LOCATION	CAPITAL COST ($ million CAN)	ANNUAL GHG SAVING (kt CO_2 e)
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 at Wastewater Treatment Plant	Ottawa	4.5	
Wastewater heat recover	Sony City, Japan		3.5 (v)
CARBON SEQUESTRATION AND 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)
Dongtan	Shanghai		750 (v) expected

Table 7.3 Capital costs and annual greenhouse gas savings for the case studies (v = verified; * = GHG calculation undertaken by the project team).

- **Sydney's Source Separation and Energy Recovery System** achieves a 70% diversion rate and produces enough electricity to power the separation facility. The estimated GHG savings are 210,000 t CO_2 e 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 t CO_2 e per year,

In addition to these five cases, our data set includes four other projects with annual GHG savings over 100,000 t CO_2 e, but for which the capital costs are unknown to us. These are: a solar thermal electricity plant in the Mojave desert (270,000 t CO_2 e per year); a series of over twenty geothermal power plants in Northern California (950,000 t CO_2 e per year); Chicago's plan to double its tree canopy (170,000 t CO_2 e per year); and the Dongtan sustainable community development planned near Shanghai (750,000 t CO_2 e per year).

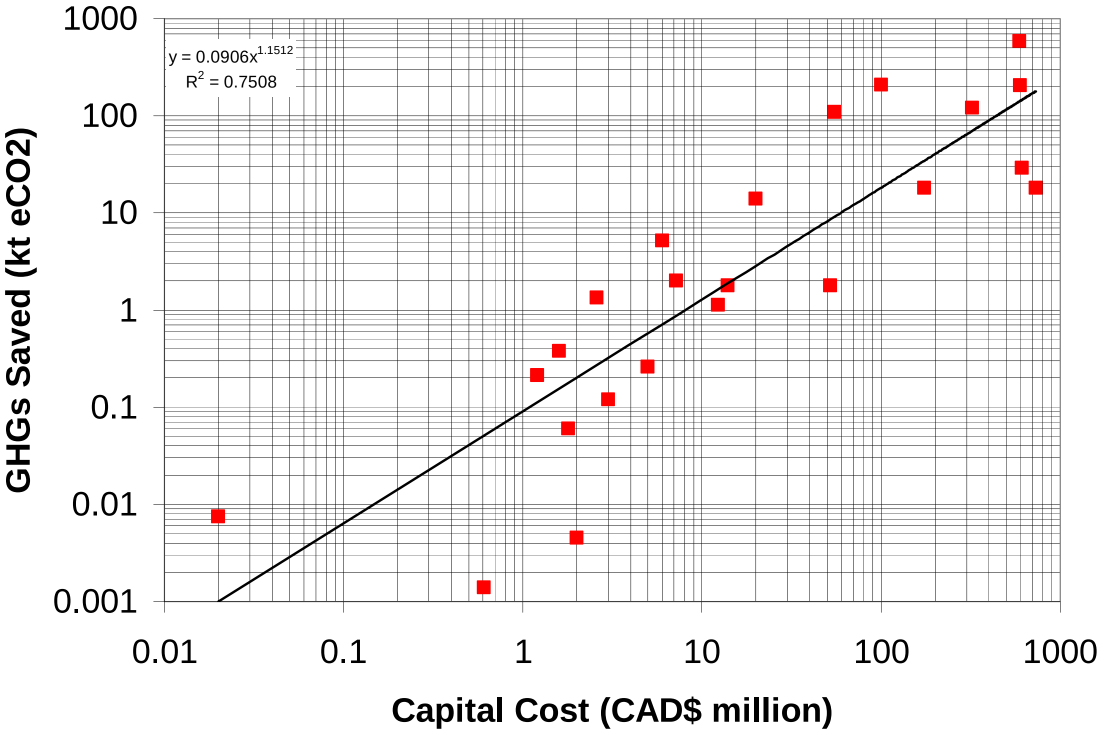

Figure 7.2 Log-log plot of annual GHG savings versus capital costs for infrastructure case studies.

These nine cases with savings over 100,000 t CO_2 e 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 our 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 t CO_2 e / yr / \$million) is on average better than for our case studies (414 t e CO_2 e / 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 t CO_2 e / yr / \$million.

