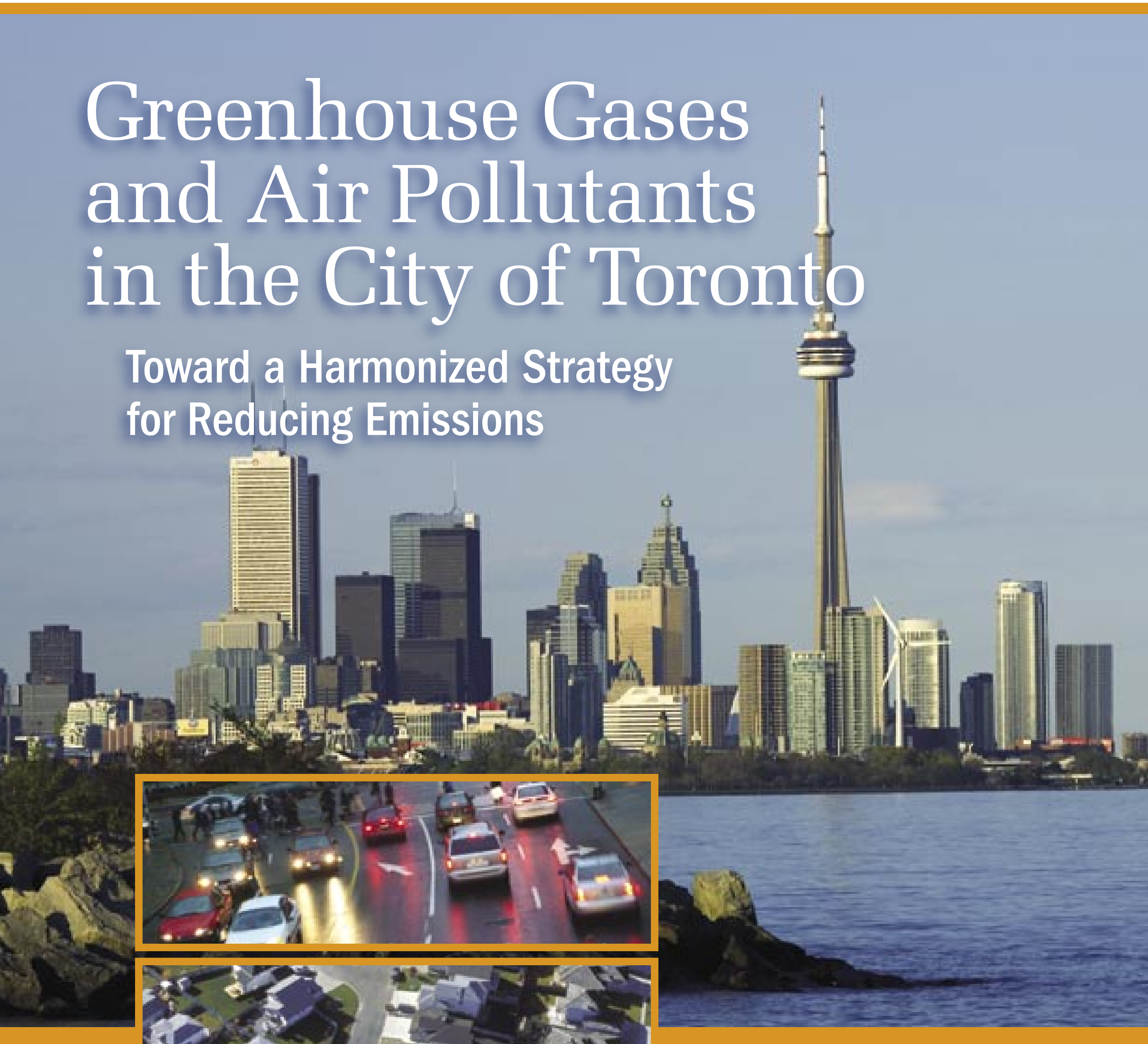
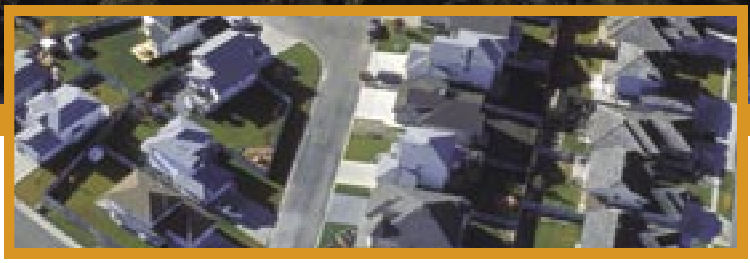
Greenhouse Gases and Air Pollutants in the City of Toronto

Toward a Harmonized Strategy for Reducing Emissions





Prepared by:

ICF International

in collaboration with

Toronto Atmospheric Fund

and Toronto Environment Office

June 2007

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Executive Summary

Taking an integrated approach to air emissions in Toronto

This 2004 emissions inventory represents the first attempt by the City of Toronto to create an integrated survey of both greenhouse gas (GHG) and criteria air contaminant (CAC) emissions for both the City corporation and the community at large.

The City has previously undertaken similar inventories of greenhouse gas emissions, but saw the need to better address the interconnected nature of the issues of climate change and air pollution. These interconnections extend from common sources of emissions to the amplifying effect of an increasingly warmer climate on smog formation. There is also a strong overlap in potential solutions. In particular, reducing fossil fuel consumption simultaneously addresses emissions of carbon dioxide, the principal greenhouse gas, and of nitrogen oxides (NOx), the primary CAC.

But while there are clear benefits in developing coordinated measurements and responses to GHG and CAC emissions, there are also major challenges, largely because assessing CAC emissions requires a much greater level of detail about specific emissions than assessing GHG emissions requires. Calculating GHG impacts generally only requires information about the amount and type of fuel consumed, while assessing air pollution impacts requires broader information, including the characteristics of the fuel (e.g., low or high sulphur), how it is being used (e.g., high-efficiency boiler or small engine), and whether there are any pollution controls in place. This analysis also varies for each different air contaminant, so that the resulting challenge is one of assessing a large number of permutations and combinations of base conditions and impacts.

Another complicating aspect is the importance of weather (or atmospheric conditions) and release point in determining the actual impact of CACs on air quality. Higher temperatures and sunlight, for example, are crucial to the formation of ground-level ozone, so CAC emissions are likely to have a larger impact during high temperature periods. Similarly, temperature inversions or other atmospheric conditions that push contaminants closer to the ground will make the actual air quality that city residents experience worse than on days when these contaminants are largely found higher up. So while we can attempt to measure CAC releases, we don't know what the actual impact of these releases will be on any given day – other than to say that the more we release, the greater the potential is for problems to occur.

This detailed level of analysis of the air quality impacts of CACs is simply beyond the scope of this inventory. Therefore, in order to get a preliminary assessment of the situation that would provide some helpful insights, we focused on emissions of key CACs, particularly nitrogen oxides, where we have some base assumptions in place.

The key emissions – how do we measure them?

We know from past inventories that there are three dominant sources of emissions within the City for which information on fuel inputs and CAC emission factors are largely available: natural gas burning (mostly in residential and commercial buildings for heating); electricity production (mostly beyond Toronto's boundaries but counted as part of Toronto's GHG emissions to the extent Torontonian's demand for electricity gives rise to the power production); and burning of gasoline and diesel fuel in the millions of cars and trucks moving throughout the city every day.

Still, challenges remain, especially in terms of the assessment of impacts associated with mobile sources, such as cars and trucks. For stationary sources like power plants and buildings, we can largely rely on readily available data about fuel or electricity consumption and type of usage to determine emissions. With cars and trucks, this becomes much more challenging. Information on fuel sales within the City of Toronto is available, but doesn't tell us where the fuel was used or in what type of vehicle. Similarly, provincial licensing data tells us how far vehicles were driven (based on reported odometer readings), but, again, not where. For the community at large section of this inventory, we have relied on municipal traffic count data and estimates of the vehicle mix within the city. For the corporate side, we have used city fleet data on vehicle types and annual travel.

Assessing corporate and community emissions

For this inventory, we have divided results between emissions that result directly from the operations of the City corporation and those that are from the community at large. We define the community at large as being the area within the city's boundaries with a couple of exceptions: we factor in the emissions that result from electricity usage within the city even though this electricity is almost all generated at power plants outside of the city; and we factor in emissions from waste disposal landfill sites that are, for the most part, located outside of the city, including the future emissions that will result from waste sent to landfill in the inventory year. We also include the emissions that result from trucking the city's waste to landfills in Michigan and the methane emissions that will result in future from this landfilled waste.

What elements of the emissions are included within the corporate side of the inventory are guided by well-established protocols commonly used by cities worldwide to guide their inventory processes. We adhere to these protocols in this inventory to ensure our results are comparable with those of other municipalities.

By quantifying corporate and community emissions separately, we can ascertain both the direct contribution of the City's operations to city-wide emissions and help the City understand what it can do to ensure its own house is in order as a way of demonstrating leadership to the community at large.

In terms of their emissions profiles, the major difference between the corporation and the community at large is that a higher percentage of corporate emissions result from electricity usage (due to lighting and equipment usage in city facilities as well as street lighting, traffic signals and water pumping), while community emissions are weighted more heavily toward natural gas usage (mostly for home heating systems).

Results

Community at large emissions

Figure 1 • Sources of GHG emissions – Community at large

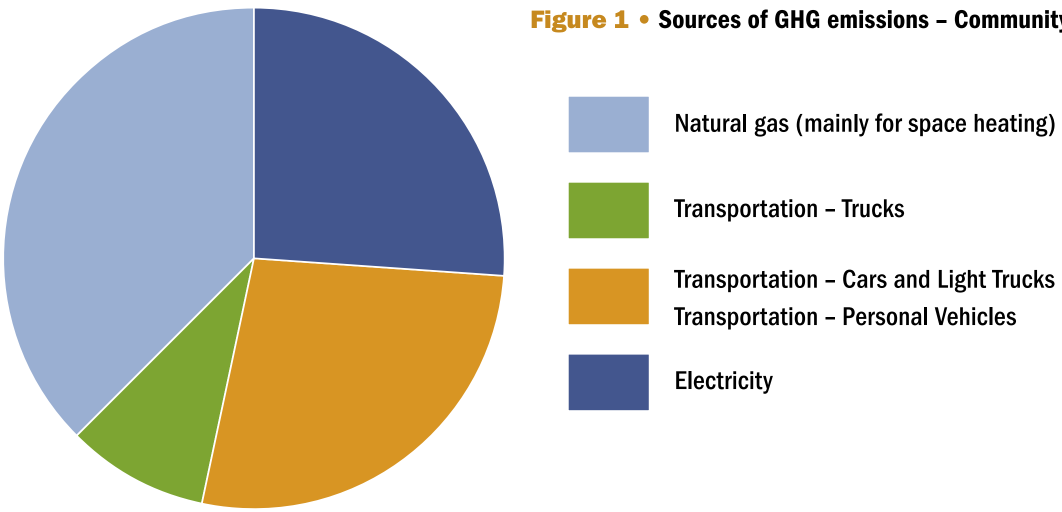
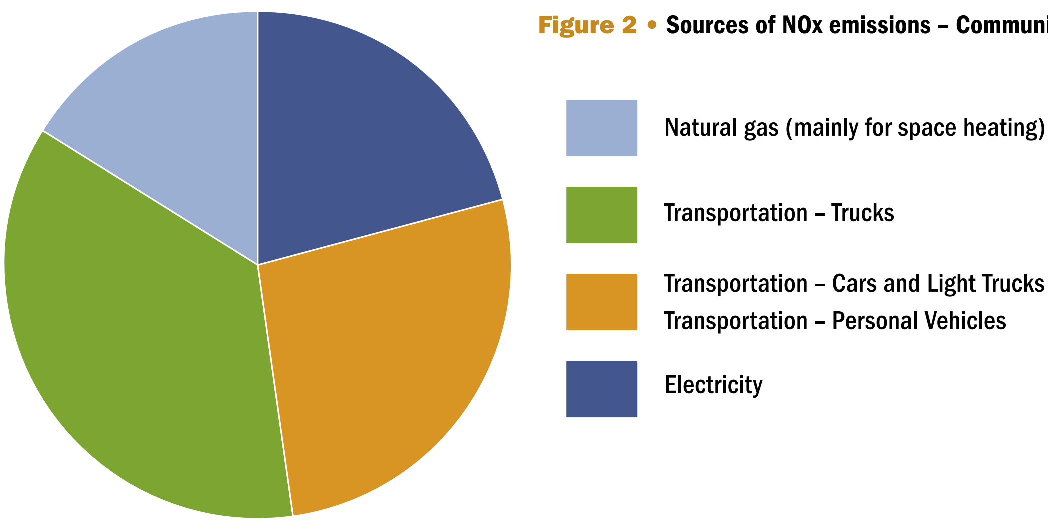
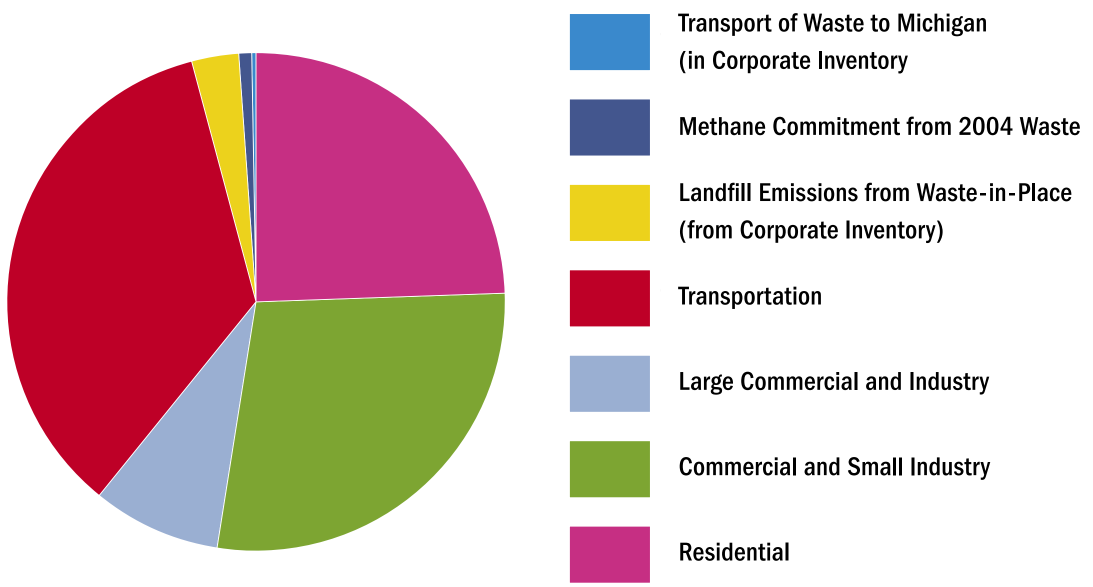


Figure 2 • Sources of NOx emissions – Community at large



In terms of greenhouse gas emissions, energy use in Toronto in 2004 led to the release of about 23.4 megatonnes eCO_2, with transportation fuels and natural gas accounting for about 36 percent and 37 percent of the total, respectively, and emissions from electricity use making up the additional 26 percent. Information on how these emissions were produced based on end-use categories is reflected below, with the transportation sector, commercial and small industry sector, and residential sector having the greatest impact.

Figure 3 • GHG emissions by sector – Community at large



For NOx emissions, transportation-related emissions accounted for 63 percent of the energy-related emissions from all sources, including emissions that were the result of electricity generation outside Toronto required to meet the city's needs. In fact, transportation was responsible for 73 percent of the NOx emissions that occurred directly within the City.

The results also indicate that diesel trucks contribute disproportionately to NOx emissions in the city. While diesel trucks account for an estimated 13 percent of vehicle traffic on Toronto's roads, they produce 36 percent of all NOx emissions from Toronto energy use and fully 45 percent of all NOx emissions inside the City itself. Emissions of volatile organic compounds (VOCs) are even more highly concentrated, in this case coming almost exclusively from gasoline-powered cars and light trucks.

Corporate emissions

The scope of the corporate emissions considered in the inventory includes the energy-related emissions associated with the natural gas, electricity, gasoline, diesel and other fuels consumed by buildings, vehicles and facilities operated by the City of Toronto, as well as the waste-related greenhouse gas emissions from the City's own garbage and from the landfills owned and operated by the City. The major components of the City's consumption of fuel and electricity consist of buildings, lighting (street, traffic signals, and parks), water pumping and treatment, and vehicle operation.

Figure 4 • Major stationary sources of GHGs – Corporate

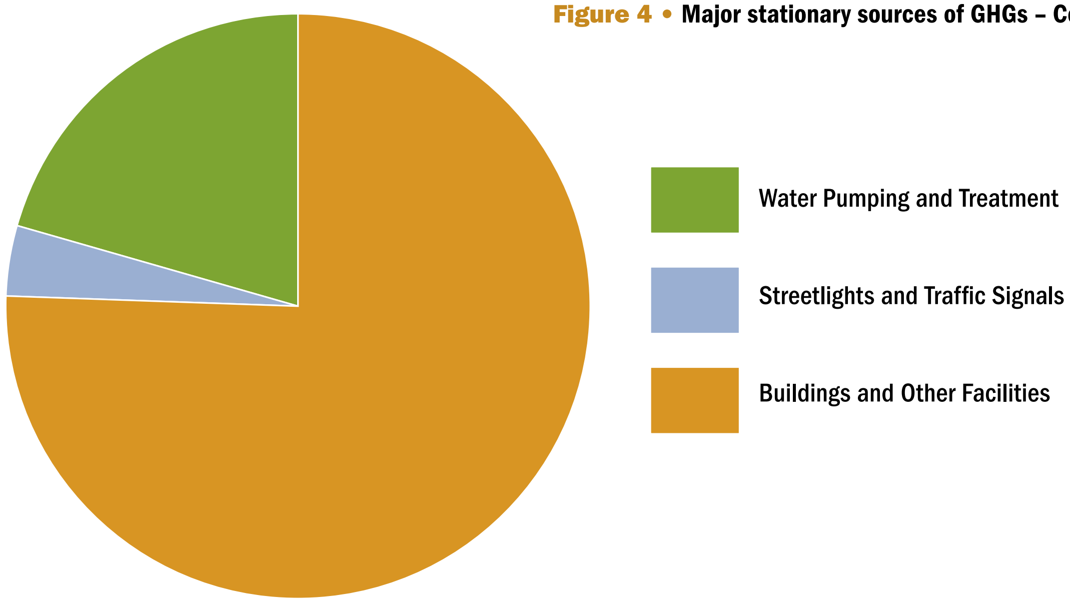
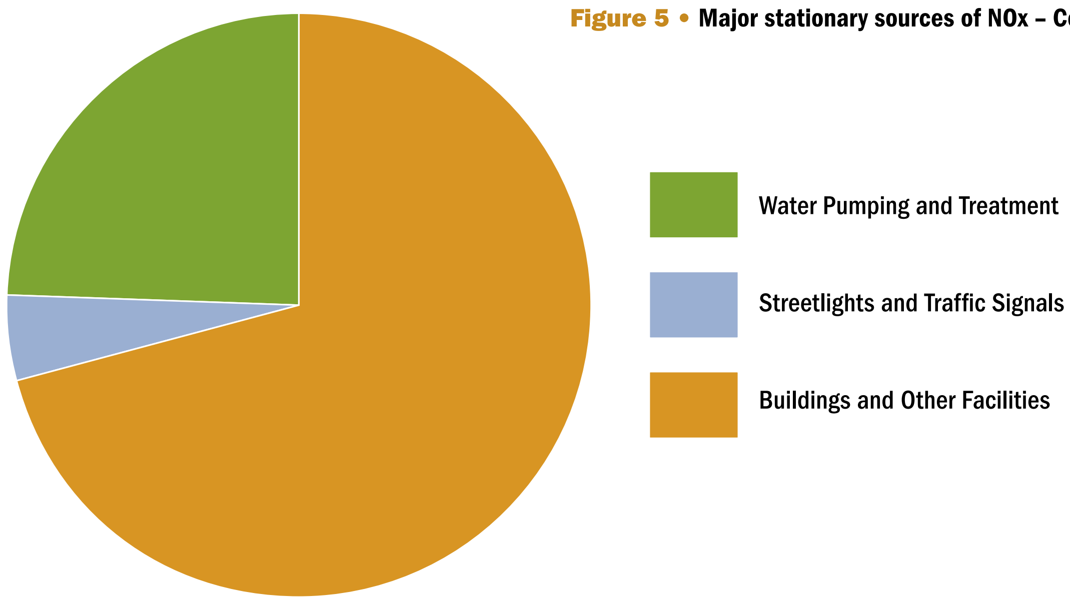


Figure 5 • Major stationary sources of NOx – Corporate



In terms of greenhouse gas emissions, corporate operations in Toronto in 2004 led to the release of about 1.6 megatonnes eCO_2 or 6.5 percent of the community-wide total. More detailed information on the sources of these emissions follows.

For greenhouse gas emissions, the City of Toronto's corporate operations were responsible for 776 kilotonnes eCO_2, of which 54 percent is from electricity-related emissions. For CAC emissions, electricity-related emissions account for 68 percent of NOx emissions form the City's stationary energy use, and about 35 percent of VOC emissions.

City of Toronto stationary operations (buildings, facilities, etc.) are responsible for about 3.5 percent of this type of energy use in the community at large and produce a similar share of GHGs and VOCs, and a somewhat larger share (4.2 percent) of NOx.

Transportation

Greenhouse gas emissions from the City's vehicle fleet fuel consumption totaled about 58 kilotonnes of eCO_2, which is only about 10 percent of the emissions associated with the stationary fuel and electricity use of the City's buildings, water pumping, streetlighting and other facilities.

Although the GHG emissions from the fleet are relatively small compared to the emissions associated with both natural gas and electricity use for corporate operations, the fleet emissions of CACs are more significant. Of particular note are the NOx emissions from the garbage trucks, dump trucks and other heavy vehicles. These vehicular NOx emissions are heavily concentrated in the Class 8 dump trucks and garbage packers.