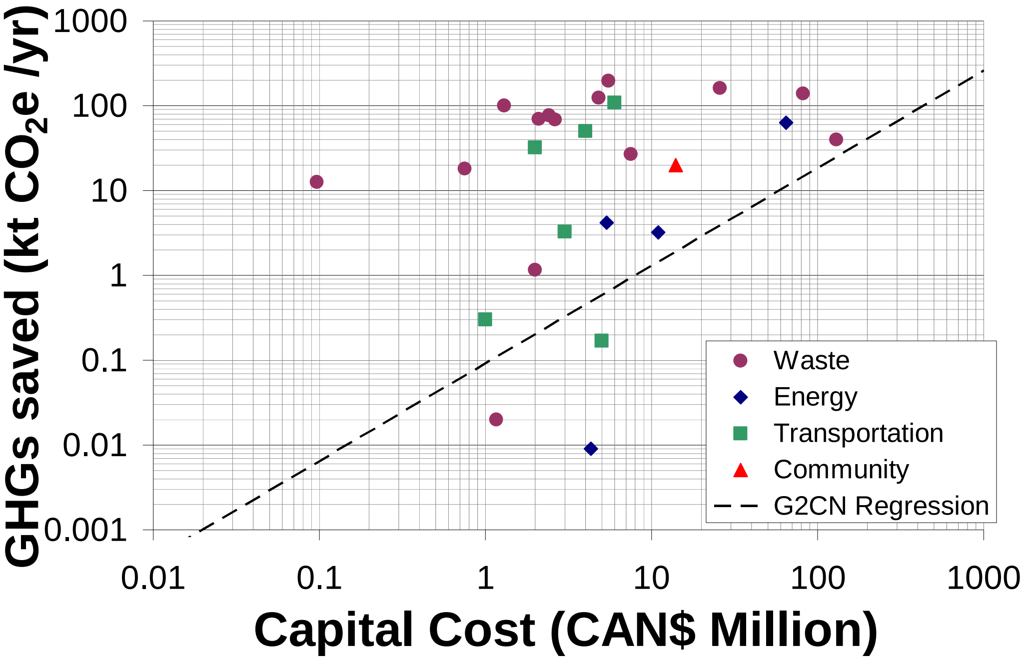

Figure 7.3. Log-log plot of annual GHG savings versus capital costs for infrastructure projects funded under the Federation of Canadian Municipalities "Green Municipal Fund." (FCM, 2009). The dashed line is from the regression of our data shown in Figure 7.2.

Several caveats have to be given to 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 application 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 merits 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% 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.

Other Benefits

For many of the case studies we were able to document other benefits beyond the reduction in greenhouse gas 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 55-60% less water consumption 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. The planned Dongtan Eco-City in China will provide ecological management of wetlands and will reduce waste to landfill by 90% through collection for energy production, recycling, and composting. A further example is at the Bromma and Henriksdal biogas plants in Stockholm, Sweden, where the sewage sludge from waste water 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%). 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: real estate value, retail/commercial improvement, 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 Freiberg, 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) programme organised 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., reduction on 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. The opening of Seattle's high occupancy vehicle lanes were also seen as a means to increase the reliability of bus services.

In some cases, the increased reliability clearly provided economic benefits, e.g., 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 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 have clear economic benefits. Compost from the organic stream of Sydney's sources 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 emissions reduction projects within the city. Spending offset dollars within the municipality, stimulates local economic activity and boosts expertise in green technology**.** There is the further added benefit of reducing energy consumption from underprivileged communities in San Francisco.

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. For about fifteen of the cases, in particular for transportation projects, we obtained details on the key hurdles that were overcome in implementation.

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 route to the city centre or the university. Transit ridership in Edmonton increased by 45 percent 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 which 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 1.2MW SeaGen Tidal System – the first installation of a truly commercial scale tidal stream electricity generator – installed 400m off the coast of Northern Ireland. The engineering challenges for offshore renewable energy systems are formidable; primarily 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 therefore, paradoxically 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 the project and making it cost more as a result. The consenting process also became more difficult as a result of sometimes unsubstantiated controversies surrounding 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 in the future price of energy was generally an issue to be overcome in the energy supply cases. This also 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 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. They then had to work with abatement equipment manufacturers and certification authorities to help vehicle operators make their vehicles compliant. Lorry and bus operators had to be accepting of 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 our 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 with 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 programme, 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 authorisations from underground network providers, such as electricity, water and heating providers; each single station requiring separate studies. Then there was authorisation 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 taking detriment of visibility and integration of bike parks into the Parisian landscape into account. Implementation of the programme 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 the 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 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 traveled.

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; and fighting the political turf. These are examples of what it takes.

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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 GHG emissions for cities in Canada and abroad. While each case details the success of a specific project, achieving carbon neutrality, or near-neutrality, requires a synergetic 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.; and Vauban District in Freiberg, 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.

Moreover, the potential for carbon neutrality extends beyond the community scale to the city scale, demonstrated by the planned development of Dongtan Eco-City near Shanghai, China. The proposed city will be carbon neutral (at least with respect to direct emissions) with advanced energy efficient homes, emission-free transportation technology, renewable electrical generation, and combined heat and power facilities.

Case 8.1: Dockside Green, Victoria, British Columbia

Dockside Green is a 15-acre 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 45-55% 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, as well as reduce transport emissions with a mini-transit system and car share program. Compared to a traditional development, 5,215 t CO_2 e / year are avoided through biomass use, space heating efficiency, and electricity efficiency.

Reference:
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Case 8.2: Beddington Zero-Energy Development (BedZED), London, UK

BedZED, short for Beddington Zero-Energy Development, is a high-density, mixed use, carbon-neutral community developed on an urban brownfield site in Southwest London 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% for heating and water heating; 40% for home electricity, and 50% less water consumption. The energy sources for space heating, cooling, and electricity generation are carbon-neutral.

References:
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Case 8.3: Vauban District of Freiberg, Germany

Vauban is an environmentally sustainable city district of Freiberg, 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 450m^2 of solar collectors provide 45% of the community's electricity requirements as well as district heating. The community is "parking-free" and close to 50% 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 Freiberg city centre. The community design is estimated to save 28 GJ of energy, 2100 t CO_2 e and 4 t SO_2 e per year.