The fleet is also the dominant source of VOC emissions from City operations, with the estimated vehicular emissions totalling more than seven times the emissions from natural gas use in City facilities. The VOC emissions are heavily concentrated in the gasoline-powered fleet of passenger vehicles, vans, and pickup trucks.

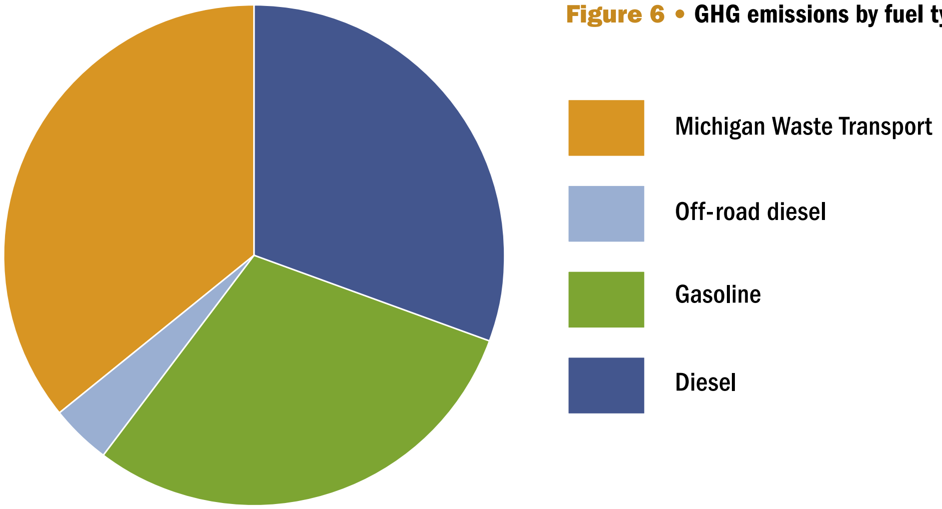
Landfills

The primary source of GHG emissions for landfills are from waste that has already been deposited ("waste in place") in the Keele Valley, Brock West, Thackery and Beare Road landfills that are owned and operated by the City of Toronto.

Reported emissions from the Keele Valley and Brock West landfill sites in 2004 were 441,354 tonnes eCO_2 and 127,277 tonnes eCO_2, respectively.

The Beare Road landfill was opened in 1968 and closed in 1983 after receiving 9.6 million tonnes of waste. In 2004, methane emissions before recovery were esti-

Figure 6 • GHG emissions by fuel type – Corporate fleet



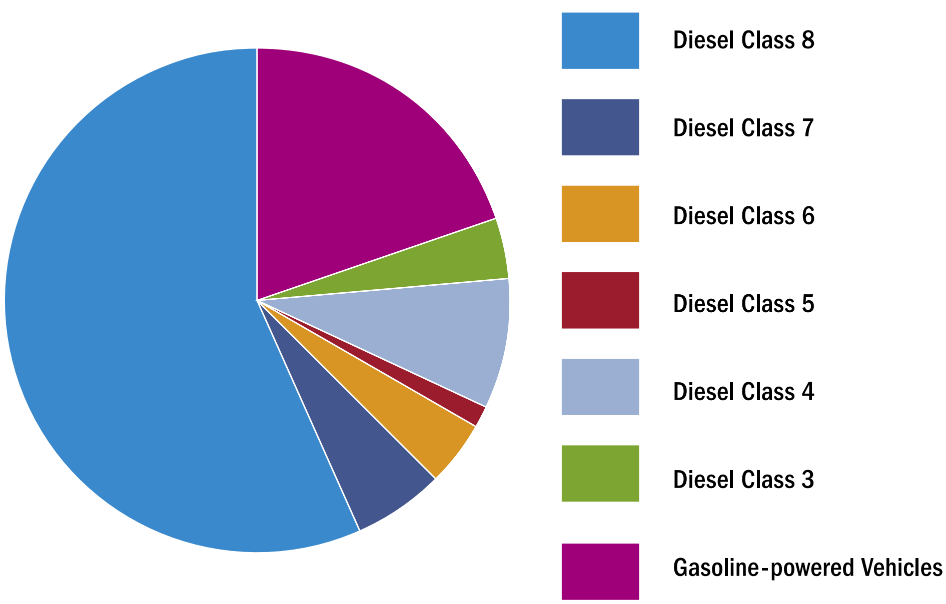


Figure 7 • NOx emissions by vehicle class – Corporate fleet

mated to be 278 kilotonnes eCO_2. This was reduced by 64 percent by the on-site methane recovery system to yield estimated net emissions of 100,175 tonnes eCO_2.

The Thackeray landfill site opened in 1968 and closed in 1978 after receiving 2.3 million tonnes of waste. There is no landfill gas collection system at the Thackeray site and emissions in 2004 were estimated at 52,678 tonnes eCO_2.

In 2004, 1.05 million tonnes of waste were trucked to the Arbor Hills and Carlton Farms landfills in Michigan. Using various assumptions about the make-up of this waste and methane recovery at the landfills, we calculated that the future methane emissions from the Michigan landfills resulting from waste shipped there by Toronto in 2004 is about 221 kilotonnes eCO_2, less than one percent of the 23.4 million tonnes eCO_2 of our total community at large energy-related emissions.

Some strategic implications of the Inventory findings

Diesel Trucks. Compared to their share of total traffic and total energy use, NOx emissions come disproportionately from heavy diesel trucks, especially Class 8 diesel trucks. Reducing tailpipe NOx emissions from diesel trucks and/or reducing diesel truck traffic during smog conditions merits further analysis as a priority smog prevention measure, as does the use of lighter and more efficient vehicles, hybrid and plug-in hybrid vehicle technologies, biodiesel, hydrogen fuels for diesel engines, and other NOx reduction technologies.

Space heating. Natural gas combustion in both residential and commercial buildings in Toronto is responsible for nearly 40 percent of Toronto's greenhouse gas emissions. In order for the City of Toronto to achieve ambitious greenhouse gas emission reductions, a determined, strategic effort to reduce natural gas use for heating through conservation and through fuel substitution using renewable energy sources will be necessary.

New energy approaches. District energy, combined heat and power, geothermal sources of heating and cooling, released heat recapture, and other means to reduce reliance on natural gas in both new developments and established neighbourhoods also provide the City with leadership opportunities. The condominium sector is a notable example, since construction of condominiums account for 90 percent of the new housing for Torontonians.

Cars and light trucks. Gasoline used by mostly light-duty vehicles in Toronto accounts for about 28 percent of community energy-related eCO_2 emissions and 27 percent of community NOx emissions. The City of Toronto has significant opportunities for encouraging the reduction of eCO_2 and NOx emissions from these vehicles by adopting parking, licensing, and related municipal measures that encourage taxis, corporate fleets, and individuals to purchase fuel efficient, low polluting vehicles, enhanced by growing biofuel use. There are also technology demonstration opportunities for hybrid and plug-in hybrid technologies in the City's own corporate fleet—which has pioneered alternative fuelled vehicles in Toronto. Other integrated transportation measures such as closing lanes in favour of public transit will also have a positive impact on eCO_2 and NOx from transportation-related emissions.

Greening electricity. Electricity related greenhouse gas emissions account for 38 percent of emissions from City of Toronto operations. Hence, reduction in the carbonaceous content of electricity consumed throughout Toronto as a whole and by the City of Toronto's own buildings and facilities represents an important opportunity for action. Accomplishing this goal should involve a multifaceted strategy that includes continued support for the Government of Ontario's coal phase out program; renewable energy generation in Toronto's own corporate facilities; procurement of electricity from renewable energy sources from electricity retail providers; and focusing conservation efforts on high electricity end uses in the City's departments, agencies, and boards.

Landfill gas capture. For the City of Toronto corporate emissions analysis, landfill methane emissions dominate the greenhouse gas inventory. Thackeray landfill, the last remaining landfill not equipped with a methane recovery system, represents the single largest "point source" opportunity for reducing the City's corporate eCO_2 emissions with a single project.

Demonstrating efficient lighting. Lighting typically constitutes 30-45 percent of the electricity used by municipal buildings, so it presents significant opportunities given rapid advancements in lamp and control integration technologies. Getting the City of Toronto's own "house in order" in this regard will provide excellent demonstration platforms for leadership in the community.

Continuous improvement of energy measurement. The tracking of the City's own energy use and related emissions, and the management of their strategic reduction to sustainable levels, requires on-going senior political and managerial support, the development of a permanent and automated information and knowledge base for energy and emissions, and the establishment of permanent technical and managerial capacity within City Hall to sustain a long-term commitment to emission reduction.

Looking ahead

This first attempt to produce an integrated greenhouse gas and air pollutant inventory for the City of Toronto has been a valuable learning experience. A number of information gaps have been identified and there is strong and growing interest in ensuring better information is available for future inventories.

However, even given the limitations we encountered, there is no doubt about the value of this exercise. Without a detailed knowledge of where emissions are coming from, we will be much less effective in focusing our efforts, particularly in areas where there are strong potential synergies to reduce both GHGs and CACs. Even an initial analysis can help us in what has become a race against the clock to address climate destabilization and deteriorating air quality.

As well, better information means a clearer picture of where problems really lie. The notion, for example, that it is "big smokestack" industries that are the major contributor to air pollution problems turns out to not be the case, at least for the City of Toronto. Many smaller sources, from residential furnaces to diesel trucks, are now responsible for a significantly greater share of air polluting emissions in the City.

However, for GHGs, large point sources in the form of coal-fired electricity generating stations continue to be major contributors, which is especially important to note given that location of emissons is much less critical when it comes to global climate change.

These findings have important implications and lessons that can be applied to the design of City of Toronto actions to combat climate change and to improve local air quality. Continuous improvement and use of the Inventory tools and methods established during this project also provide a way to benchmark and accurately measure our progress against emission reduction goals.

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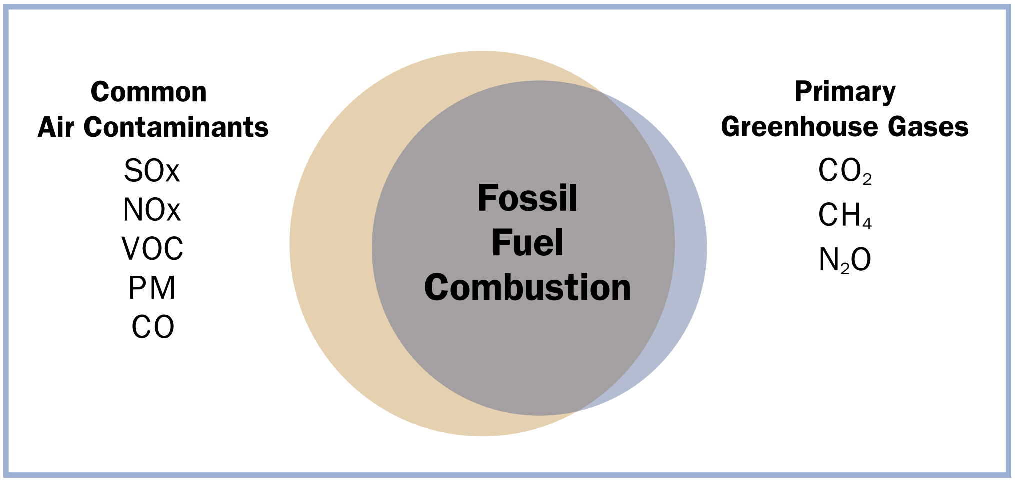
1. Background

Since 1990, several greenhouse gas inventory initiatives have been undertaken to provide information about the sources of Toronto's greenhouse gas emissions. However, no comprehensive study has been completed for the post-amalgamated city, and no study has attempted to integrate both air quality and greenhouse gas emission concerns. This report describes the results of the first attempt to develop an integrated inventory of emissions of greenhouse gases (GHG) and criteria air contaminant (CAC) emissions[1], for both the City's own operations and for the community at large, and to provide a preliminary analysis of harmonized strategies for reducing those emissions. The scope of this report is restricted to GHG emissions from waste management practices and to both the GHG and CAC emissions from fossil fuel combustion.

The combustion of fossil fuels (in the case of Toronto comprised mainly of natural gas, heating oil, gasoline and diesel fuel) accounts for most of Toronto's GHG emissions. This same fuel combustion results in emissions of key air pollutants – nitrogen oxides (NOx), sulphur oxides (SOx), volatile organic compounds (VOCs), carbon monoxide (CO) and particulate matter (PM).

Figure 1



1 The term "criteria air contaminant" (CAC) derives from the U.S. Clean Air Act, which initially established criteria for acceptable pollution levels for five common air pollutants: nitrogen oxides (NOx), sulphur oxides (SOx), volatile organic compounds (VOCs), carbon monoxide (CO) and particulate matter smaller than ten microns in diameter (PM_{10}). The term "criteria air contaminants" has entered the common lexicon of air quality analysis as referring to this group of five air pollutants. Canadian usage of "criteria air contaminants" has been dynamic but currently includes six CACs plus two secondary contaminants that are by-products of CACs. Ontario's inclusion of seven contaminants under the term is different again (see O.Reg 127/01) in several respects.

We are interested in developing a harmonized approach to GHG and CAC emissions because of the role that fossil fuel combustion plays as a central emissions driver of both types of pollution; because of the risk that our efforts will be at cross purposes if we develop independent strategies for each pollutant; and because of the potential for positive synergy through the pursuit of technologies and techniques that can yield reductions in both GHG and CAC emissions.

However, there are important differences between GHG and CAC dynamics, or more precisely between global warming and clean air dynamics, that must be borne in mind when conducting the type of integrated assessment presented here. Aside from the fact that there are emissions sources that are not common sources of both GHGs and CACs, there are also differences between GHGs and CACs in the ways in which fossil fuel combustion leads to emissions, environmental impacts and ultimately human impacts. In **Table 1**, we summarize some of these differences with respect to a few key factors that shape our method and the nature of the input data required for a study like this. (As the focus here is on the role of fossil fuels as a common source for both GHG and CAC emissions, and as carbon dioxide is the GHG of primary concern in fossil fuel combustion, the content of **Table 1** refers to CO_2 rather than to all GHG emissions.)

There are also differences in the approaches that have developed historically for reducing emissions of air pollutants vs. reducing emissions of greenhouse gas emissions. In the case of CAC emissions, reduction strategies have focussed on "end-of-pipe" or mitigating technologies such as catalytic converters on vehicles, particulate filters on chimneys or on modifications to fuels (e.g., low sulphur fuel) or combustion technology (e.g., low NOx burners at power plants).

In the case of greenhouse gas emissions, and particularly carbon dioxide emissions, there is no "end-of-pipe" mitigating technology, and strategies for reducing GHGs have, of necessity, been based on measures for substituting renewable energy for fossil fuel or on measures for substituting a less carbon intensive fuel for another (e.g., natural gas for oil or coal) as well as on measures that reduce the use of fossil fuels (e.g., conservation and efficiency improvements).

The impetus for conducting an integrated inventory of GHG and CAC emission sources, and for developing harmonized strategies for emission reductions, is therefore twofold. First, it is important to identify and minimize actions for reducing one type of pollutant that lead to an increase in the other. Second, and perhaps more importantly, we wish to identify those conservation, efficiency, fuel substitution, and urban heat island mitigation measures that can be effective at simultaneously reducing emissions of both greenhouse gases and criteria air contaminants.

Table 1 • Carbon Dioxide Emissions vs. CAC Emissions – Some Key Factors

	Carbon Dioxide	Criteria Air Contaminant
Importance of fossil fuel combustion to emissions	Fossil fuel combustion accounts for nearly all CO_2 emissions in Toronto, which in turn account for most GHG emissions in Toronto.	Fossil fuel combustion is the most important source of emissions of NOx, CO, and SOx in Toronto, less so for particulate matter and volatile organic compounds.
Relation between emissions and fuel combustion	Emissions are directly proportional to the level and the type of fuel being burned, with coal emitting nearly twice as much CO_2 per unit of energy as natural gas, and petroleum fuels (e.g., gasoline, diesel, and fuel oil) about midway between coal and natural gas.	Air quality emissions depend on the amount of fuel being burned, the level of contaminants in the fuel (e.g., sulphur, ash), the combustion technology and conditions, and mitigating or pollution control technology employed (e.g., catalytic converter, particulate filter).
Relation between emissions and impacts	Impacts are global, location of emissions is not important but may ultimately change local weather patterns and local air quality.	Air quality impacts are more immediate and more local and depend on local meteorology and atmospheric chemistry; emission location is critically important, including height above ground of emissions source.
Relation between local emissions and local impacts	Local climate change impacts in Toronto, such as increasing summer temperatures and heat waves, are affected by the global level of GHG emissions.	Concentrations of air contaminants in Toronto depend upon: (a) local emissions of air contaminants; (b) local ambient temperatures and sunlight, which directly affect ground level ozone formation; and (c) local meteorology and atmospheric chemistry. Furthermore, the impact of emissions that take place upwind from Toronto, even hundreds of kilometres upwind, and are dependent on the nature of prevailing winds and weather.
Relation between local emissions and global impacts	Ground level ozone formed in Toronto may be transported by wind currents through the atmosphere elsewhere, such as to the Arctic, and thus cause localized warming in other places.	Ground level ozone is both an important air contaminant and a greenhouse gas, though its impact on local warming is difficult to quantify due to variations in meteorology.
Important synergies	With some exceptions, measures that reduce fossil fuel combustion through substitution by renewable energy, conservation and improved efficiency will reduce emissions of both carbon dioxide and CACs. In addition, local fossil fuel combustion contributes to the urban heat island effect by emitting precursors to ozone, which when catalyzed by summer heat and sunlight may act as a greenhouse gas and enhance local warming, which in turn exacerbates the further deterioration of local air quality. Some measures to control CAC emissions can increase CO_2 emissions (e.g., NOx control technologies on vehicles can result in a fuel efficiency penalty). Some measures to reduce GHGs can result in an increase in CAC emissions (e.g., higher temperature combustion can increase efficiency but also increase NO_2 emissions.) Ideally, one set of CAC measures should seek to limit the availability of ingredients in ground level ozone, primarily NOx and VOCs, or reduce urban heat (with cooler urban surfaces) that enhances ozone formation. Such measures will likely reduce GHG emissions, as well, e.g., lowering urban heat in the summer would reduce air conditioning demand. A second set of measures that target particulates will be worthwhile from a public health perspective, and may also reduce local GHG emissions, if lower carbon fuels are substituted for diesel fuel in vehicles. Some evidence also suggests, however, that use of biodiesel fuel, while reducing GHG emissions, may increase NOx emissions. This possible trade off merits further investigation.	

2. Method, Data Sources and Quantification Protocol Issues

2.1 Method, Scope and Quantification Conventions

The emissions inventory method used here is derived from the approach to municipal greenhouse gas quantification developed in the early 1990s for the Cities for Climate Protection Campaign, which was pioneered in Toronto and other cities that were members of the original CO_2 Reduction Project of the International Council for Local Environmental Initiatives. It involves a two track approach – one for local government operations and one for the community as a whole. By definition emissions from local government operations – the "Corporate" emissions – are a subset of the "Community" emissions; adding the two inventories together will double count the emissions from local government operations.

The rationale for conducting separate analyses for corporate and community emissions is based on practical considerations. The data and the methods for counting and tracking emissions from corporate operations are different than for the community at large. In the case of the Corporate inventory, estimates of fuel and electricity use can be based on actual utility billing records and vehicle fuel consumption records, and emissions can be reduced through measures that are under the direct control of the local government. In the case of the Community inventory, estimates of fuel and electricity consumption are more aggregate and approximate, the data sources and quantification methods are different than for corporate operations, and local government opportunities to reduce emissions in the community are necessarily based on the application of indirect control and influence over energy consumption and waste generation in the community at large.

In both cases – Corporate and Community – the emissions covered include the greenhouse gas and CAC emissions associated with fuel and electricity use, as well as methane emissions associated with organic waste management. For fuel consumption, the emissions included are the emissions that take place within the boundaries of the city. An exception to this are the emissions from the trucks used to transport Toronto's waste to landfills outside the city. For electricity use, emissions are based on the emissions per average kilowatt-hour on the Ontario grid in the inventory year. Landfill methane emissions from waste sent to landfills in the inventory year are counted as part of Toronto's inventory even though they typically take place at landfills outside of Toronto.

Given that the Corporate inventory is a subset of the Community inventory, the conventions for what is included are somewhat arbitrary. In general, in accordance with the basic rationale for having a separate Corporate inventory, emissions are included if they fall under the direct control of the City. The emissions from the following energy use and waste management practices are included in the Corporate inventory:

- Fuel and electricity use of all City-owned buildings, facilities and vehicles.

- Fuel and electricity use of the Toronto Community Housing Corporation.

- Emissions associated with electricity use for streetlights, traffic signals, water pumping and sewage treatment.

- In the case of public transit, the fuel and electricity use for the TTC's buildings and service vehicles are included in the Corporate inventory, but the emissions of the transit vehicle fleet itself are included in the Community inventory.

- The fuel and electricity use of Toronto Hydro's buildings and service vehicles are included in the Corporate inventory, but the electricity provided by Toronto Hydro to members of the community is within the scope of the Community inventory.

- In future, the city will improve its knowledge and incorporate the emissions stemming from GO Transit vehicles (buses and trains), VIA and other trains, school buses (which were only partly detailed and incorporated in the 2004 inventory[2]), other bus or coach operations, and aircraft (private and transit related uses) in airport based emission assessments. These will similarly be counted in the Community inventory rather than in the Corporate inventory.