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Case 8.4: Dongtan Eco-City, Chongming Dao, China

On the south-east end of Chongming Island at the mouth of the Yangtze River, Dongtan Eco-City is planned to be environmentally, socially, economically, and culturally sustainable. Forty-percent of the land area will be urbanized, leaving space for organic agriculture and existing wetlands. All housing will be within walking distance to social infrastructure, reducing demands for transportation. Public transportation will use emission-free technologies, and visitors will leave vehicles that expel tail pipe emissions outside the city. Green roofs and advanced building technologies, including natural ventilation, will reduce building energy demands. Electricity will be produced from renewable sources, including photovoltaic cells, wind turbines, and biogas from municipal waste and sewage. In addition, a combined heat and power plant running on biomass waste from agriculture will provide district heating. Energy will also be managed through resident education, smart metering, and financial incentives.

The development is planned to have near-zero carbon emissions. The aim is for a 66% reduction in energy demand compared to conventional design. Savings of 350,000 t. CO_2 e /yr. will be due to building energy efficiency; with a further 400,000 tonnes CO_2 e saved annually from transportation.

Reference:
Arup Press Office. Dongtan Fact Sheet. Provided by Beth Huran (personal communication).

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 Rules of Thumb. By following the example calculation techniques, a municipality may create their own scenarios of reduction strategies towards the development, or assessment, of plans for emissions 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 Rules of Thumb 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.

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 dollars (based on provincial GDP weighted by employment data). The total land area for the City, kept constant in all scenarios, is about 63,000 hectares.

a) 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 10ft and 12ft 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) of 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 gCO2e/kWh (68.3 tCO2e/TJ) and the emissions intensity of natural gas to be 56.1 tCO2e/TJ (as shown in Table 2.2). In Toronto in 2004, buildings were responsible for about 14 megatonnes of GHG emissions.

		Low-Rise Residential	**Apartments**	**Commercial**
Energy Intensity (GJ/m^2)[1]		0.83	0.68	1.65
Total Energy Breakdown				
Canadian Average[2]	Non-electrical Energy	62%	52%	56%
	heating)	38%	48%	44%
Toronto[3]	Natural Gas	82%	82%	51%
	Electricity	18%	18%	49%
Total Natural Gas Breakdown				
Canadian Average[2]	Space Heating	72.5%	72.5%	85%
	Water Heating	27.5%	27.5%	15%
Total Electricity Breakdown				
Canadian Average[2]	Lighting	21.5%	21.5%	25%
	Appliances	60%	60%	58%
	Space Cooling	18.5%	18.5%	17%

[1] As previously shown in Table 3.1

[2] National Resources Canada NEUD Tables

[3] Calculated from the 2004 Toronto GHG Inventory

Table 8.1 Energy, natural gas, and electricity breakdown by end-use for different building classifications.

	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 (TJ)	*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 (ktCO2e)	**4,498**	**2,114**	**7,386**	**13,997**

Table 8.2 Estimated energy use and emissions for the Toronto building stock in 2004.

b) 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 available from the Toronto Transit Commission (Toronto Transit Commission, 2008), and given there were no major infrastructure changes, it was assumed to be similar to the 2004 infrastructure:

- 1545 Buses
- 248 Streetcars, 69.2 km of Streetcar tracks
- 706 Subway cars, 68.3 km of Subway tracks

The resultant vehicle kilometres traveled, VKT (km), 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%. This mode share fraction was subsequently subtracted from the GHG emissions of each motorized mode.

To calculate the per-kilometre emissions intensity (gCO2e/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 (gCO2e/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 (gCO2e/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.

	Private Automobiles	**Bus**	**Streetcar**	**LRT**	**Subway**	**TOTAL**
VKT per capita (km)	4,077	29	12	-	39	4,157
Emissions Factor (kgCO2e/km)	0.271	2.01	1.07	1.15	0.852	-
Per Capita Emissions Before Savings (kgCO2e)	1,103	59	13	-	33	1,208
Emissions Before Savings (ktCO2e)	**2,920**	**155**	**33.8**	**-**	**87.5**	**3,197**
MODE SHARE SAVINGS						
Active Transport						
Biking (ktCO2e)	*26*	*1.4*	*0.3*	-	*0.8*	28
Total Savings (ktCO2e)	***26***	***1.4***	***0.3***	**-**	***0.8***	***28***
Total Emissions (ktCO2e)	**2,895**	**154**	**33.5**	**-**	**86.7**	**3,169**

Table 8.3 Vehicle kilometres-travelled (VKT), emissions, and mode share savings for Toronto's transport infrastructure in 2004. Values estimated using the MUNTAG model.

Emissions calculated using the Rules of Thumb 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% difference in numerical values. Although the Rules of Thumb in the Guide exclude emissions from industrial buildings, trucks, and waste, the calculations for other sources were shown to be verifiable.

	2004 Toronto GHG Inventory	2004 Base-Case	Percent Difference
Population (millions)	2.65	2.65	-
BUILDINGS (ktCO2e)	**14,884**	**13,997**	**-6%**
Low-Rise Residential (ktCO2e)	*5,997*	*4,498*	10%
Apartments (ktCO2e)		*2,114*	
Commercial[1] (ktCO2e)	*8,887*	*7,386*	-17%
PASSENGER TRANSPORT (ktCO2e)	**8,559**	**3,169**	-
Private Automobiles (ktCO2e)	*2,839*	*2,895*	2%
Bus (ktCO2e)	*172*	*154*	-11%
Streetcar (ktCO2e)	-	*34*	-
LRT (ktCO2e)	-	-	-
Subway (ktCO2e)	-	*87*	-
Other Vehicles (incl. trucks) (ktCO2)	*5,549*	-	-
WASTE (ktCO2e)	**978**	-	-

[1] From 2004 Toronto GHG Inventory, includes industrial emissions ("Commercial and small industrial" and "Large commerical and industrial")

Table 8.4: Comparison between 2004 Toronto GHG Inventory and 2004 Base-Case Scenario.