- With regard to waste-related methane emissions, emissions from landfills that are owned and operated by the City of Toronto are counted in the Corporate inventory, even if they are located outside the City. These include the Keele Valley, Brock West, Thackeray, and Beare Road landfills. The waste in these landfills has been placed there in the past, sometimes in the distant past, and the landfill gas emissions from these landfills can only be reduced by the landfill's owner/operator (City of Toronto) through the installation of landfill gas recovery systems. The landfill gas produced at these sites is a mixture of methane and carbon dioxide, but only the methane is counted in the inventory as the CO_2 from these sites is considered to be biogenic and therefore by common convention is not counted as an anthropocentric emission. The emissions counted are net of any landfill gas recovery at the sites.[3]

- Future methane emissions from organic waste generated by households and businesses in Toronto and sent to landfills during the inventory year are also included in the inventory, but these emissions are assigned to the Community inventory. Currently, this waste is being shipped to landfills in

2 However, Public and Separate School Board school bus movements, TTC and GO-Transit bus movements were used in the City's air quality modelling and analysis exercise to successfully confirm the Province's estimated data (MTO) for buses operating with in Toronto.
3 The City of Toronto has not included any carbon credit offset in its inventory for its provision of methane to a third party electricity producer at any landfill.

Michigan, but the same method will be used after Green Lane is owned and operated by the City of Toronto.

- In future inventories, estimates of waste that is collected from inside the City, hauled to and deposited in landfills by private contractors will be included if possible (these amounts are not currently included in the inventory). Current estimates suggest this privately managed waste is approximately twice the amount collected by the Corporation. The amount and manner in which it will be included in the City of Toronto inventory is pending further investigation and a more detailed understanding of this waste stream. The goal is to fully represent the emissions generated from all waste originating in Toronto.

- Future methane emissions from landfilled organic waste generated by the City's own operations are assigned to the Corporate inventory (although in the current inventory, a lack of data meant this item was excluded from the final numbers).

For the energy-related emissions, the essential method for quantifying emissions of greenhouse gases and criteria air contaminants is to multiply quantities of fuel and electricity use by emission factors that specify the emissions per unit of energy for each of the greenhouse gases and air pollutants of interest for each type of fuel or energy. The scope of this work includes all the fuel combustion that takes place within the City of Toronto (stationary and mobile), as well as the emissions that take place at power plants (mostly outside the city) as a result of electricity consumption in the City of Toronto.[4]

For greenhouse gas emission estimates, the key inputs for energy-related emissions are the emission factors and data on the types and quantities of fuel being burned. For the CAC emissions there is an additional requirement to know the sector and the type of combustion technology being employed, as energy-related emissions of many of the air pollutants depend not only on the type and quantity of fuel being burned, but on the specific combustion conditions and the presence or absence of any pollution control technology. For example in

4 This scope (i.e. fuel combustion in the city as well as power plant emissions that result from fuel combustion in the city) is the one that has been used historically in developing greenhouse gas inventories for Toronto, and it corresponds to the emissions that can be affected by actions taken to improve efficiency and the application of renewable energy technologies within the City of Toronto, even though in the case of electricity the actual emission reductions from such measures may take place at a power plant outside the city. This is the protocol adopted by the international Cities for Climate Protection program and the Canadian Partners for Climate Protection program, and we have applied it here to the criteria air contaminants as well. Because the impact of greenhouse gas emissions on global warming does not depend on the location of the emissions, this protocol has been favoured as it captures the GHG emissions over which the city and its residents have direct or indirect control and influence. In the case of criteria air contaminants, the location of emissions is all-important, and this is very important to bear in mind when assessing the emissions inventory presented here. As with the GHGs, the inventory developed here specifies the CAC emissions that take place within the city from fuel combustion but unlike the GHG inventory, the air quality source inventory excludes the emissions from electricity power plants located outside the city. The impact of such emissions on Toronto's air quality is, however, modelled by including them as part of the trans-boundary inputs. The relative importance of these emissions to air quality within the City of Toronto varies over the different pollutants and over time, and in some cases (e.g., CO emissions from fuel combustion in Toronto, NOx emissions from power plants to supply electricity to Toronto) is not very important at all to Toronto air quality.

the case of natural gas, emissions depend on the total volume (in cubic metres) and the chemical details (such as its specific sulphur content) of the gas being burned as well as the particular boiler or furnace being used.

Considering all the different fossil fuels being burned in Toronto and all the different types of furnaces, boilers and vehicles in which the fuels are being burned, the development of a CAC emissions inventory for the City of Toronto is a potentially unmanageable task. Fortunately, we know from past experience with Toronto inventories that almost all energy-related greenhouse gas emissions from energy use in the City of Toronto derive from three principal fuel/end-use/sector combinations for which input data can be obtained and for which CAC emission factors are available. These principal energy-related emission sources are natural gas burning (mostly in residential and commercial building heating), electricity production (mostly beyond Toronto's boundaries but counted as part of Toronto's GHG emissions to the extent Torontonian's demand for electricity gives rise to the power production), and burning of gasoline and diesel fuel in the millions of cars and trucks moving throughout the city every day.

2.2 Data Sources

Key data sources for the Community and Corporate inventories are summarized in **Table 2** and **Table 3**, respectively. The raw data used to estimate emissions

Table 2 • Sources of Input Data for the Community Emissions Inventory

	Source of data	Basic data provided	Geographic area	Data categories
Natural Gas	Enbridge Gas Distribution Inc. (Toronto)	Total Annual "Billed" cubic metres (m^3)	By Forward Sortation Area a.k.a first three digits of Postal Code)	- Residential - Apartments - Commercial - Industrial
Electricity	Toronto Hydro	Total Annual "Billed" kilowatt-hours (kWh)	By Forward Sortation Area	- Residential - General Service <5MW - General Service >5MW
Vehicle Volume Movements	City of Toronto's Transportation Services Division	a) Mean traffic volumes and vehicle kilometres travelled (Vkt) collected between 1987-2004, but the latest collected data - mostly after 2001 - always used	By Street Segment (between intersections)	For each street in Toronto classified as City Highways, Major Arterials, Minor Arterials, or Collectors as well as every local road (using mean volumes based on Road Classification Class)
		b) Proportion of Trucks in Vehicle Volumes Data (2004)	At 776 representative intersections	
	Ontario (MTO) Traffic Data (web data)	c) Mean traffic volumes	For provincial highways in Toronto	

Table 3 • Sources of Input Data for the City of Toronto Corporate Emissions Inventory

	Source of data	Basic data provided	Geographic area	Data categories
Natural Gas	City of Toronto Data (Energy CAP OnLine)	Total annual cubic metres (m^3) "billed" by Enbridge	By billing meter (m^3) usually by specific building	By building user or manager (City's ABC or D)
Electricity	City of Toronto Data (Energy CAP OnLine)	Total annual kilowatt-hours (kWh) as "billed" by Toronto Hydro	By billing meter (kWh) usually by specific building	By building user or manager (City's ABC or D) e.g., Streetlights & Traffic Lights
City Vehicle Kilometre Travelled Volume Movements	City of Toronto's Fleet Management Services Division and Police, Fire and Ambulance Services (individually)	a) Fleet breakdown data of (2624) individual vehicles b) Total gasoline and diesel consumption c) Fleet breakdown data of (2428) individual vehicles	Geography of vehicle use is unknown	By approximated amount of fuel consumed by number of vehicle type
Methane Emissions from Solid Waste	Toronto Waste Management Services Division	History of tonnage landfilled by year and location Biogas collection efficiency by site Scholl-Canyon curve calculation Residual waste composition Tonnage, distance, and numbers of trucks to Michigan	No geography necessary as not included in air quality modeling Distance traveled by trucks (full & empty)	For closed landfills (WIP) Keele Valley Brock West Beare Thackeray For active landfills (MC) Carleton Farm (Michigan) Arbour Hills (Michigan)

produced by heating buildings and operating electrical equipment and appliances is known with a high level of accuracy as this data is based on the "billed" quantities of cubic metres of natural gas and the kilowatt-hours of electricity. The raw data used to estimate emissions produced by vehicles (cars, trucks and buses) is not as precise. The volume of all vehicle fuels consumed (ie., combusted by an operating engine) within the boundaries of the City is simply not known. The amount of fuel sold at gas and diesel pumps in Toronto might be obtained, but it would still impossible to know whether all this fuel was combusted in Toronto just as it would be impossible to know how much fuel purchased outside of Toronto (e.g., in vehicles operated by commuters from the GTA or trucks from even further away) was combusted within Toronto. Instead, we use traffic counts and vehicle registration data to estimate the number of vehicles by type and their daily and annual distances travelled on Toronto roads.

2.3 Imminent Inventory Improvements

In 2007, Toronto Environment Office (TEO) staff are scheduled to finalize the assembly of 2005 and 2006 data, improve the detail of the most significant raw data, and to include more detailed sub-sector breakdowns and estimates of emissions from other sources.

Respecting the amount of electricity and natural gas used in buildings in 2005 and 2006 (and beyond), TEO has initiated a process with Enbridge and Toronto Hydro to obtain improved temporal data (changing from annual to monthly data) and improved spatial data (changing from Forward Sortation Area [FSA] to Local Distribution Unit [LDU] resolution where FSA is the first half of a postal code and LDU is the second half of a postal code) while still ensuring customer privacy is not jeopardised in any way.

Road traffic data can also be improved in the future by sampling vehicle types when collecting traffic flow data. Annual traffic counts for particular locations can also be used to improve estimates of year-to-year growth in total traffic volumes. Other estimates of transportation-related emissions, such as from airplanes, trains, coaches and buses, ships and boats, will also be improved by obtaining more complete data of their movements than is currently provided by incomplete time-table/schedule movements.

Solid waste operations have changed since 2004 with the greater adoption of the Green Bin program for organics. This relatively new activity and its related management aspects will also be analysed and included. It is also hoped that sampling of residual waste (i.e., waste put in garbage bags rather than blue boxes or green bins) will be continued and extended in future to provide a more solid basis for estimating the impacts of such waste in landfill situations. The Corporation's contribution to such residual waste, as well as to the organic and recyclable components, will also be individually identifiable in future.

2.4 Emission Factors for Fuel and Electricity Consumption

2.4.1 Stationary Fuel Combustion

Most fossil fuel combustion in Toronto is in the form of natural gas (in residential and commercial buildings) and gasoline and diesel transportation fuel. Fuel oil and propane make smaller (and less easily quantified) contributions to total fuel use in Toronto.

The greenhouse gas emissions from burning fossil fuels are well known, and we have used the emission factors used by Environment Canada in the national inventory.[5] These factors are shown in the natural units used by Environment

5 Environment Canada, "National Inventory Report: 1990–2004, Greenhouse Gas Sources and Sinks in Canada", Environment Canada, Ottawa, 2006. In particular, refer to Appendix 13, "Emission Factors". Document available at www.ec.gc/ghg-ges.

Table 4 • CAC and GHG Emissions for Stationary Combustion

			NOx	VOC	TPM	CO	SOx	GHG (eCO_2)
Natural Gas	Residential furnaces	Grams per cubic metre	1.51	0.09	0.12	0.64	0.01	2,007
	Small boilers		1.60	0.09	0.12	1.35	0.01	
	Large boilers (>100 MM BTU/hour)		3.05	0.09	0.12	1.35	0.01	
Fuel Oil[6]	Residential furnaces	Grams per Litre	2.16	0.09	0.05	0.60	4.258	2,856
	Small boilers		2.40	0.04	1.2	0.60	4.258	
	Large boilers (>100 MM Btu/hr)		5.64	0.02	1.4	0.60	4.708	
Propane	Residential furnaces	Grams per Litre	1.68	0.06	0.05	0.23	0.002	1,534
	Small boilers		1.68	0.06	0.05	0.23	0.002	
	Large boilers (>100 MM Btu/hour)		2.28	0.06	0.07	0.38	0.002	
Natural Gas	Residential furnaces	Grams per GJ	39	2.3	3.2	17	0.3	52,526
	Small boilers		42	2.3	3.2	35	0.3	
	Large boilers (>100 MM BTU/hour)		80	2.3	3.2	35	0.3	
Fuel Oil	Residential furnaces	Grams per GJ	56	2.2	1.2	15	109.7	73,608
	Small boilers		62	1.1	30.9	15	109.7	
	Large boilers (>100 MM Btu/hr)		145	0.6	37.1	15	121.3	
Propane	Residential furnaces	Grams per GJ	66	2.4	1.9	9	0.1	60,608
	Small boilers		66	2.4	1.9	9	0.1	
	Large boilers (>100 MM Btu/hour)		90	2.4	2.8	15	0.1	

Canada (per L, per m^3) and have then been converted to standard energy units (gigajoules GJ) using the energy content values indicated. Greenhouse gas emissions from fossil fuel use do not depend on combustion technology, and there are no practical emission reduction technologies that can be applied. Therefore, emission factors are constant for any particular fuel and are listed in **Table 4**.

For the criteria air contaminants, emissions depend on the quality of the fuel (especially for SOx and TPM) as well as on the combustion technology,

6 For fuel oil, the SOx factor assumes sulphur content of 0.25 percent.

combustion conditions, and the presence of pollution control technologies (e.g., catalytic converters on automobiles). This results in a separate emission factor for each pollutant, for each fuel, and for each unique combination of combustion and control technology.

CAC emissions in Toronto come mainly from what air pollution analysts call "area sources" (as opposed to large "point sources"). These area sources are comprised of the hundreds of thousands of building heating systems and the millions of vehicles on the road in Toronto. Emissions from these sources are not usually directly measured or monitored and so the emission factor approach is the only way to gain a quantitative estimate of their magnitude.

In addition, while we can estimate the total emissions of these gases through the application of simple emission factors, their contribution to air quality also depends on spatial and temporal factors that are not so important in the case of greenhouse emissions. The effect that air pollutant emissions will eventually have on air quality depends on exactly where and when the emissions take place – time of year, weekday or weekend, time of day, how high off the ground, what part of the city, etc. These are all factors that must either be known or estimated before air quality models can estimate the impacts of local air pollution.

Air quality depends on weather, winds, temperature inversions, and atmospheric chemistry (which varies seasonally and also has very different dynamics at night as compared to during the day when solar energy drives many important chemical reactions in the atmosphere that affect air quality). Even to the extent that air pollutant emissions are important, local air quality can be, and in some conditions is, more affected by emissions that take place upwind, sometimes hundreds of kilometres upwind, from the affected air. We return to this problem in more detail later in this report, but it bears repeating that local emissions of air pollutants are only one input to the complex chemical and meteorological dynamics that determine local air quality, and the importance of local emissions varies with time and weather in ways that are difficult to specify with the models and the data currently available. Indeed, one of the key reasons for taking on this integrated assessment of GHG and CAC emissions was to begin the process of better understanding how local emissions affect local air quality.

We begin, however, with emission factors that allow us to simply estimate the quantity of emissions of air pollutants associated with different types of fuels used in Toronto. The simplest of the CAC emission factors are those related to the stationary combustion of natural gas, propane and fuel oil in furnaces and boilers. We have used the emission factors published in the "AP42" database maintained by the U.S. EPA for these emissions[7], and they are expressed in **Table 4** in terms of grams per GJ of fuel burned so that they can be compared with each other and with the electricity emission factors presented below in

7 U.S. EPA, "Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources", AP 42, Fifth Edition. Available at http://www.epa.gov/ttn/chief/ap42/index.html.

Table 5 and **Table 6**. We do not know how accurately an inventory based on these factors would track actual measurement of these emissions in Toronto (we do not measure them and it would be expensive to do such measurement, even to the extent of statistically significant sampling). However, the AP42 database is the most widely used and authoritative database for such emission factors.

2.4.2 Electricity

The emission factors used for computing both the GHG and CAC emissions associated with electricity use in Toronto (in 2004) are shown in **Table 5** and **Table 6** and are based on the average emissions per kilowatt-hour from all electricity used in the province. The annual electricity GHG emission factors published by Environment Canada form the basis for the factors used here.[8]

Table 5 • Emission Factors for Average Kilowatt-hour of Electricity in Ontario in 2004

	NOx	VOC	TPM	CO	SOx	GHG (eCO_2)
Grams per kW-hour	0.348	0.005	0.102	0.830	0.063	244
Grams per GJ	97	1.4	28	231	17	62,550

Table 6 • Electricity Emission Factors, 1990 - 2004

Year	grams CO_2e/kWh
1990	224
1991	215
1992	216
1993	140
1994	114
1995	135
1996	152
1997	191
1998	256
1999	261
2000	304
2001	289
2002	285
2003	332
2004	244

8 Environment Canada, "National Inventory Report: 1990–2004, Greenhouse Gas Sources and Sinks in Canada", Environment Canada, Ottawa, 2006. Available at www.ec.gc/ghg-ges.

However, we require an estimate of GHG emissions per kilowatt-hour of electricity end-use, whereas the Environment Canada factors are for kilowatt-hour of electricity production and do not incorporate the transmission and distribution losses that occur between the power plants and the end users. To adjust the Environment Canada factors for T & D losses, we have applied a multiplier of 1.10.[9] The resulting emission factor for electricity use in Ontario in 2004 is 244 grams eCO_2 per kilowatt-hour.[10]

In the case of air pollutant emissions associated with electricity use, we used a similar method to that used for greenhouse gas emissions. Estimates of total power plant emissions of the five criteria air contaminants were taken from the National Pollution Release Inventory and divided by total electricity consumption to produce the end use emission factors included in **Table 5**.

The emission factors for GHGs for grid-supplied electricity in Ontario change from year to year due to annual variations in the proportion of coal-fired generation in the overall generation mix. Such changes can profoundly affect the calculation of total GHG emissions in Toronto from one year to the next – between 1990 and 2004, the emission factor for Ontario electricity varied from a low of 114 grams CO_2e/kWh in 1994 to a high of 304 grams CO_2e/kWh in 2000. In the future, the Government of Ontario's coal phase-out plan will lead to dramatic reductions in the greenhouse gas intensity of Ontario electricity, dropping to 45 grams CO_2e/kWh or lower after the last of the coal plants is shut down.

2.4.3 Emissions Factors for Transportation Fuels

For greenhouse gas emissions, emissions from transportation fuels (gasoline, diesel, propane) can be estimated if the quantity and type of fuel burned is known. This data can be multiplied by the fuel-based GHG emissions factors developed by Environment Canada, which are listed in **Table 7.**

For the criteria air contaminants, vehicle emissions are typically expressed in terms of grams of emissions per vehicle-kilometre of travel, and can only be converted to or compared with energy based emissions factors (e.g., emissions per GJ or per litre of fuel burned) if the fuel efficiency of the vehicle is also known or estimated. The CAC factors used here are from Environment Canada and are shown in **Table 7** in grams per vehicle-kilometre for each pollutant for vehicles of different types and sizes. **Figure 2** below illustrates the types of trucks that characterize the different truck weight classes.

9 The emission factors used here, based on Environment Canada's factors, do not make any allowance for electricity imports and exports. While it is possible to make such adjustments, for most years the net import of electricity is too small to make much difference in the average CO_2 intensity of electricity used in Ontario.

10 Emissions per kilowatt-hour from electricity production vary over a wide range, depending on the type of power plants and their operating efficiency. Hydro and nuclear plants do not emit greenhouse gases, coal plants emit around 1,000 grams eCO_2 per kWh; gas-fired power plants emit around 300 grams eCO_2 per kWh; and oil-fired power plants fall about midway between coal and gas in the range of 600 grams eCO_2 per kilowatt-hour. The emission factor for the end use of electricity depends on the mix of these different types of plants on the Ontario grid in any particular year.

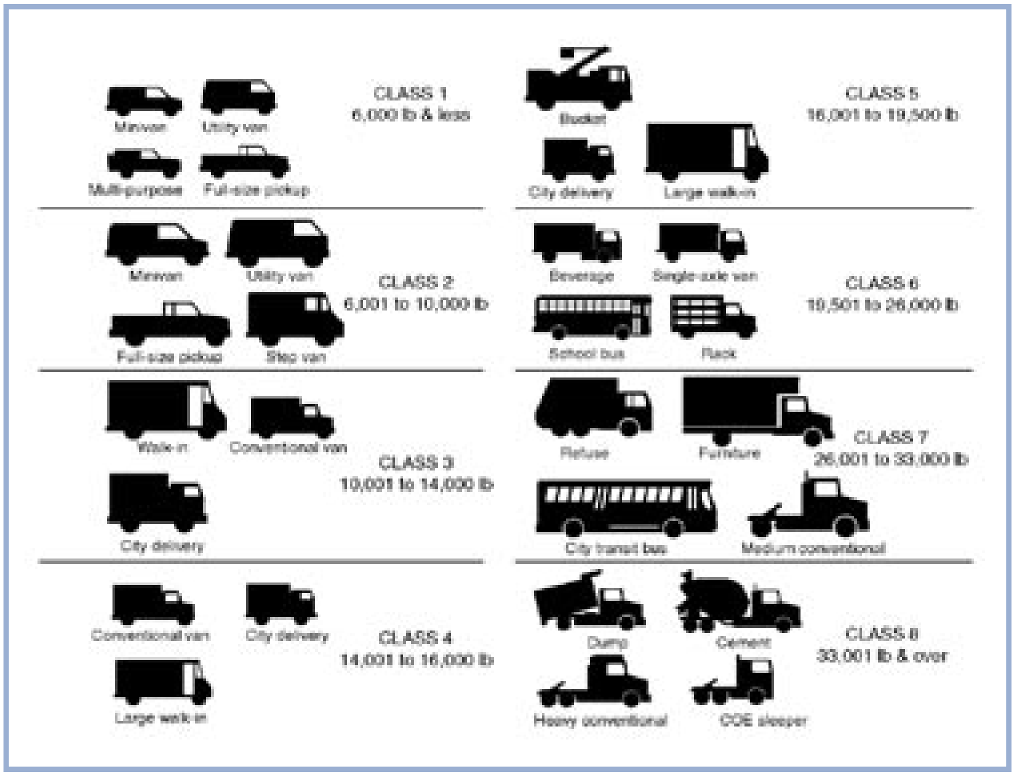
Table 7 • Emission Factors for Vehicles

	CAC Emissions in grams per vehicle-km						GHG Emissions in kg eCO_2 per GJ
	NOx	VOC	TPM (total)	TPM (Exhaust)	CO	SO_2	
Passenger Cars – Gas	0.502	0.471	0.016	0.003	8.287	0.007	70
Light Trucks – Gas	0.576	0.553	0.016	0.004	10.674	0.009	
Motorcycles – Gas	0.88	2.66	0.024	0.01	10.61	0.00	
Passenger Cars – Diesel	0.552	0.166	0.080	0.067	0.684	0.041	73
Diesel Truck Classes:							
Class 1 and 2	0.55	0.24	0.093	0.08	0.51	0.06	73
Class 2B	2.61	0.13	0.089	0.08	0.61	0.10	
Class 3	3.23	0.16	0.100	0.08	0.72	0.11	
Class 4	3.82	0.20	0.104	0.09	0.91	0.13	
Class 5	3.62	0.18	0.083	0.07	0.86	0.13	
Class 6	5.04	0.26	0.146	0.13	0.92	0.15	
Class 7	6.76	0.34	0.168	0.15	1.24	0.17	
Class 8a	10.80	0.30	0.221	0.19	1.64	0.20	
Class 8b	11.24	0.33	0.215	0.18	1.80	0.21	
Diesel Transit Bus	12.39	0.41	0.509	0.49	3.16	0.30	
Diesel School Bus	8.10	0.40	0.220	0.20	1.29	0.21	

The CAC emission factors for transportation fuels are expressed in terms of emissions per vehicle-kilometre of travel (VKT), and are applied to estimates of VKT for different vehicle types and sizes to obtain an inventory of transportation related CAC emissions. This means there is no straightforward comparison with the emission factors in **Table 4** for stationary fuel consumption, which are expressed in terms of emissions per unit of fuel or energy used.

However, typical vehicle fuel efficiencies can be used to allow a general comparison of the intensity of CAC emissions from transportation vs. stationary fuel consumption. Such a comparison clearly shows that transportation-related fuel consumption is significantly more "CAC emissions intensive" per unit of fuel burned than stationary fuel consumption. For example, the NOx emission factor for passenger cars of 0.50 grams per vehicle-kilometre translates into about 180 grams per GJ of gasoline consumption if one assumes a typical mid-sized car fuel efficiency of 8 L/100km. In comparison, the emission factor for natural gas combustion in residential furnaces is only about 30 grams/GJ.

Figure 2 • Examples of Trucks in Different GVW Weight Classes[11]



2.5 Greenhouse Gas Emissions from Waste Management Practices

All the pollutant emissions and the bulk of the greenhouse gas emissions within the scope of this analysis are emissions related to the consumption of fuel and electricity, but we also include an analysis of the greenhouse gas emissions associated with waste management practices.

Appendix A provides a briefing on the greenhouse gas emissions from alternative waste management measures for various materials – from the fuel consumption of the collection trucks to the methane gas emissions at landfills to the upstream greenhouse gas reductions that result from the reduction or recycling of certain types of materials. The material in **Appendix A** is based on a recent report prepared for Environment Canada and the quantification of all waste-related greenhouse gas emissions included in both this inventory and related emission reduction analysis is taken from that report.[12]

The largest greenhouse gas impacts of waste management are the emissions of methane from the landfill itself and the upstream carbon sequestration and carbon dioxide reductions that result from Three-Rs programs, which are the

11 Source for figure: *Commercial Carrier Journal* (http://www.ccjmagazine.com).
12 ICF Consulting, "Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions, 2005 Update", prepared for Environment Canada and Natural Resources Canada, Contract No. K2216-04-0006, Ottawa 2005.

focus of this section. In comparison to these sources, the emissions associated with the fuel consumption of the trucks and equipment and the fuel and electricity use of buildings and other waste management-related facilities are relatively small, although the long distances that Toronto's waste is currently transported for landfill (to Michigan) makes waste transport-related emissions higher for Toronto than for most communities. These smaller emissions are captured in other aspects of this inventory, such as the emissions analysis of the city's vehicle fleet and the emissions analysis of the city's buildings

All organic waste will decay anaerobically (without oxygen) when buried at a landfill site, and anaerobic decay results in emissions of methane, a powerful greenhouse gas.[13] How much methane is generated and reaches the surface of the landfill depends on both the "methagenic potential" of the landfilled waste (e.g., wet food waste will generate more methane, tonne for tonne, than will twigs and other woody biomass waste) and on the conditions in the landfill. In addition, if the methane is captured and burned when it reaches the surface (regardless of whether it is simply flared in the open air or if it is burned to generate heat for electricity or other industrial processes), this will reduce the methane emissions from a landfill by an amount equal to the efficiency (as a percentage) of the methane capture system. Methane emissions will begin after the waste has been covered and the anaerobic processes get underway and the emissions will continue for decades into the future, gradually declining over time.

The long time period over which methane emissions will be generated and released means that a consideration of Toronto's greenhouse gas emissions must include both current methane emissions from past landfilling activities as well as future methane emissions from waste that is being landfilled today. The methane emissions that are occurring now from the landfills that have been receiving the city's waste in recent decades (most of which are no longer receiving new waste) are quantified using the "waste-in-place" method. The emissions that will result in the future from waste that is landfilled today are quantified using the "methane commitment" method.

For both the "waste in place" method and the "methane commitment" methods, we have only estimates of total emissions, and these estimates are much more approximate than the emission factors used to estimate greenhouse gas emissions from energy use. The same basic mathematical formula is used for the "waste-in-place" and "methane commitment" methods and it is a simple first-order exponential decay function in which the key inputs are the a time series of the quantities of each type of organic waste in the landfill, the ultimate

13 Landfill gas is made up of both methane and carbon dioxide, in roughly equal portions. However, the carbon dioxide component of the landfill gas is not considered "anthropogenic" in the accepted and standard conventions for greenhouse gas accounting and is therefore not counted in the city's inventory of greenhouse gas emissions. It is considered "biogenic" insofar as it is carbon dioxide that would have eventually cycled back to the atmosphere under conditions of natural decay of the organic matter. In contrast, the methane is only being generated because of the anaerobic conditions created by the human activity of landfilling, so it is therefore counted as anthropogenic and goes into the inventory.

methagenic potentials of the types of organic waste, and the time constant of the decay function (which reflects the landfill conditions). The efficiency of any landfill collection system that may be present is then applied to produce the final estimate of atmospheric release of methane.

In the case of the "waste-in-place" calculation, the methane emissions are based on estimates of the amounts and types of waste already in place in the landfill. For the "methane commitment" method, an annual series of future methane emissions is computed based on the types and quantities of waste being put into the landfill in the current year, and this time series is then summed to produce the estimated total future methane emissions from waste being placed in the landfill in the current year.

In this analysis, waste-in-place emissions from the Thackeray and Beare Road landfills, as well as the methane emissions from the landfill in Michigan that has been receiving Toronto's waste since 1998, are estimated using the Canadian Greenhouse Gas Software for Cities®, which uses a default value of 170 m^3 of methane per tonne of landfilled waste for the average methagenic potential of the landfilled waste and a default value of 0.05 yr-1 for the time constant. There is no landfill gas recovery at the Thackeray site and a 64 percent recovery efficiency is assumed for the methane collection system at the Beare Road site. For the Keele Valley and Brock West landfills, the City of Toronto files certified estimates of methane emissions and we have used those in the 2004 inventory.

In recent years, research has shown that there are significant amounts of organic material in landfills that have not decomposed even after several decades. This landfill carbon sequestration is discussed in **Appendix A** but no allowance has been made for landfill carbon sequestration in the development of Toronto's greenhouse gas emissions inventory.

Finally, for some materials the reduction or recycling of waste that would otherwise be landfilled causes significant greenhouse gas emission reductions in the industries that manufacture those materials. This is primarily because of the manufacturing energy savings that result from waste reduction and recycling, as well as non-energy related emissions reductions that result from the reduction or recycling of aluminium. These impacts do not affect the greenhouse gas inventory for the City of Toronto (the emissions of these industries are already included in the inventory for any facilities located in Toronto). However, to the extent that the City's Three-Rs programs cause reduction and recycling of these materials, the emission benefits can be considered as a type of offset against the city's own emissions.[14]

14 Note that there is as yet no official recognition of the greenhouse gas benefits of waste reduction and recycling activities in national or international greenhouse gas accounting protocols.

3. Community Emissions of Greenhouse Gases and Air Pollutants

3.1 Emissions from Stationary Energy Consumption

Total consumption of electricity and natural gas was provided by Toronto Hydro and Enbridge, respectively. The electricity data is disaggregated by customer class: Residential, General Service (< 5MW), and Large Users (> 5MW). The natural gas data was disaggregated by sector: Residential, Commercial and Industrial.

We have grouped the General Service (< 5 MW) electricity and the natural gas Commercial use into a sector called "Small commercial and industrial" and we have grouped the electricity Large Users and natural gas Industrial consumption into a category called "Large commercial and industrial." The resulting profile of CAC and GHG emissions from natural gas and electricity consumption is summarized in **Table 8**.[15]

Table 8 represents most but not all of the emissions associated with the stationary use of energy in Toronto given that most stationary energy use in Toronto is in the form of natural gas or electricity. There are other fuels used in Toronto on a much smaller scale than natural gas, but we have little or no quantitative data on these fuels. Fuel oil (primarily for home heating) is the most significant of these other fuels. We do not have data on either the total residential oil consumption or the number of households heated with oil in Toronto, but the total impact of residential oil consumption on Toronto's stationary energy use and emissions inventory can be estimated at less than one percent.[16]

3.2 Emissions from Transportation

The focus here is on the tailpipe emissions that take place within the city, regardless of the where the trips in question begin or end, regardless of where the vehicles in question are registered, and regardless of the residency of the drivers. The quantification of transportation energy use and related emissions

15 In accordance with the convention used throughout this study, emissions associated with electricity (italicised in the table) are included in Toronto's GHG inventory, even though those emissions generally take place at power plants located outside the city. In the case of greenhouse gas emissions, the location of the emissions does not affect the impact they have on global warming. In the case of CAC emissions, the location of the emissions is important in determining air quality impacts in Toronto. The CAC emissions in the table are simply an inventory of CAC emissions associated with fuel and electricity consumption in the City of Toronto, on an annual basis. In the case of the emissions associated with electricity, they generally do not take place in Toronto, and the extent to which they have direct bearing on Toronto air quality depends on the extent to which Ontario power plant emissions contribute to air pollution in Toronto. In the case of the emissions from natural gas consumption, the emissions in the table do take place in the city, but their impact on Toronto's air quality will vary depending on local temperature and wind patterns and boundary layer atmospheric chemistry.

16 On an Ontario-wide basis, according to the federal Office of Energy Efficiency, in 2004 there were 431,000 households in Ontario heating with oil. Theses households are not evenly distributed in the province – many are in rural areas not served by natural gas, and most of them are single family detached dwellings. In Toronto, less than a third of households (about 300,000) are in single family dwellings. This would suggest an estimate in the range of 20,000 single family detached households in Toronto may still be heating with oil. This would make less than a one percent difference in the totals presented for energy and emissions from natural gas and electricity use in Toronto.

Table 8 • CAC and GHG Emissions from Natural Gas and Electricity Consumption in Toronto in 2004

	Residential	Commercial and small industrial	Large commercial and industrial	Totals
Energy (TJ)				
Natural Gas	89,523	47,139	28,520	165,182
Electricity	*19,089*	*64,995*	*7,432*	*91,516*
Total	108,611	112,134	35,952	256,698
NOx Emissions (tonnes)				
Natural Gas	3,531	1,978	1,197	6,706
Electricity	*1,848*	*6,291*	*719*	*8,858*
Total	5,379	8,269	1,916	15,564
VOC Emissions (tonnes)				
Natural Gas	207	109	66	381
Electricity	*26*	*89*	*10*	*126*
Total	233	198	76	507
TPM Emissions (tonnes)				
Natural Gas	285	150	91	527
Electricity	*334*	*1,137*	*130*	*1,601*
Total	620	1,288	221	2,128
CO Emissions (tonnes)				
Natural Gas	1,503	1,662	1,005	4,169
Electricity	*542*	*1,845*	*211*	*2,598*
Total	2,044	3,507	1,216	6,767
SOx Emissions (tonnes)				
Natural Gas	23	12	7	42
Electricity	*4,404*	*14,994*	*1,715*	*21,112*
Total	4,426	15,006	1,722	21,154
Greenhouse Gas Emissions (kilotonnes eCO_2)				
Natural Gas	4,702	2,476	1,498	8,676
Electricity	*1,295*	*4,409*	*504*	*6,208*
Total	5,997	6,885	2,002	14,884

in cities is the most problematic area of urban emissions quantification. Ideally, estimates are built up from a detailed profile of the vehicle-kilometres of travel within the city, disaggregated by type of vehicle, type of fuel, average speed, and time of year and day.

In practice, data on all these inputs is either not collected or is only collected sporadically. Information on transportation fuel sales is available, but is not useful as it provides no indication of where the fuel is burned. Information on vehicle registrations by type is available, but this does not tell us where the vehicles are operated or the distribution of vehicle-kilometres by vehicle type.

For greenhouse gases, it would be sufficient to know the total amount of gasoline and diesel and other fuels being consumed. For the CAC emissions, it is also necessary to know how the travel (VKT) is distributed between vehicles with different emission profiles (e.g., compact cars vs. SUVs vs. heavy trucks, etc.).

We begin with an estimate of total VKT in Toronto. For each road type in Toronto, traffic count data is combined with the total length of each road type to estimate total vehicle-kilometres of travel. Traffic count data is collected by the City to facilitate road operation decision making, but it is not undertaken in a comprehensive form that supports this type of analysis of annual transportation energy use and emissions. Furthermore, while traffic counts for some

Table 9 • Assumed Disaggregation of Toronto Vehicle-Kilometres of Travel

Vehicle Type	Percent of VKT	Average Fuel Efficiency in Litres/100km
Passenger Cars – Gas	52.0%	9.1
Light Trucks – Gas	35.0%	16.7
Motorcycles – Gas	0.50%	6.7
Diesel Truck Classes		
Class 1 and 2	1.0%	13.4
Class 2B	6.0%	16.5
Class 3	0.5%	22.5
Class 4	0.5%	27.8
Class 5	0.5%	29.9
Class 6	0.5%	33.8
Class 7	0.5%	37.0
Class 8a	0.5%	41.5
Class 8b	2.0%	41.5
Diesel Transit Bus	0.4%	62.5

road segments are done annually or even more frequently, there are some traffic counts in the database that date to 1987.

Based on the traffic count and road length data, we estimate there was a total of 24.6 billion VKT in the City of Toronto in 2004.

Unfortunately, the City of Toronto traffic counts are simple counts (mostly with the rubber tube technology) and do not contain information about type of vehicle, capacity factors, etc., that would be useful for transportation planning and emissions analysis. To use the emission factors in **Table 7** to estimate GHG and CAC emissions, we need to disaggregate the VKT according to the fuel types and vehicle types represented in that table. In the absence of Toronto data to do this, we have assumed the average fuel efficiencies and VKT splits by vehicle type shown in **Table 9**. We have restricted this summary to gasoline and diesel vehicles. The contribution to total energy use and emissions of CNG and propane-fuelled vehicles is insignificant on a city-wide basis. Combining the fuel economies and VKT shares from **Table 9** with the emission factors in **Table 7** yields the total annual emissions shown in **Table 10**.

Table 10 • Transportation-Related Emissions of CACs and GHGs in Toronto in 2004

	CAC Emissions (kilo-tonnes)						GHG
Vehicle Type and Fuel	**NOx**	**VOC**	**TPM** (total)	**TPM** (exhaust)	**CO**	**SO_2**	**eCO_2** (tonnes)
Passenger Cars - Gas	6,417	6,028	205	40	106,014	94	2,838,506
Light Trucks – Gas	4,962	4,765	142	31	91,905	80	3,515,750
Motorcycles – Gas	108	328	3	2	1,305	0	20,090
Diesel Truck Classes							
Class 1 and 2	136	59	23	20	126	14	92,573
Class 2B	3,854	189	132	113	894	148	682,681
Class 3	397	20	12	10	88	14	77,479
Class 4	470	24	13	11	112	16	95,709
Class 5	446	22	10	8	106	16	102,978
Class 6	620	32	18	16	113	18	116,218
Class 7	832	42	21	19	153	21	127,114
Class 8a	1,329	37	27	23	202	24	142,724
Class 8b	5,530	160	106	91	884	102	570,897
Diesel Transit Bus	1,219	40	50	49	311	30	171,948
Diesel School Bus	199	10	5	5	32	5	4,299
Total Emissions in Tonnes	**26,519**	**11,755**	**767**	**437**	**202,243**	**584**	**8,558,966**

3.3 Summary of Energy-Related Emissions

The estimates of emissions from transportation in Toronto have a higher degree of uncertainty than the corresponding emissions from stationary energy use. In the case of the stationary energy use, the total consumption of natural gas and electricity is relatively well known from the utility sales data, and emissions are then estimated by applying emission factors that are estimates of average emissions per unit of energy use. In the case of emissions from transportation, the uncertainty increases, partly because the energy use itself must now be estimated and partly because transportation-related emissions vary over a wide range related to vehicle and engine characteristics, weather, driver behaviour, driving conditions, engine maintenance, fuel quality, etc.

The above estimates of GHG and CAC emissions from energy use in Toronto in 2004 are summarized in **Table 11** for GHG, NOx and VOCs. As we have repeatedly emphasized, in the case of CACs, knowing the annual quantity of emissions from different sources does not give an indication of which emissions are contributing how much to air pollution at what time. The electricity-related emissions in **Table 11** almost all take place at power plants that are outside Toronto. The natural gas-related emissions take place mostly during the heating season, and disproportionately during non-daylight hours. The transportation-related emissions take place year round, but with greater intensity between 7 a.m. and 7 p.m. on weekdays. All these factors and many more (meteorology, external pollution sources, etc.) must be considered in understanding air quality in Toronto. Nevertheless, the emissions estimates presented above do reveal a number of features of Toronto's energy-related greenhouse gas and CAC emissions that are important when considering policy options.

Table 11 • Summary of Annual Energy-Related GHG and CAC Emissions, 2004

	(All quantities in kilotonnes)		
	GHG	**NOx**	**VOC**
Electricity	6,208	8.9	0.1
Transportation - Cars and Light Trucks Transportation - Personal Vehicles	6,374	11.5	11.1
Transportation – Trucks	2,185	15.0	0.6
Natural Gas (mainly for space heating)	8,676	6.7	0.4
Totals	23,443	42.1	12.3
Shares	**GHG**	**NOx**	**VOC**
Electricity	26%	21%	1%
Transportation - Cars and Light Trucks Transportation - Personal Vehicles	27%	27%	91%
Transportation – Trucks	9%	36%	5%
Natural Gas (mainly for space heating)	37%	16%	3%

- With respect to greenhouse gas emissions, in 2004 Toronto's energy use caused about 23.4 Megatonnes eCO_2, with transportation fuels and natural gas accounting for about 36 percent and 37 percent of the total respectively, and emissions from electricity use making up the additional 26 percent.

- With regard to NOx emissions, transportation-related emissions account for 63 percent of the energy-related emissions but fully 79 percent of the energy-related emissions that take place within Toronto (e.g., excluding the electricity-related emissions). This pattern appears even more pronounced for the VOC emissions, but this also illustrates a danger of focusing exclusively on energy-related emissions. There are other sources of VOCs that are larger than the energy-related sources (i.e., biogenic and anthropogenic solvent emissions). In Toronto, biogenic emissions are responsible for more than 90 percent of total VOC emissions. (Please see **Appendix B** for further discussion.) This example justifies the need to not only integrate the inventory assessment, but to also integrate analysis and conclusions between global climate change and local air quality, which is the central tenet of this study.

- The results also indicate that diesel trucks contribute disproportionately to NOx emissions in the city. Diesel trucks account for an estimated 13 percent of vehicle traffic on Toronto's roads, but produce 36 percent of all NOx emissions from Toronto energy use and fully 45 percent of all NOx emissions inside the city (e.g., excluding emissions at power plants outside Toronto). Emissions of VOCs are even more highly concentrated, in this case coming almost exclusively from gasoline-powered cars and light trucks.

- The CAC emissions in **Table 11** include very large quantities of air pollutants that are being released undiluted near ground level into the boundary level air that Torontonians breathe. While a full appreciation of the significance of this can only be gained through detailed analysis of wind and dispersion patterns, atmospheric chemistry, etc., the sheer magnitude of the emissions in **Table 11** give some indication of the importance of local emissions to local air quality. For example, consider the 26,500 annual tonnes of transportation-related NOx, which corresponds to emissions on a typical weekday of about nine tonnes. By comparison, the air quality standard for a one-hour concentration of NOx is 100 millionths of a gram (micrograms) per cubic metre of air. To dilute nine tonnes of NOx to this level would require a volume of air that covered the entire City of Toronto to a height of 500 metres.

3.4 Waste-Related Greenhouse Gas Emissions

For the community inventory of greenhouse gas emissions, as discussed above, we use the "methane commitment" method to estimate the future stream of landfill gas emissions that will result from waste that is sent to landfill in the inventory year.[17] In 2004, 1.05 million tonnes of waste were trucked to the Arbor Hills and Carlton Farms landfills in Michigan. In estimating the future methane emissions from this waste, we have assumed that the composition of the waste being trucked to Michigan is 25 percent paper products, 20 percent food wastes, 5 percent plant wastes, 5 percent wood and textiles, and 45 percent inorganic. We further assume the Michigan landfills have methane recovery systems with 70 percent efficiency. No allowance is made for carbon sequestration at the landfills. Under these assumptions, the stream of future methane emissions from the Michigan landfills resulting from waste shipped there by Toronto in 2004 is about 221 kilotonnes eCO_2, less than one percent of the 23.4 million tonnes eCO_2 of energy-related emissions described in the previous section.

3.5 Summary of Energy and Waste Greenhouse Gas Emissions

Table 12 combines GHG emissions from energy use in the community with emissions from landfills and waste. The combined emissions for Toronto for 2004 total approximately 24.4 million tonnes of eCO_2.