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 Rules of Thumb 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 3.08 million. The city's GDP is projected to be 178 billion dollars, and the land area will remain the same at 63,000 hectares.

a) 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% by 2031. Ten percent of the increase in residential GFA was assigned to Low-Rise Residential housing and the remaining 90% was assigned to Apartments. Commercial GFA was assumed to grow at the same rate as employment, which is projected to increase 10% 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 tCO2e/TJ, and the projected Integrated Systems Plan electrical emissions intensity (including line losses) was taken to be 37.8 gCO2e/kWh (10.5 tCO2e/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; and promoting commercial green roofs.

Banning incandescent bulbs

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

Requiring ENERGY STAR Appliances

The ENERGY STAR Rule of Thumb offers a range of potential savings based on different appliances. The average savings was taken as 30% for these calculations, and it was assumed 60% of residential appliances and 30% of commercial appliances are not already ENERGY STAR rated. The energy savings to appliance electricity is therefore 18% for residential buildings and 9% 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 Rule of Thumb states that R2000 homes use 30% 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%. 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 1960's-era high-rise towers, as well as promote neighbourhood revitalization initiatives (Kesik et al., 2008). To simulate the effects of this, a 30% savings on space heating energy will be applied to all Toronto Community Housing Corporation buildings, as per the Building Retrofits Rule of Thumb. 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% saves 49.4 kilotonnes of GHG emissions.

Promoting commercial green roofs

The Vegetation Rule of Thumb describes green roofs as reducing peak summer cooling loads by 25% in roofs immediately below the green roof. The green roof initiative targets to cover 10% of commercial buildings with green roofs (City of Toronto, 2009b). Assuming the savings would apply to 10% 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.

	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 (ktCO2e)	**3,814**	**2,485**	**4,469**	**10,767**
SAVINGS				
Incandescent bulbs to CFL bulbs (ktCO2e)	*16.5*	*10.8*	*12.8*	*40.1*
All appliances EnergyStar rated (ktCO2e)	*15.8*	*10.3*	*35.4*	*61.5*
R2000 standards in 2012 OBC (ktCO2e)	*14.8*	-	-	*14.8*
Mayor's Tower Renewal Retrofits (ktCO2e)	-	*49.5*	-	*49.5*
Commercial roof space 10% green (ktCO2e)	-	-	*0.3*	*0.3*
Total Savings (ktCO2e)	***47.1***	***70.6***	***48.5***	***166.2***
Total Emissions (tCO2e)	**3,767**	**2,414**	**4,421**	**10,601**

Table 8.5: Projected energy use, emissions, and policy-related emissions savings for the Toronto building stock in 2031.

b) 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 availability of public transport. The three other initiatives that were quantified in this scenario include: an increased adoption of electric vehicles; an increase to the length of bicycle facility; and a 10% 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:

- 1737 Buses
- 248 Streetcars, 65.6 km of Streetcar tracks
- 1063 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 (gCO2e/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 (gCO2e/MJ) of either diesel fuel (in Table 2.2; for buses) or Integrated Systems Plan electricity (10.5 tCO2e/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 5% by 2020 (Office of the Premier, 2009). Assuming an exponential increase in years following, the percentage of private automobile VKTs traveled by electric vehicles was taken to be 20% in 2031. The remaining 80% 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% more efficiently than internal combustion engines. Therefore, the average energy intensity (MJ/VKT) was estimated to be 35% 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 tCO2e/TJ). With these assumptions, the per-kilometre emissions intensity of electric vehicles was calculated to be 93.55 gCO2e/VKT. Accordingly, GHG emissions savings associated with the 20% adoption of electric vehicles in 2031 is 4.39 kilotonnes.

Increasing length of bicycle facility to promote active transport
The bicycle facility in Toronto is planned to increase from 403 km to 1004 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% was made. According to the Parking Price Rule of Thumb, 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% of personal vehicles to electric vehicles. When combined, the planned initiatives reduce transport related GHG emissions to about 3.1 megatonnes in 2031.

	Private Automobiles	Bus	Streetcar	LRT	Subway	TOTAL
VKT per capita (km)	4,017	28	11	21	54	4,131
Emissions Factor (kgCO2e/km)	0.271	2.01	0.163	0.175	0.130	
Per Capita Emissions Before Savings (kgCO2e)	1,087	57	1.8	3.6	7.1	1,156
Emissions Before Savings (ktCO2e)	**3,348**	**176**	**5.4**	**11**	**22**	**3,562**
TECHNOLOGY SAVINGS						
Vehicle Technology						
20% Battery Electric Vehicles (emissions factor of 94 gCO2e/km) (ktCO2e)	*439*					*439*
ADDITIONAL MODE SHARE SAVINGS						
Active Transport						
Biking (ktCO2e)	*22*	*2.3*	*0.07*	*0.15*	*0.28*	*25*
Parking Fees						
10% Increase in Parking Price (ktCO2e)	*12*	*-0.2*	*-0.01*	*-0.01*	*-0.02*	*12*
Total Mode Share Savings (ktCO2e)	***473***	***2.1***	***0.07***	***0.14***	***0.26***	***476***
Total Emissions (ktCO2e)	**2,875**	**174**	**5.4**	**11**	**21**	**3,086**

Table 8.6 Vehicle kilometres-travelled (VKT), emissions, and planned mode share savings for Toronto's Metrolinx infrastructure in 2031. 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% 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 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.

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 Rules of Thumb provided. This scenario represents one aggressive plan that could help Toronto get closer to carbon neutral.

a) 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. Overall, several energy-saving measures were used to reduce 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; and outfitting commercial buildings with solar air heating and 25% 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% more efficient than incandescent bulbs and 60% more efficient than CFL bulbs. Assuming the same percentages of incandescent lighting as in the Planned-Policy Scenario (70% of residential lighting energy and 10% of commercial lighting energy), and assuming the remaining lighting energy is currently met with CFL bulbs, implementing CFL bulbs would save 81% of lighting electricity in residential buildings and 63% 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 Rule of Thumb states that retrofitting can reduce energy demand by 30% for apartments and commercial buildings and can save up to 50% for low-rise residential homes. Taking the average energy savings to be 30% 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 Rule of Thumb, these buildings can be designed to consume 60% 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% 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 Rule of Thumb assigns 45% 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 Rule of Thumb, outfitting all pre-2012 low-rise residential homes with ground source heat pumps would save 30% 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% savings to heating energy and 70% 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 Rule of Thumb, there is the potential for 25-47% saving to space heating energy. Using the conservative estimate that 30% 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 target to cover 25% of commercial buildings with green roofs. Assuming the Rule of Thumb's 25% savings to peak cooling needs would again apply to 10% 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, building account for about 4.9 megatonnes of emissions in 2031 Toronto.

	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 (ktCO2e)	**3,814**	**2,485**	**4,469**	**10,767**
SAVINGS				
Incandescent and CFL bulbs to LEDs (ktCO2e)	*25.5*	*16.6*	*107.8*	*149.9*
All appliances EnergyStar rated (ktCO2e)	*15.8*	*10.3*	*35.4*	*61.5*
All pre-2012 buildings retrofitted (ktCO2e)	*1,079.7*	*566.2*	*1,074.9*	*2,720.8*
Post-2012 buildings follow energy efficiency standards (ktCO2e)	-	*301.3*	*124.0*	*425.3*
Post-2012 homes built to R2000 standards with BTES systems (ktCO2e)	*61.3*	-	-	*61.3*
Pre-2012 homes outfitted with Solar Water Heating (ktCO2e)	*445.4*	-	-	*445.4*
Pre-2012 homes outfitted with Ground Source Heat Pumps (ktCO2e)	*790.8*	-	-	*790.8*
Half of apartment buildings outfitted with an ATES system (ktCO2e)	-	*222.8*	-	*222.8*
Commerical solar air heating (ktCO2e)	-	-	*966.3*	*966.3*
Commerical roofs are 25% green (ktCO2e)	-		*0.7*	*0.7*
Total Savings (ktCO2e)	***2,418.5***	***1,117.2***	***2,309.1***	***5,844.8***
Total Emissions (ktCO2e)	**1,396**	**1,368**	**2,160**	**4,922**

Table 8.7 Energy use, emissions, and aggressive emissions savings for the Toronto building stock in 2031.

b) Transport

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 in 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 1004 km by 2012. Continuing to increase linearly through to 2031 would result in a bicycle facility 2431 km in length. With this aggressive increase, the active transport mode share would be 2.33% 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% 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, D.C. 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.

	Private Automobiles	Bus	Streetcar	LRT	Subway	TOTAL
VKT per capita (km)	4,017	28	11	21	54	4,131
Emissions Factor (kgCO2e/km)	0.271	2.01	0.163	0.175	0.130	
Per Capita Emissions Before Savings (kgCO2e)	1,087	57	1.8	3.6	7.1	1,156
Emissions Before Savings (ktCO2e)	**3,348**	**176**	**5.4**	**11**	**22**	**3,562**
INFRASTRUCTURE AND TECHNOLOGY SAVINGS						
Transit Infrastructure						
LRT infrastructure changed to Subway infrastructure (ktCO2e)	*701*			*11*	*-27*	*686*
Vehicle Technology						
100% Battery Electric Vehicles (emissions factor of 94 gCO2e/km) (ktCO2e)	*1,731*					*1,731*
ADDITIONAL MODE SHARE SAVINGS						
Active Transport						
Biking (ktCO2e)	*21*	*4.1*	*0.1*	*0.0*	*1.1*	*27*
Parking Fees						
10% Increase in Parking Price (ktCO2e)	*6.4*	*-0.2*	*0.0*	*0.0*	*0.0*	*6.2*
Taxes and tolls						
VMT tax (ktCO2e)	*134*					*134*
Freeway toll (ktCO2e)	*19*					*19*
Total Savings (ktCO2e)	***2,613***	***3.9***	***0.1***	***11***	***-26***	***2,603***
Total Emissions (ktCO2e)	**735**	**172**	**5.3**	**0**	**47**	**959**

Table 8.8 Vehicle kilometres-travelled (VKT), emissions, and mode share savings for Toronto's Metrolinx infrastructure with aggressive transport changes in 2031. Values estimated using the MUNTAG model.

With more aggressive actions taken, buildings 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%.