Table 12 • Toronto Community GHG Emissions in 2004

Residential	5,997,042
Commercial and Small Industry	6,884,767
Large Commercial and Industry	2,002,172
Transportation	8,558,966
SUBTOTAL	**23,442,947**
Waste	
Landfill Emissions from Waste-in-Place (from Corporate Inventory)	721,550
Methane Commitment from 2004 Waste	221,000
Transport of Waste to Michigan (in Corporate inventory)	35,507
TOTAL COMMUNITY GHG	**24,420,939**

17 We also count the emissions from landfills that are owned and/or operated by the City which are no longer receiving waste from the city, but these so-called "waste-in-place" emissions are included in the corporate inventory, discussed below.

4. Corporate Emissions of Greenhouse Gases and Air Pollutants

The scope of the "corporate" emissions considered here includes the energy-related emissions associated with the natural gas, electricity, gasoline, diesel and other fuels consumed by buildings, vehicles and facilities operated by the City of Toronto, as well as the waste-related greenhouse gas emissions from the City's own garbage and from the landfills owned and operated by the City. The major components of the City's consumption of fuel and electricity is are buildings, lighting (street, traffic signals, and parks), water pumping and treatment, and vehicle operation. We consider each of these in turn, followed by an analysis of the City's waste-related greenhouse gas emissions.

4.1 Stationary Energy Consumption in City Facilities

Records of the fuel and electricity consumption of city facilities were compiled by City staff. The City owns and operates an astonishing array of facilities that use fuel and electricity: administrative buildings, police and fire stations, dozens of libraries, community and recreation centres, parks, arenas, theatres, tennis courts, swimming pools, homes for the aged, shelters, childcare centres, water pumping and treatment stations, waste management facilities, parking lots and garages, Exhibition Place, the Toronto Transit Commission,[18] streetlights, traffic signal lights, park and outdoor lighting, thousands of community housing units, and the Toronto Zoo (including a ferret barn, a finch barn and an orangutan holding facility).

The fuel and electricity consumption for these facilities is contained in some 2,898 records organized by facility name and summarized by Level 2 cost centre in **Table 13**. The number of records is an approximate indicator of the number of facilities in each row, but the size of the facilities varies over a wide range. For example, the 1,126 records for the Toronto Community Housing Corporation include single family dwellings as well as low rise and high rise multiple family dwellings.

In addition to the natural gas and electricity use shown in the table, there are a few city buildings that are wholly or partly heated by a district energy system serving the downtown area, including City Hall, Metro Hall, the Old City Hall, the Hummingbird Centre and the St. Lawrence Centre. In total, these facilities use about 70,000 GJ of district heat energy.

The fuel and electricity use in **Table 13** represents an annual expense for the City in excess of $120 million. Unlike the energy patterns in the community at

18 The Partners for Climate Protection convention is adopted for this analysis, in which the fuel consumption of public transit vehicles is included in the Community inventory (to support a comparative analysis with private vehicles) but the energy use of the transit stations, administrative and maintenance facilities are included in the city's Corporate inventory.

large, where the ratio of natural gas to electricity in providing stationary energy is 64:36, for the City of Toronto operations the ratio is nearly reversed to 42: 58. This is due to the electricity-intensive profile of the mostly commercial type building operations of the City, and the use of electricity for water pumping and streetlighting. Whereas for the community at large, electricity provides 42 percent of stationary energy, for the City of Toronto corporate operations, electricity provides fully 58 percent of stationary energy, a figure that rises to 70 percent if City-owned community housing is left out of the calculation. On a cost basis, electricity dominates to an even greater extent, with electricity's 58 percent share of stationary energy use accounting for about 80 percent of the combined natural gas and electricity expenditures.

The data in **Table 13** do not indicate how much of the energy and related emissions are associated with energy use in buildings vs. energy use for other applications, so to provide a disaggregation that will help identify emission reduction measures, we have allocated each of the records to one of three end use categories – street and traffic lights, water pumping and treatment, and buildings/other facilities – as shown in **Table 15** for energy and in **Table 16** for emissions.

With regard to greenhouse gas emissions, the City of Toronto's corporate operations account for 776 kilotonnes eCO_2, of which 54 percent is accounted for by electricity-related emissions. With respect to CAC emissions, electricity-related emissions account for 68 percent of NOx emissions from the City's stationary energy use, and about 35 percent of VOC emissions.

In comparison to total stationary energy use and related emissions in the community at large, the corporate operations of the City of Toronto contribute about 3.5 percent of stationary energy use, a similar share of GHG and VOC, and a somewhat larger share (4.2 percent) of NOx.

The greenhouse gas and CAC emissions associated with the energy use in **Table 13** have been estimated by applying the appropriate emission factors for natural gas and electricity, and the results are summarized in **Table 14**. The emissions associated with the natural gas consumption take place within the City of Toronto at the point where the fuel is used, whereas the electricity-related emissions take place at power plants that are generally outside of Toronto. NOx, SOx and TPM emissions associated with the City of Toronto's stationary energy use are heavily dominated by electricity consumption, whereas VOC and GHG emissions are more evenly distributed between gas and electricity.

Table 13 • Summary of City of Toronto Stationary Energy Use in 2004, by Cost Centre

Cost Centre (Level 2)	Records	Energy Use		Energy Use (GJ)	
		Gas (m³)	Electricity (kWh)	Gas	Electricity
Arena Boards	8	170,325	7,077,334	6,508	25,458
Children's Services	22	245,517	1,783,461	9,381	6,415
Community Centre Boards	9	463,667	3,421,450	17,717	12,307
Economic Development & Culture	26	226,446	2,548,489	8,653	9,167
Emergency Medical Services	35	722,491	5,093,997	27,606	18,324
Exhibition Place	10	780,636	34,878,081	29,828	125,461
Facilities & Real Estate	119	4,545,665	110,124,807	173,690	396,132
Fire Services	95	2,197,032	9,949,696	83,949	35,790
Homes for the Aged	13	3,892,407	28,445,316	148,729	102,321
Other ABCs	27	432,414	9,351,333	16,523	33,638
Parking Authority	100	171,231	23,132,123	6,543	83,209
Parks & Recreation	751	13,912,289	123,760,294	531,589	445,181
Police Services	45	2,722,490	30,674,954	104,026	110,342
Public Health	10	423,329	1,907,913	16,175	6,863
Public Library	95	2,200,574	29,990,586	84,084	107,880
Shelter, Support & Housing Admin	16	871,578	4,596,988	33,303	16,536
Social Services	14	274,374	6,236,514	10,484	22,434
Solid Waste Management	27	1,728,159	20,181,363	66,033	72,595
Toronto and Region Conservation Authority	1	7,591	-	290	-
Toronto Community Housing Corp	1,126	106,081,918	421,617,967	4,053,390	1,516,611
Toronto Economic Development Corp	16	0	4,953,944	0	17,820
Toronto Hydro	-	1,173,509	19,759,757	44,840	71,078
Toronto Transit Commission	138	21,266,000	116,092,774	812,574	417,600
Toronto Water	117	10,879,360	563,442,743	415,700	2,026,772
Toronto Zoo	23	2,371,917	11,194,285	90,631	40,267
Transportation Services	54	773,253	2,383,933	29,546	8,575
Streetlighting[19]	1	-	119,684,717	-	430,521
TOTAL	2,898	178,534,172	1,712,284,818	6,821,791	6,159,298

19 The last entry in the table, for streetlighting, was provided by Toronto Hydro and represents total sales in that category. As discussed below, however, there is a significant amount of electricity on other lines in the table that is used for street and traffic lighting.

Table 14 • CAC and GHG Emissions from Natural Gas and Electricity Use by the City of Toronto Corporate Operations in 2004

	Natural Gas	Electricity	Total
NOx (kg)	286,250	596,195	882,445
VOC (kg)	15,744	8,453	24,196
TPM (kg)	21,755	107,784	129,539
CO (kg)	240,450	174,851	415,301
SOx (kg)	1,717	1,420,916	1,422,634
GHG (tonnes eCO_2)	358,318	417,797	776,116

Table 15 • Corporate Natural Gas and Electricity Use in 2004

	Natural Gas (m^3)	Electricity (kW hours)	Natural Gas (GJ)	Electricity (GJ)	Total (in GJ)
Buildings and Other Facilities	167,654,812	1,029,157,358	6,406,090	3,702,005	10,108,095
Streetlights and Traffic Signals	-	119,684,717	-	430,521	430,521
Water Pumping and Treatment	10,879,360	563,442,743	415,700	2,026,772	2,442,473
Totals	178,534,172	1,712,284,818	6,821,791	6,159,298	12,981,089

Table 16 • CAC and GHG Emissions from Natural Gas and Electricity Use by the City of Toronto (corporate operations, agencies, boards and commissions) in 2004

	Buildings and Other Facilities	Streetlights and Traffic Signals	Water Pumping and Treatment	Totals
NOx (kg)				
Natural gas	268,807	-	17,443	286,250
Electricity	358,339	41,673	196,183	596,195
Total	627,146	41,673	213,627	882,445
VOC (kg)				
Natural gas	14,784	-	959	15,744
Electricity	5,080	591	2,781	8,453
Total	19,865	591	3,741	24,196
TPM (kg)				
Natural gas	20,429	-	1,326	21,755
Electricity	64,783	7,534	35,467	107,784
Total	85,212	7,534	36,793	129,539
CO (kg)				
Natural gas	225,798	-	14,652	240,450
Electricity	105,093	12,222	57,536	174,851
Total	330,890	12,222	72,189	415,301
SOx (kg)				
Natural gas	1,613	-	105	1,717
Electricity	854,032	99,319	467,565	1,420,916
Total	855,645	99,319	467,670	1,422,634
GHG (tonnes CO_2)				
Natural gas	336,483	-	21,835	358,318
Electricity	251,114	29,203	137,480	417,797
Total	587,598	29,203	159,315	776,116

4.2 Energy Use and Emissions from the Corporate Vehicle Fleet

Based on the information provided to quantify fuel consumption and emissions from the City's vehicle fleet, data on the City's vehicles and associated fuel consumption is fragmented; inventory and fuel consumption data is not integrated; and there are no consistent historical time series of vehicle fuel consumption. We have used the 2005 data on fuel consumption to estimate emissions as this is the only year for which comprehensive fuel consumption was provided and reasonably complete. That information indicates a total of 11.7 million litres of diesel and 10.5 million litres of gasoline. In addition, there is 1.42 million litres of dyed diesel, but we have no information about the off-road vehicles that use

Table 17 • Corporate Fleet Energy and GHG Emissions, 2005

	Litres (thousands)	GJ	eCO_2 (tonnes)
Diesel	11,321	433,607	30,568
Gasoline	12,480	436,787	29,452
Off-road Diesel	1,422	54,463	3,839
Michigan Waste Transport	13,125	502,688	35,438

Table 18 • No. of Vehicles by Fuel and Weight Class

Passenger Vehicles and Light Trucks	Gasoline	1194
	Diesel	55
	Hybrids	24
	Natural Gas	142
Trucks by GVWR		
Class 3	Gasoline	44
	Diesel	78
Class 4	Gasoline	24
	Diesel	184
Class 5	Gasoline	11
	Diesel	35
Class 6	Diesel	86
Class 7	Diesel	93
Class 8	Diesel	654
Total Vehicles		**2,624**

this fuel. As summarized in **Table 17**, greenhouse gas emissions from the City fleet's fuel consumption total about 58 kilotonnes of eCO_2, only about 10 percent of the emissions associated with the stationary fuel and electricity use of the City's buildings, water pumping, streetlighting and other facilities.

The CAC emissions from this fuel consumption depend on the types of vehicles being operated by the City and how much of what type of fuel is used in each of them. With regard to the mix of vehicles, City staff provided an inventory of 2,624 on-road vehicles owned and operated by the City of Toronto in 2004, with fairly detailed information about each vehicle (model, model year, make, serial number, license, in-service date, and type of fuel used – gasoline, diesel, natural gas). We did not have data on Toronto Hydro vehicles. Fuel consumption by police and fire protection vehicles is included in the total, but we had no details on those vehicles. In addition, we do not have odometer readings for the vehicles, or hours of use, or fuel consumption records for each vehicle. We can therefore only make a rough estimate of the CAC emissions from the City's vehicle fleet.

A summary of the characteristics of the 2,624 vehicles for which information was provided is included in **Table 18** by fuel and weight class and in **Table 19**

Table 19 • No. of Vehicles by Type and Fuel Type

Passenger vehicles	Gasoline	128
	Hybrids	11
Minivans, SUV's, compact pickups	Gasoline	261
	Natural gas	8
	Hybrids	2
Cargo and cube van	Gasoline	309
	Diesel	77
	Natural gas	35
Pickup trucks	Gasoline	547
	Diesel	63
	Natural gas	97
	Hybrids	11
Dump trucks	Diesel	456
Garbage trucks	Diesel	419
Other Trucks	Gasoline	32
	Diesel	168
Total Vehicles		**2,624**

by vehicle type and fuel type. The vehicle profile reflects the responsibilities and operations of the City, which require a fleet with a large number of heavy diesel trucks – 25 percent of the City's fleet is comprised of the heaviest class of trucks (Class 8), mostly dump trucks and garbage trucks.

To estimate the CAC emissions from the vehicle gasoline consumption in **Table 17**, we have applied the emission factors in **Table 7** for gasoline-powered trucks, combined with an assumption that the City's gasoline-powered vehicles (mostly pickup trucks and small vans) have an average fuel economy of 12 Litres/100 km.

To estimate the CAC emissions from the diesel consumption in **Table 17**, we partitioned the diesel consumption over the truck classes 3-8 according to their share of the vehicle population, and then applied the emission factors in **Table 7**, along with fuel efficiency assumptions for each truck size.

The resulting estimates of CAC emissions from the City of Toronto's vehicle fleet are summarized in **Table 20**. Clearly, the incompleteness of the available information and the number of assumptions required to produce these estimates mean that they can only be used as a guide to the relative magnitude of the vehicle fleet CAC emissions. Nevertheless, there are a couple of important and factually solid conclusions revealed by the CAC emission estimates:

- Although the greenhouse gas emissions from the fleet are relatively small compared to the emissions associated with both natural gas and electricity use for corporate operations, the fleet emissions of CACs are more significant.

Table 20 • Estimated CAC Emissions from City of Toronto Vehicle Fleet

		Emissions (kilograms)				
	Default Fuel Efficiency (L/100 km)	NOx	VOC	TPM	CO	SOx
Gasoline-Power Vehicles	12	59,929	57,554	1,714	1,110,082	969
Diesel Vehicles						
Class 3	23	11,190	556	345	2,487	389
Class 4	28	25,328	1,293	688	6,022	847
Class 5	30	4,243	211	98	1,012	154
Class 6	34	12,855	653	372	2,339	380
Class 7	37	17,044	861	423	3,126	434
Class 8	42	170,578	4,806	3,490	25,871	3,129
Michigan Waste Transport		283,614	7,990	5,802	43,015	5,203

Of particular note are the NOx emissions, especially from the garbage trucks, dump trucks and other heavy vehicles. The vehicular NOx emissions are twice as large as the emissions from natural gas consumption in city facilities, and they are heavily concentrated in the Class 8 dump trucks and garbage packers.

- The fleet is also the dominant source of VOC emissions from City operations, with the estimated vehicular emissions totalling more than seven times the emissions from natural gas use in City facilities. The VOC emissions are heavily concentrated in the gasoline-power fleet of passenger vehicles, vans, and pickup trucks.

With respect to the emissions from the trucks that transport Toronto's waste to the Michigan landfills, we assumed that a diesel truck carrying 34 tonnes of waste to Michigan will emit 1.2 tonnes eCO_2 per round trip. In 2004, 1.05 million tonnes of Toronto's waste were trucked to Michigan, resulting in vehicular greenhouse gas emissions of 35.5 kilotonnes eCO_2. Applying the Class 8 truck emission factors from **Table 7**, the CAC emissions associated with the Michigan waste transport have also been estimated and are included in **Table 20**. While most of the emissions from the Michigan transport do not take place within the City of Toronto, in magnitude they exceed the greenhouse gas and CAC emissions from the entire City of Toronto vehicle fleet.

4.3 Greenhouse Gas Emissions from Landfills

The greenhouse gas emissions of primary interest in the City of Toronto corporate greenhouse gas inventory are the emissions from the waste-in-place at landfills that are owned or operated by the City of Toronto. These include the Keele Valley and Brock West landfills, for which the city files annual certified emissions estimates, and the emissions from Thackeray and Beare Road landfills, for which estimates are based on the method described in Section 2.5.

Reported emissions from the Keele Valley and Brock West landfill sites in 2004 were 441,354 tonnes eCO_2 and 127,277 tonnes eCO_2, respectively.

The Beare Road landfill was opened in 1968 and closed in 1983 after receiving 9.6 million tonnes of waste. In 2004, methane emissions before recovery were estimated by 278 kilotonnes eCO_2. This was reduced by 64 percent by the on-site methane recovery system to yield estimated net emissions of 100,175 tonnes eCO_2.

The Thackeray landfill site opened in 1968 and closed in 1978 after receiving 2.3 million tonnes of waste. There is no landfill gas collection system at the Thackeray site and emissions in 2004 were estimated at 52,678 tonnes eCO_2.

4.4 Summary of Corporate Emissions Inventory

Ranking the top 10 emitting sources for CO_2, NOx, and TPM may assist in prioritizing a City of Toronto corporate emissions reduction strategy. Hence, these rankings are given in **Appendix C**. The following conclusions can be drawn from the rankings:

- About 48 percent of the City's corporate CO_2 emissions are actionable by new measures—three of the City's largest landfills accounting for 52 percent of corporate emissions have already been equipped with methane recovery systems in the 1990s. Of the remaining sources that are actionable, the leading ones are (in order of priority): Toronto Community Housing Corporation (primarily high rise residential buildings); Toronto Water (water pumping and treatment facilities); gasoline and diesel powered fleet vehicles used by various departments and agencies; and Thackeray landfill. These four sources account for more than half of the City's actionable corporate eCO_2 emissions sources. The remaining emissions that are actionable include transport of waste to Michigan by heavy diesel trucks, with the remaining sources dispersed among a wide variety of buildings, facilities, and departments.

- Corporate NOx and TPM emissions that are actionable by new measures are dominated by the same sources and agencies (excepting Thackeray landfill, as it does not emit NOx), with the transport of waste to Michigan by heavy diesel trucks at the top for NOx emissions, as well as emissions from Toronto Water, Toronto Community Housing Corporation, gasoline and diesel fleet vehicles, and Parks and Recreation—which combined account for 77 percent of the City's corporate NOx emissions and 76 percent of the City's corporate TPM emissions.

Table 21 • Summary of Corporate Greenhouse Gas Emissions, 2004

	GHG tonnes eCO_2	NOx Kg	VOC kg	TPM kg	CO kg	SOx kg
Buildings and Facilities	587,598	627,146	19,865	85,212	330,890	855,645
Streetlights, Traffic Signals	29,203	41,673	591	7,534	12,222	99,319
Water Pumping and Treatment	159,315	213,627	3,741	36,793	72,189	467,670
Gasoline Vehicles	29,452	59,929	57,554	1,714	1,110,082	969
Diesel Vehicles	30,568	241,238	8,380	5,417	40,857	5,334
Off-road Diesel	3,839	?	?	?	?	?
Michigan Waste Transport	35,438	283,614	7,990	5,802	43,015	5,203
Landfills (Waste in Place)	721,550	n/a	n/a	n/a	n/a	n/a
Totals	**1,596,962**	**1,467,226**	**98,120**	**142,472**	**1,609,254**	**1,434,140**

The above analysis suggests that a strategic approach that harmonizes actions on greenhouse gas and smog precursor emissions, while prioritizing a few agencies and departments, may be available to the City. Several independent agencies and boards of the City contribute significantly to the Corporate inventory, and often have independent sources of revenue that may be able to facilitate alternative financial mechanisms for emissions reduction investments.

5. Air Quality Analysis

By Dr. Christopher Morgan, Senior Specialist, Air Quality Improvement, City of Toronto

A central objective of this work is to move toward a harmonized approach to greenhouse gas and CAC emissions analysis and policy development for the City of Toronto. The community at large emissions analysis presented above (Section 3) was incorporated into the City of Toronto's Air Quality model. This involved characterizing the energy use in more detail (especially with regard to location, height above ground of the emissions, temporal pattern of emissions) than has been described in the above summaries, and then using that information to enhance the traditional "top down" data sources used to drive the city's air quality model.

This work was led by Dr. Christopher Morgan, the City of Toronto's Senior Air Quality Specialist, and the model and methods are described in more detailed in **Appendix B**. The rest of this section is taken directly from Dr. Morgan's technical memoranda and summarize the most significant conclusions and findings:

- In Toronto, NOx and PM_{10} are significant problems. $PM_{2.5}$ is less significant, while SO_2, and CO are not significant.[20]
- The significance of VOC and O_3 needs further model evaluation of available input data and its reliability before conclusions can be appropriately reached using the City's air quality model system.
- Further verification of general resultant concentrations, as by monitoring, is pending.
- Historically "targeted" sources, such as tall industrial smokestacks, are not the City's most problematic sources with respect to "general" air quality. The potentially greater significance of local industrial sources during smog events needs further examination.

20 "Significance" is established and expressed here in keeping with the Ontario and Canadian accepted ambient air concentration standards for the established time periods for each contaminant. As such, emerging health based information that suggests the long established standards, (for NOx for example) may well need to be improved (to a higher standard with lower numbers) are not addressed. Equally, the published standards are also adhered to, in which PM_{10} is seen to be more significant than $PM_{2.5}$ for example, despite epidemiological assessments that $PM_{2.5}$ is a more serious health threat. "Significance" is determined based on a comparison with established air quality standards and does not necessarily reflect the latest health based information. At a future time when health based concerns are better reflected in published ambient air quality standards, "significance" may have to be reassessed.