	2004 Base-Case	**2031 Planned-Policies**	**2031 Aggressive-Alternatives**
Population (millions)	2.65	3.08	3.08
BUILDINGS (ktCO2e)	**13,997**	**10,601**	**4,922**
Low-Rise Residential (ktCO2e)	*4,498*	*3,767*	*1,396*
Apartments (ktCO2e)	*2,114*	*2,414*	*1,368*
Commercial[1] (ktCO2e)	*7,386*	*4,421*	*2,160*
PASSENGER TRANSPORT (ktCO2e)	**3,169**	**3,086**	**959**
Private Automobiles (ktCO2e)	*2,895*	*2,875*	*735*
Bus (ktCO2e)	*154*	*174*	*172*
Streetcar (ktCO2e)	*34*	*5.4*	*5.3*
LRT (ktCO2e)	-	*11*	-
Subway (ktCO2e)	*87*	*21*	*47*
TOTAL (ktCO2e)	**17,166**	**13,687**	**5,881**
TOTAL per capita (tCO2e)	**6.48**	**4.44**	**1.91**

Table 8.9 Comparison of final emissions values for all scenarios and 2004 Toronto GHG inventory (all values in tCO2e).

The aggressive actions were applied to Toronto in this scenario, and equally as aggressive actions could be successfully applied in any municipality in Canada. Individually, projects invoking these strategies are demonstrating success in cities throughout the world, described in the previous boxed case studies in this guide. When treated as systems working together, these strategies have allowed for the creation near-carbon neutral communities, such as Dockside Green and BedZED, and even carbon neutral cities, such as Dongtan. Implementing bold, 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		Saskatchewan	
		2006		2006		2002		2006		2006		2006		2006	
Single Detached	Energy Intensity (GJ/m2)	0.87		0.83		1.03		0.69		1.22		0.82		1	
	Stock (million m2)	1,076		442		186		155		110		39		36	
		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)	Shares %	GHG (Mt of CO2e)
Table 34	Electricity	37.7	19.9	30.2	-	56.3	-	40.0	-	16.0	-	50.4	-	23.8	-
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	71.5	1.3
	Heating Oil	5.7	3.9	3.9	1.1	12.4	1.7	0.6	0	0.0	0	0.2	0	1.4	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	1.1	0
	Wood	8.4	1.5	4.4	0.3	23.0	0.8	6.4	0.1	0.2	0	5.5	0	2.3	0
Single Attached	Energy Intensity (GJ/m2)	0.8		0.83		0.87		0.64		0.92		0.76		0.94	
	Stock (million m2)	168		85		28		23		16		3		2	
		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)	Shares %	GHG (Mt of CO2e)
Table 36	Electricity	40.2	3.1	32.1	-	65.9	-	42.8	-	19.8	-	51.9	-	22.9	-
Table 42 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	72.7	0.1
	Heating Oil	5.6	0.6	3.8	0.2	15.3	0.3	0.5	0	0.0	0	0.2	0	1.6	0
	Other (coal, propane)	1.0	0.1	1.4	0.1	0.3	0	0.7	0	0.5	0	0.7	0	1.0	0
	Wood	4.1	0.1	2.5	0.0	9.8	0	3.8	0	0.2	0	3.0	0	1.9	0
Low Rise	Detached	86.5%		83.9%		86.9%		87.1%		87.3%		92.9%		94.7%	
Weighted ave of Detached															
and Attached	Attached	13.5%		16.1%		13.1%		12.9%		12.7%		7.1%		5.3%	
	Stock (million m2)	1,244		527		214		178		126		42		38	
Table 36	Energy Intensity (GJ/m2)	0.861		0.830		1.009		0.684		1.182		0.816		0.997	
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)	Shares %	GHG (Mt of CO2e)
	Electricity	38.0	17.6	30.5	-	57.6	-	40.4	-	16.5	-	50.5	-	23.8	-
	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	71.6	1.2
	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	1.4	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	1.1	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	2.3	0.0
Apartment	Energy Intensity (GJ/m2)	0.72		0.68		0.81		0.65		0.92		0.58		0.75	
	Stock (million m2)	338		120		117		43		22		9		6	
		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)	Shares %	GHG (Mt of CO2e)
Table 38	Electricity	47.8	6.5	29.6	0	67.7	-	43.8	-	17.6	-	51	-	27.4	-
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	69	0.2
	Heating Oil	8.0	1.4	3.7	0.2	16.8	1.2	0.4	0	0	0	0.2	0	1.3	0
	Other (coal, propane)	0.7	0.1	1.3	0.1	0.3	0	0.6	0	0.5	0	0.6	0	0.9	0
	Wood	4.0	0.2	2.3	0.0	6.6	0.1	2.7	0	0.2	0	2.7	0	1.5	0
Commercial/Institutional	Energy Intensity (GJ/m2)	1.62		1.65		1.8				1.6		1.6		2.12	
Table 1	Stock (million m2)	667.7		255.9		126.7				95.8		26.5		23.4	
		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)
*Quebec data - 2006	Electricity	43.5	26.8	44	-	54.6	-			32.7	-	40.1	-	30.9	-
	Natural Gas	42.9	23.3	47	10	29	3.3			63.4	4.9	55.1	1.2	49.5	1.2
	Light Fuel Oil and Kerosene	6.9	5.5	4.6	1.4	9.5	1.6			0.1	0	0.8	0	0.4	0
	Heavy Fuel Oil	3.9	3.1	1.8	0.6	5	0.8			1.2	0.1	1.2	0	13.2	0.5
	Steam	0.2	0	0.1	0	0	0			0	0	0	0	4.4	0
	Other (coal, propane)	2.5	1.7	2.6	0.7	1.8	0.3			2.6	0.2	2.9	0.1	1.5	0
High Rise	Apartment	33.6%		31.9%		48.0%		31.6%		18.7%		25.4%		20.4%	
Weighted ave of Apartment															
and Commercial/Institutional	Commercial/Institutional	66.4%		68.1%		52.0%		68.4%		81.3%		74.6%		79.6%	
	Stock (million m2)	1,006		376		244		136		118		36		29	
Table 36	Energy Intensity (GJ/m2)	1.318		1.340		1.325		1.067		1.473		1.341		1.840	
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)	Shares %	GHG (Mt of CO2e)
	Electricity	44.9	20.0	39.4	-	60.9	-	43.9	-	29.9	-	42.9	-	30.2	-
	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	53.5	1.0