- We should now recognize that "many small sources" are more significant than "fewer large sources" in Toronto. The significant "many small sources" are vehicles and residential natural gas furnaces. The "fewer big sources" (e.g., commercial and industrial natural gas combustion) are less significant.
- Trans-boundary sources pollute our airshed, but for all non-smog days in Toronto, trans-boundary sources essentially only pollute the air above our heads – not the air we breathe.
- Smog is caused by weather, but is characterized by pollutant concentrations (on a single pollutant, first-past-the-post principle).[21]
- We cannot change the weather (global warming impacts not withstanding) but the number of smog events and pollutant concentrations that vary from year to year better reflect weather pattern changes than source emission changes.

6. Lessons and Strategic Implications of the Harmonized Emissions Analysis

By Philip Jessup, Executive Director, Toronto Atmospheric Fund

We are still in the early stages of our understanding of the effects of local air pollution on Toronto's air quality. It is a complex issue that has not been studied in-depth or provided with the kind of substantial resources that have been given to municipally based Air Quality Management Districts in the United States. Indeed, we do not yet know enough about the level of spatial and temporal resolution of the emissions inventory or the nuances of local atmospheric chemistry that will be necessary to support effective policy and regulation making. However, notwithstanding our tentative understanding of local pollution dynamics, the sheer magnitude of the local emissions of NOx suggests they represent a detriment to local air quality, particularly during extreme or prolonged periods of summer heat and temperature inversions.

By comparison, conducting a greenhouse gas inventory is relatively straightforward, but requires reliable and relevant energy data—particularly end-use and technology data—to support analysis of municipal policy options. Acquiring this level of detail has always been challenging in the municipal sector. Nonetheless, the analysis of greenhouse gas emissions in Toronto is fairly advanced, the result of multiple inventories and end-use studies supported by the City of Toronto and the Toronto Atmospheric Fund over the past 15 years.

21. A "river of ozone", and other pollution from transboundary sources, flows over Toronto year round, but well above the street level at which Torontonians breathe air or experience "smog". The pollution is above our heads every day of the year that we don't have a smog event. Only on those days when the weather pushes the polluted air to the ground and the local emissions from Torontonians can not readily escape upwards (as normally occurs), do we experience "smog". Effectively, "smog" is caused by the weather, but is characterized by the pollution it brings down to breathing level.

Such analysis has shown, for instance, that municipal government operations alone contributed approximately nine percent of total local greenhouse gas emissions in 1990 (the year against which all signatories to the Kyoto Protocol calculate emissions).

According to the current analysis, municipal government operations alone contributed approximately six percent to total local greenhouse gas emissions in 2004. This implies that by undertaking its own "house in order" measures, the City of Toronto has reduced its carbon footprint locally, (e.g., its share of the Toronto community's overall emissions). Further City of Toronto actions, however, are certainly feasible and will not only inspire further positive actions locally, but can have an additional positive impact on reducing overall emissions for the Toronto community as a whole.

With the data presentation and analysis in this report, we have undertaken to integrate criteria air contaminants and greenhouse gases into a single, cohesive emissions inventory. As a result, we have learned one overriding lesson, namely that the major source of those emissions has shifted from a relatively small number of smokestacks at big industrial sites to the emissions from millions of vehicle tailpipes and building chimneys.

Research Summary

When air pollution sources are (or were) dominated by emissions from a relatively small number of "point sources" – tall smokestacks at power plants and large commercial and industrial establishments – it is (or was) a relatively manageable task to determine the location, height, and time pattern of the emissions. Now the so-called "area" emissions (e.g., energy use and related emissions from residential and commercial chimneys throughout the city) and "linear" emissions (vehicular tailpipe emissions along transportation corridors) have come to dominate local pollutant emissions in Toronto, and this has implications for the type and amounts of data we need to collect about energy use in the city.

It has always been challenging to quantify energy use in cities with sufficient subsector detail to support the prioritization of policy measures aiming to reduce greenhouse gas emissions, and the goal of adding CAC emissions to that analysis amplifies the challenge. Fuel and electricity consumption data are not generally compiled at the city level, and restructuring in both the energy commodity industries, as well as in the municipal sector itself, have made the production of reliable data time series all but impossible.

The City of Toronto's databases present a particular challenge due to the difficulty of combining and integrating data from the municipal governments that existed prior to the amalgamation of the former City of Toronto with its municipal neighbours. Ideally, the City needs a consistent and credible multi-year time series record of the fuel and electricity used in the city's own buildings, facilities, and operations, so that changes from year to year can be followed and progress quantified and compared to policy targets endorsed by City Council. While comparisons with emissions prior to 2004 are essential, enough detailed information has now been collected and analyzed to ensure that future changes that impact the baseline dataset can be clearly identified and addressed on a yearly basis.

At the community-wide level, we have good information on total natural gas and electricity consumption (thanks to the cooperation of Toronto Hydro and Enbridge Gas, combined with the regulated and monopolistic nature of the distribution of electricity and gas), but consumption of oil, gasoline, diesel and all other energy commodities can only be estimated using indirect techniques. The same is true for end uses, subsectors, technology market shares and saturations, time of use and spatial resolution.

Various emissions inventories for Toronto, at least for GHGs, have been calculated over the past two decades. Each effort has varied in the level of effort, the strategies employed, the information used, and the degree of success achieved. While the methods of collection, organization, and analysis of data is consistent across these inventories, comparative interpretation needs to be approached cautiously because the actual data sets and sources may be different from one inventory to another. Nonetheless, with that caveat, the following broad research conclusions are worth noting.

Summary—Total emissions in Toronto

- In 2004, the Toronto's community's total greenhouse gas emissions and NOx were as follows:

Emissions Sector Source (2004)	eCO_2(t)	NOx(kg)
Residential	5,997,042	5,379,000
Commercial & small industry	6,884,767	8,269,000
Large commercial & industry	2,002,172	1,916,000
Transport	8,558,966	26,519,000
Transport of waste to Michigan	35,507	283,614
Streetlights	29,203	41,673
Waste	942,550	n/a
Totals	**24,450,207**	**42,408,287**

- Emissions from the City of Toronto's operations (see following section) are included above.
- Methane emissions from solid and sewage waste now account for 3.8 percent of Toronto's overall emissions.

- Toronto's per capita carbon footprint is about half that of Canada's and a third less than Ontario's, comparing emissions for energy and waste:
  - 9.6 tonnes of eCO_2 per capita (2004 with 2001 census data) for Toronto
  - 13.8 tonnes of eCO_2 per capita for Ontario (2004)
  - 18.5 tonnes of eCO_2 per capita for Canada (2002)

Summary—Emissions in City of Toronto Operations

- In 2004, the City of Toronto's greenhouse gas and nitrogen oxide emissions in municipal buildings, facilities, and operations were as follows:

Emissions Source (2004)	eCO_2(t)	NOx(kg)
Buildings & facilities	587,598	627,146
Water pumping & treatment	159,315	213,627
Street lights & traffic signals	29,203	41,673
Fleet vehicles & Michigan waste transport	99,297	584,781
Landfills (waste in place)	721,550	n/a
Totals	**1,596,963**	**1,467,227**

- The City of Toronto's greenhouse gas emissions in municipal buildings, facilities, fleets, and landfill operations have declined significantly over the period 1990-2004 – in the order of 30 percent.

- Significant eCO_2 emissions reductions occurred from 1990 to 2004 in the City's landfills due to the installation of methane recovery operations at the three largest sites, and these emissions reductions constitute the lion's share of the City's eCO_2 reductions over the 1990-2004 period.

- The carbon footprint of the City's municipal buildings, facilities, and operations, i.e., the City's share of total community Toronto emissions, has declined significantly since 1990, by approximately 36 percent over the period 1990-2004. GHG emissions from Toronto's operations were nine percent of the total community in 1990 and declined to six percent in 2004.

- The City of Toronto's total energy use in municipal buildings, facilities, and fleets decreased slightly over the period 1990-2004, likely in the range of three percent, while CO_2 emissions dropped in the range of six percent. Major influences on this trend over the period were:

  Upward Emission Influences
  - Expansion of the City of Toronto's building stock, including the addition of Metro Hall to the stock, in the 1990s;
  - Addition of the transport of waste to Michigan;
  - Intensification of occupancy of city owned buildings;
  - More comprehensive fleet data for fleets reported for 2004.

Downward Emission Influences

- Reduction in CO_2 emissions from electricity on a per kilowatt-hour basis of 13 percent, 1990-2004, due to changes in the power generation mix of Ontario's grid;
- Phasing out of incineration at Ashbridge's Bay sewage treatment plant;
- Significant energy conservation measures implemented over the period, including streetlighting retrofits.

Other important research lessons

The tracking of the city's own energy use and related emissions, and the management of their strategic reduction to sustainable levels, requires on-going senior political and managerial support, the development of a permanent and automated information and knowledge base for energy and emissions, and the establishment of permanent technical and managerial capacity within City Hall to sustain a long-term commitment to emission reduction. Good policies and program development and evaluation require that the information base be systemized so that the Energy Efficiency Office, Toronto Environment Office, and Corporate Services have ready access to energy-related data for both corporate and community energy use and emissions.

In September 2006, Council endorsed a set of recommendations from the City's then Roundtable on the Environment that direct staff to provide annual data to the Deputy City Manager responsible for environment to support GHG and air quality inventory work. The following suggestions amplify the above mentioned recommendations:

- For the City's own divisions, agencies boards and commissions, the Toronto Environment Office (TEO) should ideally have on-line access to databases containing fuel and electricity cost, consumption information, and emissions, as well as activity data (square metres of floor area for buildings, vehicle fleet data, water volumes treated, etc.). As directed by Council, this information should be routinely provided to TEO in a standardized format on an annual basis.

- For the community at large, information needs to include a detailed breakdown of levels and patterns of consumption from Enbridge and Toronto Hydro. There is a great deal of additional information required for good community-level emissions analysis and planning, and it comes from a variety of sources (e.g., population and housing data, commercial building information, disaggregated economic output data, transportation and trip-making data, etc.). It would require permanent, dedicated capacity situated in the TEO to gather and maintain the information needed for community-level clean energy and air quality planning at a city-wide level.

Local Air Quality Lessons

- Local air quality is particularly sensitive to NOx. The formation of ground level ozone, for instance, is dependent on the availability of NOx as well as heat and sunlight, and local sources of NOx are dominated by the emissions from vehicle tailpipes and building chimneys. On an annual basis as well as during summer months, vehicle tailpipe NOx emissions predominate over building emissions. Building chimney emissions that stem from building heating systems fuelled with natural gas occur disproportionately in non-daylight hours during the winter. They may play a significant role during winter smog and temporary smog-like events such as inversions.

- Compared to their share of total traffic and total energy use, NOx emissions come disproportionately from heavy diesel trucks, especially Class 8 diesel trucks. This is true on a city-wide basis, as well as for the City of Toronto's corporate NOx emissions. Reducing tailpipe NOx emissions from diesel trucks and/or reducing diesel truck traffic during smog conditions merits further analysis as a priority smog prevention measure.

- Although their emissions do not generally take place within the city boundaries, the diesel trucks that transport Toronto's waste to landfills in Michigan generate more NOx emissions than the City of Toronto's entire fleet of cars and trucks combined. The City's gasoline and diesel powered corporate vehicle fleets contribute the largest share of local corporate NOx emissions, especially Class 8 diesel trucks as noted above, followed by NOx emissions resulting from energy consumed by Toronto Water and the Toronto Community Housing Corporation.

- Electricity use in Toronto accounts for a little less than 20 percent of NOx emissions—but for most of the SOx emissions associated with Toronto energy use—on an average kilowatt-hour basis. However, these emissions do not generally take place within Toronto, but at power plants some distance from the city (some are located upwind). Further analysis is needed on the marginal impact on Toronto air quality of electricity conservation and efficiency measure. It is not clear from this first approximate analysis that Toronto air quality is particularly sensitive to Toronto electricity consumption or, conversely, that electricity conservation and efficiency in Toronto would have much immediate impact on Toronto air quality.

Greenhouse Gas Emissions Lessons

- Natural gas combustion in both residential and commercial buildings in Toronto adds up to nearly 40 percent of Toronto's greenhouse gas emissions. (Natural gas combustion in the community is also a significant source of air pollution in the winter months, as noted above.) Meanwhile, electricity use in Toronto accounts for 25 percent of community energy-related greenhouse gas emissions on an average kilowatt-hour basis.

- Gasoline used by mostly light duty vehicles in Toronto accounts for about 28 percent of community energy-related eCO_2 emissions and 27 percent of community NOx emissions. The City of Toronto has significant opportunities for encouraging the reduction of eCO_2 and NOx emissions from vehicles by adopting parking, licensing, and related municipal measures that encourage taxis, corporate fleets, and individuals to purchase fuel efficient, low polluting vehicles, enhanced by growing biofuel use. There are also technology demonstration opportunities for hybrid and plug-in hybrid technologies in the City's own corporate fleet—which has pioneered alternative fuelled vehicles in Toronto. Other integrated transportation measures such as closing lanes in favour of public transit will also have a positive impact on eCO_2 and NOx from transportation-related emissions.

- Electricity related greenhouse gas emissions account for 38 percent of emissions from City of Toronto operations. Hence, reduction in the carbonaceous content of electricity consumed throughout Toronto as a whole and by the City of Toronto's own buildings and facilities represents an important opportunity for action. Accomplishing this goal should involve a multifaceted strategy that includes:
  - Continued support for the Government of Ontario's coal phase-out program;
  - Development of renewable energy production in Toronto's own corporate facilities, with solar thermal and photovoltaic technologies offering significant long-term solutions;
  - Procurement of electricity from renewable energy sources from electricity retail providers;
  - Focusing conservation strategies on high electricity end uses in the City's departments, agencies, and boards.

- For the City of Toronto "corporate" emissions analysis, the landfill methane emissions dominate the greenhouse gas inventory (but are not important to local air quality). Thackeray landfill, the last remaining landfill not equipped with a methane recovery system, represents the single largest "point source" opportunity for reducing the City's corporate eCO_2 emissions with a single project.

- In summary, the top five opportunities in the City's buildings and operations for eCO_2 emissions are:
  - Thackeray landfill,
  - Toronto Community Housing Corporation (primarily high rise residential buildings),
  - Toronto Water (industrial water pumping and treatment facilities),
  - Gasoline and diesel powered fleet vehicles used by departments and agencies;
  - Parks and recreation (primarily buildings, skating rinks, community centres).

  These five sources account for 68 percent of the City's actionable eCO_2 emissions in 2004 in its own buildings, facilities, fleets, and operations. Furthermore, electricity-related emissions account for 59 percent of the greenhouse gas emissions of the Toronto Community Housing and Toronto Water combined, which presents important opportunities for cogeneration applications that combine electricity generation and heat production on site.

- Reducing emissions from building heating and lighting systems requires a "best technology" approach and acceleration in the City's commitment to support retrofits of residential and commercial buildings to higher levels of energy efficiency. Lighting, which typically constitutes 30–45 percent of the electricity used by municipal buildings, presents special opportunities given rapid advancements in lamp and control integration technologies. Getting the City of Toronto's own "house in order" in this regard will provide an excellent opportunity to provide leadership to the broader community.

- District energy, combined heat and power, released heat recapture, and other means to reduce reliance on natural gas for domestic heating in both new developments and established neighbourhoods also provides the City with a leadership platform. The condominium sector is a notable opportunity, since construction of condominiums account for 90 percent of the new housing for Torontonians. Furthermore, the Toronto Waterfront Revitalization Corporation will be spearheading the construction of over 40,000 new units of housing in the years ahead, an important opportunity for efficiency, district energy, and cogeneration applications.

Harmonization Opportunities and Issues

- Achieving significant reductions in both GHG and CAC emissions will require a multi-faceted, comprehensive approach to reducing overall fossil fuel use. There is no single source of both GHG and CAC emissions that is sufficiently large enough to offer the possibility of success for a narrowly focused emission reduction policy.

- Among the 10 top-ranking City of Toronto emission sources for CO_2, NOx, and TPM, several corporate sources stand out as promising for harmonized emissions reductions: Toronto Water, Toronto Community Housing Corporation, gasoline and diesel fleet vehicles, Michigan waste transport, and Parks and Recreation. These sources account for 77 percent of the City's corporate NOx emissions and 61 percent of the City's eCO_2 emissions from corporate energy sources.

- Trucks account for 10 percent of Toronto's eCO_2 emissions, and 35 percent of Toronto's NOx emissions. Hence, both for corporate operations and the community at large, truck emissions are a recommended priority for the development of a harmonized strategy for reducing both GHG and NOx emissions through the use of lighter and more efficient vehicles, hybrid and plug-in hybrid vehicle technologies, biodiesel, hydrogen fuels for diesel engines, and other NOx reduction technologies.

- The use of biodiesel in trucks and buses is a promising option for greenhouse gas reductions in vehicles. Both Toronto Hydro and Toronto Transit Commission vehicles are already using these fuels. Evidence suggests, however, that biodiesel use may raise vehicle NOx emissions, so further research on the issues related to biodiesel and the tradeoffs between GHG and CAC benefits is needed. Engine modifications that reduce NOx when biodiesel is used or NOx lowering formulations of biodiesel need to be explored.

Appendix A

Greenhouse Gas Emissions from Waste Management: A Briefing Note[1]

Prepared by Ralph Torrie, Vice President, ICF International (Revised, November 2006)

What are the factors that connect waste management alternatives and greenhouse gas emissions? What are the relative sizes of these factors and how accurately can we quantify them? What are the major sources of uncertainty in the analysis? From the pragmatic perspective of evaluating the greenhouse gas implications of waste management alternatives, which factors merit the most attention and which ones can be ignored without significantly affecting analytical results needed for practical decision-making at the level of the municipal waste manager?

Waste Management Options and Greenhouse Gas Emissions

There are a number of connections between waste management and greenhouse gas emissions (and sinks). There are the direct but relatively small emissions associated with the vehicles that collect the waste and the fuel and electricity use of the waste management facilities themselves. In the case of organic wastes, there are methane emissions associated with landfills in which the wastes are buried and decay anaerobically. Waste reduction and recycling have indirect but relatively large impacts (for some materials) on the energy use and greenhouse gas emissions of the industries that manufacture the materials. And in the case of paper products, waste reduction and recycling also impact the forest carbon balance by reducing the amount of virgin fibre the pulp and paper industry needs to take from the forest. To help categorize and compare these different sources, we have identified the following characteristics:

Size: Large – impact greater than 50 kilograms eCO_2 per tonne of waste managed, or .050 tonnes eCO_2 per tonne
Medium – impact in the range of 5-50 kilograms eCO_2 per tonne of waste
Small – impact less than 5 kilograms eCO_2 per tonne of waste

Direct or Indirect. Most greenhouse gas impacts of waste management options are indirect in the sense that there are several "cause and effect" steps between the waste management activity and the greenhouse gas impact. For example, recycling a tonne of paper that would otherwise have been landfilled has a direct effect on the amount of methane that will be generated at the landfill. Recycling a tonne of paper will also allow the pulp

1 For a more detailed discussion see ICF Consulting, "Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions, 2005 Update", prepared for Environment Canada and Natural Resources Canada, Contract No. K2216-04-0006, Ottawa 2005.

and paper industry to make a new tonne of paper with far less energy (and therefore less greenhouse gas emissions) than if they make it from freshly cut trees, but this is an indirect effect insofar as it will only occur if and when the recycled paper is used to make new paper.

Local vs. Remote. By "local" we mean that the greenhouse gas emission impacts from the waste management option occur in the community where the waste is generated. In general this will include all the emissions from the fuel use associated with the collection of the waste, as well as the landfill emissions. Emissions associated with electricity use will generally be remote because they usually occur away from the community where the electricity is used; and in some cases the landfill will also be far removed from the community. Another example of a remote effect is the reduction in emissions associated with manufacturing with recycled inputs, rather than virgin inputs; usually these emissions occur far from the community where the recyclables are collected.

Immediate Vs. Delayed. By "immediate" we mean that the greenhouse gas emissions happen within in about a year (more or less) of the waste management option. For example, all the emissions from the collection and transportation of the waste, as well as all the upstream emission impacts of waste reduction and recycling activities occur immediately, whereas the methane emissions from landfilled organic waste take place over decades and are therefore categorized as delayed.

These categories have been developed to provide a framework for comparing waste management options, and for helping to understand the challenges presented in attempting to model such a system. While the location and to a certain extent the timing of greenhouse gas emissions has little or no effect on their climatic impact, the practical reality is that *large, direct, immediate, local* impacts are of more concern than *small, indirect, delayed, remote* impacts.

Greenhouse gas emissions in this analysis are quantified starting from the point the material becomes "waste" (i.e., left at the curbside by the householder). In addition to waste reduction, there are five other waste management strategies considered here: recycling, landfilling, composting, anaerobic digestion, and incineration. For each of these strategies, and for various materials, we distinguish between the "post consumer" sources and sinks of greenhouse gases that are the direct result of waste management activities, and the indirect, upstream or "pre-consumer" sources and sinks that are affected by two of the strategies – waste reduction and recycling. (None of the other strategies affect the pre-consumer level of emissions.) Using this classification system, the sources and sinks of greenhouse gases associated with waste management alternatives are summarized in **Table A-1**. As can be seen, the largest impacts are often delayed and/or remote, whereas the smaller emission impacts are often immediate and local.

Table A-1 • Greenhouse Gas Sources and Sinks from Waste Management Strategies

		Size	Direct or Indirect	Local or Remote	Immediate or Delayed
Post-consumer sources and sinks of green-house gases from waste management activities	**1. Waste collection and transportation.** Emissions from vehicle fuel consumption for waste collection and transport to landfills, material recovery facilities, transfer stations, etc.	Medium	Direct	Fuel local, electricity remote	Immediate
	2. Landfill Heavy Equipment. Emissions from landfill bulldozers and other heavy equipment.	Small	Direct	Local	Immediate
	3. Energy Use at Waste Management Facilities. GHG emissions from fuel and electricity consumed at waste management facilities.	Small	Direct	Fuel local, electricity remote	Immediate
	4. Anaerobic Decomposition. For organic wastes only, methane emissions from anaerobic decay, primarily an issue with landfills but sometimes also from composting and anaerobic digester facilities.	Large	Direct	Local	Delayed
	5. Landfill Sequestration. For organic wastes only, carbon sinks created by landfills or other alternatives that sequester or "capture" carbon that would otherwise be naturally be released to the atmosphere as carbon dioxide.	Large	Direct	Local	Immediate
	6. Emission Offsets from Landfill or Digester Gas Utilization. For organic wastes only, if some of the methane from anaerobic decomposition is captured and used, it can displace the use of fossil fuels.	Medium to Large	Indirect	Remote	Delayed
	7. Waste Combustion. Emissions of non-biogenic CO_2 and N_2O from waste combustion.	Large for plastics, small for other materials	Direct	Local	Immediate
Pre-consumer emissions affected by waste reduction and recycling	**8. Upstream Energy.** Carbon dioxide emissions (primarily) from the fuel and electricity consumption required to acquire and transport raw materials and for product manufacture from virgin or recycled inputs.	Large for some mate-rials	Indirect	Remote	Immediate
	9. Upstream Non-energy. Greenhouse gas emissions from non-energy sources related to the manufacture of products from virgin or recycled inputs (e.g., perfluorocarbon emissions from aluminum smelters).	Large, but only applies to some materials	Indirect	Remote	Immediate
	10. Forest Carbon Sequestration. For paper products, carbon sinks in the forests that are preserved because of the reduced need for fresh fibre as the result of reduction or recycling of paper products.	Large, paper products	Indirect	Remote	Immediate

Post-Consumer Greenhouse Gas Impacts of Waste Management Alternatives

1. Waste Collection and Transportation Benchmark: 10-40 kgs eCO_2 per tonne of waste.

The trucks used for waste collection and for moving waste from transfer stations typically consume diesel fuel, which emits 2.7 kgs of eCO_2 per litre of fuel. Greenhouse gas emissions from any particular fleet of collection and waste transfer trucks can be computed by multiplying total consumption of diesel fuel by this number. Dividing that result by the total amount of waste moved in tonnes will yield emissions per tonne of waste.

The results will vary over a wide range depending on the distances travelled by the collection trucks and the efficiency of the trucks and their operation, but a typical mid-range value would be 10 kilograms eCO_2 per tonne of waste managed (or 0.010 tonnes eCO_2 per tonne of waste).

The greenhouse gas emissions represented by the transportation of waste from Toronto to Michigan represent the high end of the emissions that would occur from waste transport, and are in the range of 25-30 kg eCO_2 per tonne of waste transported. (A waste transfer truck (50 L/100 km) moving 35 tonnes of waste 450 km and then returning empty would emit about one tonne eCO_2 per round trip, or about 35-40 kg eCO_2 per tonne of waste transported.) This could be reduced by improving the efficiency of their routing and operation or the fuel

Global Warming Potentials (IPCC 100 year integral)	
Greenhouse Gas	**Global Warming Potential**
Carbon Dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous Oxide (N_2O)	310
HFC-23	11,200
HFC-125	1,300
HFC-134a	2,800
HFC-152a	140
Perfluoromethane CF4	6,521
Perfluoroethane C_2F_6	9,221
Sulphur Hexafluoride SF_6	23,921

Greenhouse Gases and Global Warming Potentials – the "eCO_2 Unit"

The three primary greenhouse gases are carbon dioxide (eCO_2), methane (CH_4) and nitrous oxide (N_2O), but there are many others associated with various industrial processes. An international protocol has established carbon dioxide as the reference gas for measurement of heat-trapping potential (also known as global warming potential or GWP). By definition, the GWP of one kilogram (kg) of carbon dioxide is 1. Methane has a GWP of 21. This means that one kg of methane has the same heat-trapping potential as 21 kg of CO_2. Values for the Global Warming Potential of various greenhouse gases are shown in the table below. In this report, all sources and sinks of greenhouse gases are quantified in units of eCO_2.

efficiency of the engines. Switching to biodiesel or hydrogen can further reduce the greenhouse gas emissions from waste transportation.

Transportation-related emissions will often increase as recycling and central composting operations are implemented, due to the need for additional, specialized vehicles and/or separate collections for the different waste streams. However, as described in more detail below, the other greenhouse gas benefits of waste recovery more than offset the additional transportation emissions.

2. Landfill Heavy Equipment Benchmark: 4 kgs eCO_2 per tonne of waste.

The large bulldozers used at landfills emit greenhouse gas emissions on a scale that is usually smaller than but on the same order of magnitude as the emissions from the waste collection truck fleet. As usual, emissions for individual landfills will vary, but diesel consumption in the range of 1.5 litres per tonne of landfilled waste is a representative benchmark. This equates to greenhouse gas emissions of about 4 kgs eCO_2 per tonne of waste landfilled.

3. Energy Use at Waste Management Facilities Benchmark: 0 .6 kgs eCO_2 per tonne of waste.

Fuel and electricity use for the buildings and equipment at waste management facilities also result in greenhouse gas emissions, but these will be even smaller, typically at least ten times smaller, than emissions from waste transportation. Emissions for any particular facility can be computed by multiplying fuel and electricity consumption by the appropriate emission factors. As with transportation, emissions will depend on individual circumstances, emissions intensity of the grid electricity being used, etc. but a typical benchmark for emissions from these facilities would be .5-1.0 kg eCO_2 per tonne (.0005-.001 tonnes eCO_2 per tonne) of waste managed.

4. Methane Emissions from Anaerobic Decomposition Benchmark (No LFG Recovery): 300-1,888 kgs eCO_2 per tonne of organic waste. Mixed MSW benchmark 1,000 tonnes eCO_2 per tonne of landfilled waste. With landfill gas recovery, values can be 75-90 percent lower.

When organic waste is buried, conditions are created for anaerobic decomposition, and the resulting landfill gas that percolates out of the landfill is a mixture of carbon dioxide and methane. The carbon dioxide portion of this gas is biogenic (and therefore not counted as a man-made greenhouse gas, see box on "biogenic carbon dioxide") but the methane is considered anthropogenic and is a powerful greenhouse gas (on a mass basis, 21 times more powerful than carbon dioxide, see box on Global Warming Potential). The methane is also flammable, and as such has been a longstanding concern for landfill managers, and methane collection and flaring is now commonplace at active landfills in Canada. Burning the methane converts the carbon to biogenic carbon dioxide, thus neutralizing its greenhouse impact. However, even with 90 percent collection efficiency residual methane emissions will be in the range of 30-200

Biogenic CO_2

When organic materials such as paper, food and yard wastes decay (whether in a landfill, a compost facility, or elsewhere) or when they are incinerated, their carbon content is released as carbon dioxide but it is not counted as an anthropogenic greenhouse gas emission because it is carbon dioxide that would have eventually been released under natural conditions. The carbon in the plants and trees from which these products are made is the result of the photosynthetic capture of carbon from the atmosphere, and in the natural carbon cycle it is returned to the atmosphere when the plant dies and decays (aerobically) on the earth's surface. For this reason, the international conventions do not include carbon dioxide from organic waste decay and incineration in the definition of what constitutes "anthropogenic emissions". This means that carbon dioxide emissions from digestors and compost facilities are not counted, and neither are the carbon dioxide emissions associated with the organic component of waste burned at incinerators.

kgs eCO_2 per tonne of organic waste and in the range of 100 kg eCO_2 per tonne of mixed MSW for all waste.

Unlike the other sources of emissions discussed above, however, these emissions are spread out over a long period of time after the waste has been buried. The rate of methane production from a particular quantity of waste will reach a maximum within a couple of years after the waste is buried, and then continue, slowly declining, for decades. The emission factors presented here refer to the cumulative emissions of methane that will eventually occur as the waste decomposes over a period of decades. For purposes of comparing waste management alternatives and the greenhouse gas benefits of three R programs and waste diversion options, this is the appropriate number to use. However, it should not be confused with the methane emissions occurring in the current year from the waste-in-place at the landfill. (From the perspective of the landfill manager considering landfill gas recovery, it is the current and projected methane emissions from the waste that has already accumulated in the landfill over previous years that is of more immediate relevance.)

Estimates of methane emissions from various organic waste types are shown in **Table A-2**. These factors are taken from work done for Environment Canada[2]. These factors do not reflect any deduction of carbon sequestration at the landfill and they are probably on the high end of the range for real landfills. In fact, these same factors are used for representing methane generation in engineered anaerobic digesters.

2 The most recent Canadian coefficients, with detailed explanation, can be found in ICF Consulting, "Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions, 2005 Update", prepared for Environment Canada and Natural Resources Canada, Contract No. K2216-04-0006, Ottawa 2005.

Table A-2 • Landfill Methane Emissions (in tonnes eCO_2 per tonne of landfilled waste)

	No methane recovery*	With 75% efficient methane recovery
Newsprint	0.30	0.08
Fine Paper	1.87	0.47
Cardboard	1.64	0.41
Other Paper	1.68	0.42
Food Waste	1.22	0.30
Yard Waste	0.58	0.14
Coated Paper	1.07	0.27
Grass	0.78	0.19
Leaves	0.60	0.15
Branches	0.62	0.15

*These are the eventual emissions that will result over time from a tonne of landfilled material, assuming none of the methane is recovered for flaring or energy utilization, but that 10 percent of the methane generated by the anaerobic decomposition is oxidized before reaching the landfill surface. For a landfill with methane recovery, these figures should be reduced by a percentage equal to the efficiency of the methane collection system. The figures in the second column reflect methane emissions at a landfill with 75 percent efficient methane recovery.

What about methane emissions from composting and anaerobic digesters?

A well managed compost operation, whether on a back-yard scale or at a centralized and engineered facility, generates little or no methane and what little methane may be generated in the interior of the compost is oxidized before it reaches the surface. An emission factor of zero is used for the methane emissions from composting.

With engineered anaerobic digesters, methane generation is very high, but it is all collected for use as an energy source, so that the methane emission factor for anaerobic digesters is also zero.

5. Carbon Sequestration at Waste Management Sites Benchmark: -100 to -1,500 kgs eCO_2 per tonne of organic waste, -400 kgs eCO_2 per tonne for mixed MSW.

According to international conventions for greenhouse gas accounting, the carbon in trees that are harvested to produce short-lived products such as paper is assumed to be released to the atmosphere as carbon dioxide and is therefore included in national inventories. However, not all carbonaceous materials break down in landfills; both laboratory experiments and excavation of old landfills indicate that significant quantities of some materials (especially newsprint) remain intact for various reasons related to the physical structure of the material and the biophysical conditions of the environment. Current reporting conventions do not yet require that this "carbon sequestration" be deducted from greenhouse gas emission inventories, or that the "carbon sink" aspect of landfills be recognized, but the scientific fact remains that a certain amount of carbon sequestration takes place in landfills. In determining the net greenhouse gas impact of a landfill, this carbon sequestration offsets the methane emissions and in a landfill with methane recovery, it can result in the landfill being a net sink for carbon.

Table A-3 • Carbon Sequestration at Landfills

Material	Tonnes of eCO_2 per tonne of waste landfilled
Newsprint	1.45
Fine Paper	0.17
Cardboard	0.91
Other Paper	0.51
Food Waste	0.09
Yard Waste	0.76
Coated Paper	1.17
Grass	0.47
Leaves	1.58
Branches	0.84

While more research is required on the subject of the extent to which different carbonaceous materials do and do not break down in landfills, there is no question that for some types of waste, like newspapers, significant quantities can remain intact in landfills for decades. Whether or not this carbon sequestration effect should be included in the quantification of greenhouse gas impacts from waste management alternatives is also partly a policy question. In this study, landfill carbon sequestration has not been included in the greenhouse gas inventory for Toronto.

6. Emission Offsets from Methane Utilization Benchmark: 50-200 kgs eCO_2 per tonne of waste

While the flaring of methane from landfills yields a greenhouse gas benefit in the range of hundreds of kgs of eCO_2 per tonne of waste, an additional though smaller benefit can be gained if energy released from burning the methane is used to displace fossil fuel combustion, either directly or by displacing electricity generated from fossil fuels. In the case of anaerobic digesters, the production of methane for energy utilization is an explicit objective. The size of the emissions benefit (in eCO_2 per tonne of waste) will depend on the rate of methane generation of the waste (see **Table A-3**), the efficiency of the methane collection system at the landfill, and the emissions intensity of the fuel or electricity being displaced. If the methane is being used to generate electricity, then the efficiency of the methane electricity generation will also be an important factor.

The largest emission benefits will occur if the methane can be used directly to offset the use of fossil fuel, as this avoids the losses from electricity generation. However, using the methane to generate electricity is the most common application of landfill methane. Generation efficiencies are relatively low (25-30 percent) but there will still be a significant greenhouse gas emission benefit if the resulting power is used to displace electricity generated from fossil fuels.

A tonne of methane (21 tonnes eCO_2) contains about 50 GJ of energy, so MSW that emits one tonne eCO_2 of methane per tonne of waste is emitting about 2.5 GJ of methane per tonne of waste. Used as a substitute for the direct use of fossil fuel, and after allowing for collection efficiency, the greenhouse gas benefit is about 100 kgs per tonne of waste for natural gas displacement and about 190 kgs per tonne of waste for coal displacement. In the more common application where the methane is used to make electricity that then displaces fossil-fired electricity, the greenhouse gas benefit is about 50 kgs per tonne of MSW for displacement of natural gas electricity and 140 kgs per tonne of MSW for displacement of coal-fired electricity. These examples are for the case of general MSW generating methane of one tonne eCO_2 per tonne of waste; for organic wastes with higher methane generation rates, the greenhouse gas benefits will be correspondingly higher.

7. Emissions from Waste Combustion Benchmark: 45 tonnes eCO_2 per tonne of MSW; 2,500-3,350 kgs eCO_2 per tonne for plastics, carpet, synthetic fibres, computers, etc

Waste incineration results in emissions of carbon dioxide, as well as trace amounts of nitrous oxide. For most materials, the carbon dioxide emitted during combustion is biogenic and therefore not counted in anthropogenic inventories. The notable exception is plastic. Burning PET yields some 2.5 tonnes eCO_2 per tonne burned and burning polyethylene plastics emits 3.35 tonnes eCO_2 per tonne burned. For other waste, nitrous oxide emissions from combustion are about 45 kgs per tonne of waste burned.

Pre-Consumer Greenhouse Gas Impacts from Waste Reduction and Recycling

Whereas the greenhouse gas emission impacts discussed above are "post consumer" and occur downstream from the waste generation point, reducing or recycling some materials results in three important types of "pre-consumer" or upstream greenhouse gas benefits:

- Emission reductions associated with fuel and electricity savings from the reduced energy needed by the industry that manufactures the material;
- Reductions in non-energy related emissions by the industry that manufactures the material (e.g., perfluorocarbons in aluminum refineries); and
- Increased carbon sequestration in the forest due to the reduced tree harvest required for paper product production.

8. Upstream Energy Benchmark: In the range of 300-5,500 kgs eCO_2 per tonne of waste, depending on the material.

Some materials require a relatively large amount of energy to manufacture (e.g., paper, metals, plastics, glass, steel) and can also be made from recycled inputs with much less energy than is required to make them from virgin inputs. For these materials, reducing or recycling has the effect of reducing the energy use of the industries that manufacture them, and therefore also reducing greenhouse gas emissions.

To estimate emission factors for upstream energy saved by waste reduction and recycling, it is necessary to estimate the total amount of energy required to manufacture each material from virgin inputs and from recycled inputs, as well as the mix of different fuels and electricity. The total greenhouse emissions "embedded" in the final product is particularly sensitive to both the amount of electricity used in the manufacturing process and the greenhouse gas intensity of that electricity. Greenhouse gas emission factors for aluminum, paper and other materials tend to be significantly lower for Canadian industry than for American industry because of the lower average greenhouse intensity of Canadian electricity and because electricity-intensive industries such as paper and aluminum tend to be concentrated in regions where there is an especially high portion of zero-emission hydroelectricity in the electricity mix.

Table A-4 lists the greenhouse gas emissions associated with the manufacture of selected energy intensive materials in Canada, for both virgin inputs and recycled inputs. These greenhouse gas benefits are indirect and typically far removed from the community in which the waste reduction or recycling takes place. Also, they can only be approximated from general information about how much energy use and greenhouse gas emissions are associated with different manufacturing processes. If they were not so large compared to other, more direct and easy-to-measure greenhouse gas benefits of waste management alternatives, they could be ignored in a consideration of how waste management options affect greenhouse gas emissions. However, even with the uncertainties associated with these numbers, it is clear that the upstream greenhouse gas benefits of reducing or recycling materials such as paper, steel, and plastics represent a very significant contribution that the waste management community can make to address the issue of climate change.

What about the energy used upstream from manufacturing, for raw material acquisition?

The factors described above reflect the greenhouse gas emissions associated with the manufacturing of the materials. In addition, energy is required for raw material acquisition (i.e., forestry and mining) and this energy will also be reduced by material reduction or recycling. However, it is generally true that the amount of energy per tonne of manufactured product required for raw material acquisition is a small fraction of the amount of energy required for product manufacture. For example, it takes much more energy to make paper from a tree than to cut down the tree and bring it to the mill. The energy consumption of the Canadian pulp and paper industry is more than 25 times the total energy use of the entire Canadian forestry industry and, on a per tonne of paper produced basis, the manufacturing energy in the mill is more than 50 times higher than the energy it takes to cut down the trees and move them to the mill. In the case of steel and metals, while mining is an energy intensive process, the smelting and refining processes are several times more energy intensive per tonne of finished product.[3]

Table A-4 • Upstream Greenhouse Gas Emissions from Manufacturing Energy Use in Canada (kgs eCO_2 per tonne of material)

	Mfg from virgin inputs	Mfg from recycled inputs	Difference (advantage of recycled over virgin)	Mfg with current mix of virgin and recycled inputs
Newsprint	890	540	350	820
Fine Paper	1,360	890	470	1,350
Cardboard	1,120	790	330	1,020
Other Paper	1,260	690	570	1,160
Aluminum	4,330	790	3,540	2,480
Steel	2,100	670	1,430	1,900
Glass	430	260	170	380
HDPE	3,080	440	2640	2,690
PET	4,670	440	4,230	3,460
Other Plastic	2,990	340	2,650	2,960
White Goods	2,350	590	1,750	2,030

9. Upstream Non-energy. Benchmark: Depends on material, 40 kgs eCO_2 per tonne for office paper to 2,200 kgs eCO_2 per tonne for aluminum

Some manufacturing processes emit greenhouse gases from processes other than fuel and electricity consumption. Of particular concern are emissions of perfluorocarbons (CF_4 and C_2F_6) in the production of aluminum from virgin inputs, which amount to 3,930 kg eCO_2 per tonne of aluminum production. There are also direct emissions of methane associated with plastics manufacture, and emissions of carbon dioxide from the oxidation of limestone in processes associated with the manufacture of various materials, including office paper and glass. Only the aluminum non-energy emissions were included in the coefficients developed in the ICF Environment Canada report cited above.

3 Aluminum production is an exception, however, as there are quite significant emissions upstream from the aluminum smelters, emissions associated with the energy intensive process (mostly for natural gas) of making alumina from bauxite. Aluminum smelters use about two tonnes of alumina per tonne of aluminum produced, and alumina production itself consumes about 25 GJ/tonne of natural gas.

10. Forest Sequestration (Paper Products Only). Benchmark: 2,770 – 4,440 kgs per tonne of paper

When paper waste is reduced or recycled, it reduces the amount of fresh fibre required by the pulp and paper industry, thus leaving carbon standing in the forest that would otherwise have to be cut. The effect is relatively large in terms of eCO_2 per tonne of paper reduced or recycled, although the computation can be complex. The emission factors shown in **Table A-5** are based on a relatively simple carbon balance calculation that takes into account the carbon content of the paper, the amount of recycled paper that makes it back to the mill (after losses), the ratio of the carbon input to the mill to the carbon contained in the mill's paper products, and the ratio of the carbon cut in the forest to the amount delivered to the mill mouth. As with landfill carbon sequestration, the forest carbon sequestration benefits of the reduction or recycling of paper products is not yet included in greenhouse gas accounting protocol.

Table A-5 • Forest Carbon Sequestration (kgs eCO_2 per tonne of paper)

	Recycling	Reduction
Newsprint	2,420	2,460
Fine Paper	2,770	4.,440
Cardboard	3,110	3,200
Other Paper	2,770	3,790

Appendix B

The City of Toronto's Air Quality Model

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Air Quality is about pollution in air, about the concentrations of contaminants that people[1] are exposed to and breathe, and the health impacts that result. Adverse air quality results from emissions of contaminants but understanding emissions alone is inadequate to comprehend air quality. People breathe ambient concentrations, not emissions. Emissions typically disperse and diffuse, but knowing where and when adverse concentrations result and who is exposed and how they are impacted is the focus of air quality assessment.

Concentrations can be typified by air monitoring estimates or by air modelling estimates. The former can only "see" the integrated combined picture of a present time (of the time when the data was collected) at the specific location (geography and height) that is monitored The latter, air quality modelling, can "see" the past, present and future, but modelling can also "see" the impacts of the various emission contributions separately and is therefore, typically considered superior as an instrument to direct management policies into the future. Largely for this reason, the City of Toronto's air quality evaluating group of the Toronto Environment Office determined that air quality modelling was to be preferred to air quality monitoring for local assessment in the gaps between the monitoring stations, and for local policy guidance, and following their needs and model ability assessment evaluation, established a CALPUFF based air quality model for the City of Toronto.

However, air quality modelling tools can not operate in the absence of both emission source data and monitored air data. The former is necessary as one of the required data input components of the model, and the latter is valuable as a verification check on the modelled data output. Consequently, air quality modelling relies on emissions inventories and emissions factors and on monitored data and focuses on analysing the sources individually, and the physics and chemistry of the active atmospheric processes to understand causal relationships and determine the best possible potential solutions to the issues revealed.