		Newfoundland		PEI		Nova Scotia		New Brunswick		Territories		Atlantic		BC and Territories	
		2006		2006		2006		2006		2006		2006		2006	
Single Detached	Energy Intensity (GJ/m2)	0.75		0.59		0.68		0.92		0.7					
	Stock (million m2)	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)				
Table 34	Electricity	64.4	-	15.1	-	45.8	-	61.1	-	33.6	-				
Table 39 for "Canada"	Natural Gas	0.0	0	0.0	0	0.0	0	2.2	0	6.2	0				
	Heating Oil	17.8	0.2	70.4	0.2	37.9	0.7	18.2	0.3	40.7	0.1				
	Other (coal, propane)	1.3	0	5.0	0	3.5	0.1	0.8	0	7.1	0				
	Wood	16.6	0	9.4	0	12.8	0.1	17.8	0.1	12.4	0				
Single Attached	Energy Intensity (GJ/m2)	0.72		0.6		0.63		0.89		0.66					
	Stock (million m2)	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)				
Table 36	Electricity	65.2	-	15.7	-	45.0	-	64.5	-	36.7	-				
Table 42 for "Canada"	Natural Gas	0.0	0	0.0	0	0.0	0	2.0	0	5.8	0				
	Heating Oil	16.4	0	63.1	0	36.9	0	17.7	0	39.1	0				
	Other (coal, propane)	1.2	0	4.4	0	3.4	0	0.7	0	6.7	0				
	Wood	17.1	0	16.8	0	14.7	0	15.1	0	11.7	0				
Low Rise	Detached	90.9%		100.0%		92.1%		96.4%		75.0%					
Weighted ave of Detached															
and Attached	Attached	9.1%		0.0%		7.9%		3.6%		25.0%					
	Stock (million m2)	22		5		38		28		4					
Table 36	Energy Intensity (GJ/m2)	0.747		0.590		0.676		0.919		0.690					
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)				
	Electricity	64.5	-	15.1	-	45.7	-	61.2	-	34.4	-				
	Natural Gas	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	6.1	0.0				
	Heating Oil	17.7	0.2	70.4	0.2	37.8	0.6	18.2	0.3	40.3	0.1				
	Other (coal, propane)	1.3	0.0	5.0	0.0	3.5	0.1	0.8	0.0	7.0	0.0				
	Wood	16.6	0.0	9.4	0.0	13.0	0.1	17.7	0.1	12.2	0.0				
Apartment	Energy Intensity (GJ/m2)	0.59		0.46		0.56		0.68		0.58					
	Stock (million m2)	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)				
Table 38	Electricity	67.4	-	17.2	-	49.8	-	64.2	-	45.2	-				
Table 45 for "Canada"	Natural Gas	0	0	0	0	0	0	2.3	0	5.1	0				
	Heating Oil	15.8	0	63	0	35.7	0.1	18.2	0	34.6	0				
	Other (coal, propane)	1.1	0	4.1	0	2.7	0	0.7	0	5.5	0				
	Wood	15.7	0	15.7	0	11.8	0	14.6	0	9.6	0				
Commercial/Institutional	Energy Intensity (GJ/m2)											1.56		1.26	
Table 1	Stock (million m2)											46.3		93.1	
												Shares %	GHG (Mt of CO2e)	Shares %	GHG (Mt of CO2e)
*Quebec data - 2006	Electricity											39.1	-	43.9	-
	Natural Gas											2	0.1	46.5	2.7
	Light Fuel Oil and Kerosene											36.8	1.9	5.8	0.5
	Heavy Fuel Oil											16.5	0.9	2	0.2
	Steam											0	0	0	0
	Other (coal, propane)											5.7	0.3	1.8	0.1
High Rise	Apartment	4.1%		2.1%		13.1%		9.7%		0.0%					
Weighted ave of Apartment															
and Commercial/Institutional	Commercial/Institutional	95.9%		97.9%		86.9%		90.3%		100.0%					
	Stock (million m2)	48		47		53		51		93					
Table 36	Energy Intensity (GJ/m2)	1.520		1.537		1.429		1.474		1.260					
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)				
	Electricity	40.3	-	38.6	-	40.5	-	41.5	-	43.9	-				
	Natural Gas	1.9	0.1	2.0	0.1	1.7	0.1	2.0	0.1	46.5	2.7				

Source NRCan NEUD tables

Appendix B: Municipal Transportation and Greenhouse-gases 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 MUNTAG, MUNicipal Transportation And Greenhouse-gases model, that is an empirical model developed for this purpose.

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

GDP pc/Pop D

For this component, the desired GDP per capita value in 2002 CA$ 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.

Motorized Pkt/p

This should be calculated by using the rule of thumb present in chapter 4.

b) Private Mode

Private PKT/p

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

Private VKT/p

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

$$\text{Private: VKT per capita} \approx 0.7 \bullet \text{PKT per capita} + 96.43 \qquad \text{(B.1)}$$

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:

$$\text{Private: VKT per capita} \approx \text{PKT per capita / v\_occ} \qquad \text{(B.2)}$$

Private GHG/p

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

c) Public Transport

Transit-km of transit in m/ha

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.

Number of vehicles per million people operating under maximum service

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:

$$T_c = 2 \cdot T_o + T_t = 2 \cdot 60 \cdot \frac{V_o}{L} + T_t \qquad \text{(B.3)}$$

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% of the two-way operating times.

Public PKT/p

Public PKT per capita should be calculated using the rules of thumb available from the Transportation chapter.

Public VKT/p

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 rule of thumb.

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, emissions 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 emissions factor present 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) Deter Automobile Use

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

The tables and rules of thumb 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.

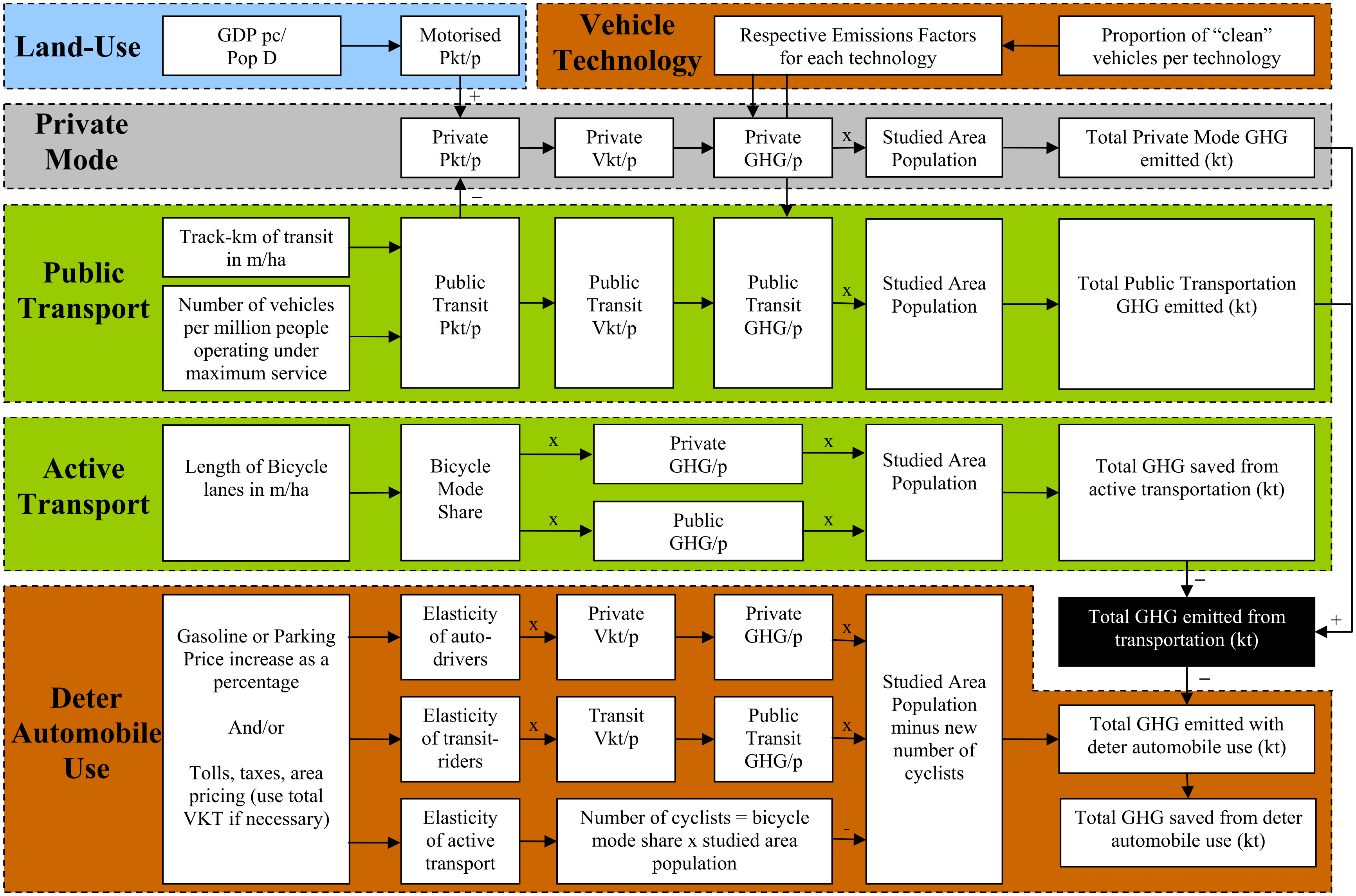

Figure B.1: MUNTAG: MUNicipal Transportation And Greenhouse-gases