Modelling air quality in Toronto (as in most parts of the world) was originally undertaken using national and provincial estimates of emissions. The original inventory was provided by Environment Canada in concert with Ontario's Ministry of Environment and included all reported industrial emissions (point sources), and all estimated vehicle emissions (line sources), and all estimated neighbourhood emissions (area sources) as from residential and commercial

1 The impact of air pollution on vegetation and materials is also apparent and often significant but it is not the main focus of concern here.

building heating, but also including estimated emissions from trees and estimates of fugitive emissions from industrial, commercial and other sources.

The process of developing the model into a reliable functioning tool was deliberately set as a multi-year and progressive task. Indeed, the identified subsequent improvements as initially identified have not yet been fully realized. Progress has been, and will remain, an ongoing balance of available resources and appropriate matching of data (availability and quality) and proving the value of the "output".

It was soon recognized that developing an air emissions inventory using locally available and relevant of local data would add tremendously to the value of the modeled findings. To this end the air quality evaluation group set about obtaining the best available data to typify (among other sources) vehicle emissions on all Toronto roads (provincial as well as municipal) and natural gas combustion across Toronto (as graciously provided by Enbridge). These, and other, data improvements have very significantly improved the confidence in the model's output and are presented below.

Clearly, the data that proves so valuable to air quality modelling in Toronto is the same data that can be so valuable in improving the greenhouse gas inventory and the conclusions drawn respecting climate change. The inventory of basic data is regarded as a common inventory for the project.

Source Emissions vs. Resultant Ambient Concentrations

There is an obvious basic air quality sequence to be aware of when assessing air quality: i) source emissions; ii) meteorological dispersion and diffusion; iii) resultant ambient concentrations; iv) human exposure; and v) health impacts.

Source emissions vary chemically by their content and chemical properties, and they vary physically by their physical location and their emission properties (temperature, height, and exit velocity etc). Obviously, emissions usually vary in their amount and in their significance both temporally and spatially. Not only do the sources of emissions vary considerably but what happens to them as they are emitted and after they are emitted also varies greatly. Wind (strength, direction, and turbulent mixing) as well as other weather, or meteorological, factors (temperature, humidity, atmospheric stability and solar radiation) act to change their spatial location (or three dimensional dispersion) and air turbulence mixes and dilutes the emission with ambient air. Meteorology determines what happens to the emissions after they leave their point of origin. As such, "source emissions" alone tell us little about "resultant concentrations".

Equally, "resultant concentrations" tell us little about health impacts (though obviously potentially much more than the further removed "source emissions"). The varying amount of time people are exposed (by the nature of where they live and work etc.) and the variation of human health impacts (by the nature of the varying sensitivity to such exposures) further confounds the sequence. But modelling creates information that will in future hopefully be used to clarify what is a rather statistically based "grey box" linking the cause (emissions plus meteorology) with the effect (human exposure and impacts).

CALPUFF Model Suite

The air quality assessment group of the Toronto Environment Office (TEO)[2] has developed a City of Toronto application of CALPUFF[3,4] with help from a series of different consultant firms over the period 2000 to the present. CALPUFF is a sophisticated state-of-the-art computer modelling system (which includes CALPUFF and CALMET modules among others) that dynamically models the dispersion and diffusion of emissions from point sources (e.g., smoke-stack emissions), line sources (e.g., traffic emissions) and area sources (e.g., residential area sources). CALMET provides the meteorological patterns of wind (speed and direction) through time that influences contaminant dispersion, and CALPUFF models the resultant contaminant concentrations impact across "regional areas" such as the City of Toronto or sub-areas such as smaller neighbourhoods or City Wards. CALPUFF is the best available model system to address complex terrain urban environments that also have complicating geophysical conditions such as the lake shoreline which causes a complex meteorology and complex contaminant-dispersion effect.

TEO maintains and operates its models to depict concentrations of ambient air contaminants or criteria pollutants in keeping with established criteria (e.g., Ambient Air Quality Criteria – AAQC and Canada Wide Standards – CWS – as and where applicable) across Toronto. The output is typically referenced to health-based Ambient Air Quality Criteria (AAQC) values of 1-hour, 8-hour, 24-hour or annual AAQCs for each CAC. Output is also typically provided as a probability of exceedance by geography (i.e., where do most and least exceedances of ambient air quality criteria occur across the City).

TEO's early model configurations enabled ambient concentrations to be estimated based on 1995 data for point, mobile and area sources and emission factors and meteorology as achieved using estimated data from the Ontario Ministry of Envi-

2 The name "Toronto Environment Office" (TEO) replaced the formerly named Environmental Services Division in 2006 when it was transferred, within the City, to the Policy, Planning Finance and Administration Department. The name "Air Quality Improvement Branch" (AQIB) no longer formally exists pending the announcement of its successor group. In this document the former AQIB group are referred to as the present TEO – even though TEO encompasses many more functions than just air quality assessment.
3 CALPUFF is an advanced non-steady-state meteorological and air quality modelling system developed and distributed by Earth Tech, Inc. The model has been adopted by the US Environmental Protection Agency (US EPA) in its *Guideline on Air Quality Models* as the preferred model for assessing long range transport of pollutants and on a case-by-case basis for certain applications involving complex terrain and meteorological conditions (as occurs with Toronto's proximity to Lake Ontario). The modelling system consists of three main components and a set of pre-processing and post-processing programs. The main components of the modelling system are CALMET (a diagnostic 3-dimensional meteorological model), CALPUFF (an air quality dispersion model), and CALPOST (a post-processing package). In addition to these components, there are numerous other processors that are used to prepare geophysical (land use and terrain) data, meteorological data (surface, upper air, precipitation, and buoy data).
4 CALPUFF is the main air quality model suite, but not the only air quality model, used by TEO.

ronment and Environment Canada and others in a "top-down" modelling approach.

Currently, TEO's latest model configuration utilizes real, locally derived data (as by TEO and other City staff) and operates the model with a predominantly "bottom-up" approach with meteorology from 2004. The latest configuration includes for the first time both inputs of trans-boundary estimates and outputs O_3 and $PM_{2.5}$. Further improvement is still to be included in respect to replacing several remaining "top down" estimates of several other area sources, such as dust from construction, and the location of VOC inputs from natural biological sources.

The "bottom-up" approach is much preferred as it provides greater confidence, local detail and ability to evaluate local issues and solutions. The model permits comparative "what-if" scenario testing of potential air quality improvements of the present and the future.

Air Quality Model Emission Factors

Beyond utilizing the best available primary "bottom-up" data as of natural gas consumption and vehicle-kilometres travelled (VKT), it is necessary to convert such data it into emissions of the criteria contaminants of interest by using "emission factors".

Converting the volume of gas (in cubic metres) as combusted in residential and commercial heating furnaces requires using "emission factors". The standard source of such emission factors as adopted by air quality modellers across North America and beyond, is the US Environmental Protection Agency's (US EPA) Clearinghouse for Inventories and Emission Factors (CHIEF), Appendix 42, Fifth Edition Volume 1, Chapter 1.4, Natural Gas Consumption, Table 1.4-1 (see: http://www.epa.gov/ttn/chief/ap42/).[5] The document provides conversion factors to allow conversion of raw fuel combusted data into lbs per million standard cubic feet,[6] which TEO converts into tonnes per million cubic feet (or grams per cubic metre) of the criteria air contaminants. The factors are as presented in the main document and are not repeated here.

The emission factors adopted in respect of the transportation volume data are essentially the same as the ones presented in the main document but are classified in different groupings. The factors and groupings employed in the CALPUFF model were taken from a standard US transportation model (MOBILE 6) and adapted for Canadian use by Environment Canada as MOBILE 6C). TEO used the latest available iteration of that adaptation (MOBILE 6.3C). These emission factors are not readily available as they are embedded within MOBILE 6, and as such they are provided here in **Table 1**. Given the obvious

5 The www.epa.gov/ttn/chief/ap42/ site is the exact same source as referenced in the parent inventory document to this appendix and indicates and confirms the integration of GHG and AQ "inventories" as described in that document.

6 TEO also follows the US EPA , CHIEF, AP42 protocol of converting to tonnes per million cubic metres by multiplying by 16/1000 or 0.88 rather than adopting 0.88184 as the factor of conversion.

uncertainty around fleet composition, (i.e., limited data plus interpolated information from select intersection truck counts), the groupings were kept to those that could be safely justified from the limited data and basic composition assumptions.

Given the importance of road dust as a causal factor in the resultant concentrations of PM_{10} and $PM_{2.5}$ the seasonal emission factors respecting re-suspension of paved road dust (as by vehicles repeatedly re-entraining such fine dust from road surfaces into a suspension in air as occurs when vehicle tires pass over and pick-up, and flick-up, such fine dust into the air) and the silt loading factors were taken from the US EPA CHIEF AP 42, Chapter 13.2.1 Paved Road. The emission factors are provided as below.

Table 1 • Mobile 6.3C Tailpipe Emission Factors (g /vkt)

Contaminant	Passenger Vehicle (Gas)	Passenger Vehicle (Diesel)	Heavy Duty Truck (Gas)	Heavy Duty Truck (Diesel)	Bus (Diesel)	Motorcycles
Expressways						
SO_2	0.0042	0.0020	0.0150	0.0091	0.0137	0.0021
CO	14.70	0.92	18.63	1.71	2.33	11.60
NOx	0.69	1.29	5.43	14.50	17.64	1.31
PM_{10}	0.016	0.11	0.078	0.25	0.47	0.109
$PM_{2.5}$	0.007	0.09	0.046	0.21	0.35	0.016
VOCs	0.91	0.29	2.24	0.23	0.23	2.38
Arterial Roads						
SO_2	0.0042	0.0020	0.015	0.0091	0.014	0.0021
CO	12.2	0.86	12.8	1.50	2.04	6.14
NOx	0.61	0.70	4.56	7.1	9.2	0.93
PM_{10}	0.016	0.11	0.078	0.25	0.65	0.283
$PM_{2.5}$	0.007	0.09	0.046	0.21	0.39	0.058
VOCs	1.002	0.33	2.538	0.30	0.29	2.105
Residential/Local Roads						
SO_2	0.0042	0.0020	0.015	0.0091	0.014	0.0021
CO	12.2	1.04	18.5	2.21	3.02	8.20
NOx	0.64	0.73	4.12	7.4	9.7	0.83
PM_{10}	0.016	0.11	0.077	0.25	2.41	2.043
$PM_{2.5}$	0.007	0.09	0.046	0.21	0.81	0.479
VOCs	1.109	0.40	3.162	0.42	0.41	2.309

Table 2 • AP-42 Emission for Seasonal Road Dust Re-Suspension (Vehicle Fleet Average)

Road Type	PM_{10} (g/VKT)		$PM_{2.5}$ (g/VKT)	
	Summer	Winter	Summer	Winter
Expressway	0.086	0.086	0.003	0.003
Arterial	0.154	0.26	0.02	0.045
Residential/Local	0.801	2.02	0.174	0.466

Table 3 • AP-42 Silt Loadings for Roadway Types, by Season

Road Type	Silt Loading (g/m²)	
	Summer	Winter
Expressway	0.03	0.03
Arterial	0.06	0.12
Residential/Local	0.6	2.6

The emission factors obtained from, and used in conjunction with Environment Canada's RDIS, are also embedded in the RDIS database and comprises too many lines of factors to be included here. The RDIS provides the factors of all area based activities and includes the factors for such detailed activities as human smoking, sweating and breathing.

Summary of Air Quality Emissions Inventory Data Used in CALPUFF Model

The emissions derived from natural gas combustion in Toronto in 2004 (combined data was graciously provided by Enbridge)[7] were apportioned to different land uses, and estimates of gas consumption in every building across the city were made, based on known floor area and volume, and were then identified as being emitted at the height of the known top of building heights. This is summarized as below as short, medium and tall buildings. The significance of emissions height was considered and hereby proven to be critical to the assessment of local air quality. Combustion of other fuels continued to be included as top-down data for area sources (see below).

Vehicle transportation volumes were estimated from City road use data collected over many years by Transportation Services. This data does not include adequate fleet composition identification data and was also collected over a

7 The data supplied by Enbridge came with the spatial resolution of FSA geography – where FSA refers to Forward Sorting Area, or the first group of letters and numbers of a Postal Code, eg M5H … is the FSA that included Toronto City Hall. TEO manipulated the data using GIS to represent other geographies such as the political Wards within the City.

long period of years – beginning as far back as 1987. However, wherever road traffic was clearly changing, frequent data updates were obtained, including sub-annual updates where warranted – as such the older data only represents traffic on roads for which there is no indication or reason to suspect change. Transportation emissions were calculated using Canadian standard Mobile 6.3C emissions factors as modified and embedded in Mobile 6C by Environment Canada (as included above).

The modelled vehicle volume data, based initially on the City of Toronto's Transportation Services data also includes trucks and was augmented (i.e., road count estimates were replaced with real use numbers re TTC buses, GO Transit Buses, and School Buses (both Boards) but excludes unavailable private Coach use volumes. GO Transit and VIA train emissions were also not available and estimates created by TEO based on train schedules and train use policies are still being developed for inclusion in 2007.

Area sources were as previously provided by Environment Canada for 1995 and 2000. Essentially, area sources include national guesstimates of many things apportioned by population and economic activity (among other factors) to Toronto. Where TEO has obtained or has developed more reliable bottom-up data (as with natural gas fuel combustion) TEO has employed special software (Air Tool as developed by TEO) to ensure no double counting occurs.

The data of the remaining "other area" sources that are modelled collectively includes (but is not limited to): industrial fugitive emissions (i.e., below threshold and not reported and published as part of the 367 point sources or smokestacks, or similar, industrial emissions in Toronto); residential and commercial fuel combustion, residential fuel wood combustion, incineration, emissions from crematoria and other similar utilities; emissions from agriculture and open land;[8] dry cleaning, fuel marketing, general solvent use, pesticides and fertilizer applications, printing, structural fires, surface coatings, meat cooking, and human emissions (including estimates of the total emissions from people smoking, sweating and breathing in Toronto!)

Data of the 2004 current NPRI reported source data was obtained from the NPRI website. The physical emission parameters including the location, height and diameter of smokestack vents were obtained from stereoscopic evaluation of City of Toronto aerial photography, and temperature and exit velocity data which was obtained from US EPA industrial modelling default factors as previously incorporated into the CALPUFF model. Large point source emitters representing between 92 and 97 percent of total emissions (the percentage varies by contaminant) were modelled as individual point sources (i.e., each "puff" of contaminant emitted was tracked in three-dimensions over time) and all

8 Particulate matter (i.e., dust) from open land was included under other area sources. Construction dust was completely omitted from the model operation. And road dust was moved from being an areas source (the standard model practice) to being a separate entity and is described as a transportation, or mobile, component.

remaining point source emissions were included as other area sources and modelled as collective "puffs" for each 1 km x1 km grid cell in the model.[9]

Table 4 •

Summary of Toronto's Annual Emissions as Used in the City's CALPUFF Based Air Quality Model (Tonnes/Year)[10]

Contaminant	Natural Gas Combustion			Mobiles	Areas	Points	Total
	Short	Medium	Tall				
CO	2,344	896	914	306,174	47,573	435	358,336
NOx	3,858	1,264	1,562	27,434	3,740	1,749	39,607
PM_{10}	304	98	123	7,432	10,848	470	19,275
$PM_{2.5}$	304	98	123	1,576	7,305	408	9,814
SO_2	24	7.7	9.7	117	8,531	304	8,993
VOC	220	71	89	25,003	562,053	1,273	588,709

Short = less than 10 metres, Medium = between 10 m and 24 metres, and Tall = greater than 24 metres

However, simply examining the volumes emitted does not indicate the reality of local air quality resultant concentrations as is discussed and indicated in outline further below. Conversely, the use of such inventories to evaluate greenhouse gas and climate change causal impacts is appropriate. Though the solution to both global climate change and local air quality issues can be seen to similarly lie with the same emitters and emissions – the relative significance of any improvement measure that reduces such emissions, and even though such improvement may well be of benefit to both climate change and air quality, the relative significance of such measures will commonly be seen to be different between climate change and air quality, and care should be taken not to falsely justify an improvement based on the assumption that improvements are equal or even significant for both.

9 The data shown in Table 4 as "point sources" reflects the emissions from the top 50 point source polluters and reflects a reality enforced by the size and speed of TEOs' current computer capability, which it is hoped to improve in 2007. New computer capability will permit for all 376 points in Toronto to be modelled as individual "puffs" but this is most unlikely to result in significant changes to any findings.

10 The inventory data shown in Table 4 is not identical to the data provided on the NPRI web site for Toronto. The included CACs are different and the source classification is different for obvious reasons, but the totals for Toronto ought logically to be the same, yet they are not. TEO undertook a very careful line by line analysis and determined that the data it chose to utilize was preferable. The equivalent NPRI "totals" data for the CACs included in Table 4 are, in tonnes per year, as follows: CO - 204,313 tonnes; NOx – 42,261 tonnes; PM_{10} – 47,688 tonnes; $PM_{2.5}$ – 12,276 tonnes; SO_2 – 5,011 tones; and VOC – 87,191 tonnes. The published NPRI data for CO, SO_2 and NOx is largely based on estimates of vehicle use and fuel use. TEO believes it has far superior actual bottom-up data and uses it. The industrial sources of CO, SO_2 and NOx are significant but not the significant part of the total. The NPRI data for PM_{10} and $PM_{2.5}$ is validly higher, but TEO removed the problematic construction dust data to a later assessment on the grounds that the evidence of road dust being a year round and city-wide problem is already overwhelming and that assessment of construction dust needs to be based on an accurate distribution more than on a accurate total. The NPRI data as to VOC is different than the top-down data also provide by Environment Canada and TEO uses the larger total that appropriately includes VOC emissions from residential and parkland areas. Further, and as noted by NPRI, their web provide emission estimate summaries contain considerable uncertainty and the "uncertainty is larger for small geographic areas i.e., postal code, urban centres and communities". (See also http://www.ec.gc.ca/pdb/querysite/location_query_e.cfm and see for the specified requested search area of "Postal Code M" (aka Toronto).

For example, new technology street sweepers can improve Toronto's local air quality, designing urban canyons to permit greater ventilation of vehicle exhaust gases can improve Toronto's local air quality, introducing community district energy systems with high elevation exhausts (to replace basement furnaces and ground level exhaust) can improve Toronto's local air quality – but none of these improves the global climate quality. Equally, improving (or avoiding) the combustion of fossil fuels in distant power stations can improve global climate quality, and improving the efficiency of methane capture from Toronto's distant landfill sites can improve global air quality – but neither of these significantly improves Toronto's local air quality.

However, improvements that lead to reduced total vehicle use and shorter trip lengths can improve both local air quality and global climate quality, and improvements that lead to reduced overall combustion emissions (e.g., district energy combined with electricity generation) can improve both local air quality and global climate quality. But the emphasis here is on the word "can". It should never be assumed that such improvements are automatic for both global climate and local air quality in every proposal.

The Air Quality Model "Process" (version - as operated in late 2006)

The following simple technical description provides an outline of the City's Air Quality modelling exercises using CALPUFF.

1. Air quality modelling was undertaken using CALPUFF and associated suite programs (CALMET, CALPOST, CALSUM etc.).
2. The model was/is largely operated in-house (with aid of consultant provided "modeller" personnel).
3. The previous model system was reconfigured to migrate "the model" from its "top-down" data approach (based on national data approximations and estimates) to using as much good "bottom-up" data (based on local/City data and real measurements) as is available.
4. The move to a "bottom up "approach is done to improve the relevance of, and confidence in, the model results obtained.
5. The latest model run is a "hybrid", since reliance has still to be placed on some "top-down" data for many "other" area source estimates, but it is intended to fully convert to an all "bottom-up" approach in the future. The major sources of local pollution as from natural gas combustion and vehicles are, however, already confidently represented by "bottom-up" data.
6. The selected meteorological base year was 2004. TEO has meteorological data for the period 1996-2000 plus 2004 and 2005. An additional prognostic data set (MM5) of upper air meteorology was not available for 2005. 2004 was the selected year for the latest model-run initiation and operation configuration as it matched the year of the major emission data being used.

7. Four source types were "modelled"
   a. Points (i.e., smokestack) sources from 2004 NPRI of locally reported data
   b. Line (i.e., mobile) sources from accumulated City traffic count data, 1997-2005
   c. Area (i.e., land use related) sources included:
      i. Data from old "top-down" Environment Canada data "apportionments" for Toronto, but also improved where possible and omitted where improvement more difficult and still required (e.g., construction dust omitted as a source of PM_{10} – subsequent inclusion will obviously raise the significance of findings re: PM_{10} even further);
      ii. Natural gas consumption data by postal geography; and by residential, commercial, industrial categorization; and by building height and volume assessment. This effectively allows examination and analysis of natural gas combustion emission impacts for low level;
   d. Trans-boundary (i.e., non-Toronto originated) from satellite data of air chemistry to depict general trans-boundary, not smog event trans-boundary. This is to be improved upon as part of trans-boundary assessment work in 2007.
8. Further improvement was obtained by operating the Air Quality Model as a set-of-runs. This to control and better distinguish the contribution of each different source to the total resultant concentration individually. As such, very high confidence can be attached readily to the appropriate findings, and reservations and subsequent needed improvements can be attached more easily and appropriately to others.
9. Temporal factors were applied (e.g., diurnal and seasonal patterns re: traffic volume; natural gas consumption; etc.).
10. Emissions and resultant concentrations from the community of the City of Toronto were modelled but emissions and resultant concentrations from the corporation of the City of Toronto were not modelled separately.[11]
11. Modelling computations were three dimensional to a height of 3,500m. But analysis and findings, as provided below, are based on evaluations of ground level concentrations only (i.e., the air people breathe).
12. Analysis of results is discussed in respect to ground-level receptor concentrations compared to standard provincial Ambient Air Quality Criteria (AAQC) or Canada Wide Standard (CWS) values for maximum experienced 1-hour, 8-hour, or 24-hour concentrations (as parameter appropriate) plus Annual and 98th percentile concentrations.
13. The set of model runs produced more than 160 resultant concentration maps and an even greater number of spreadsheet-sets – for seven Criteria Air Contaminants (SO_2, NOx, CO, PM_{10}, $PM_{2.5}$, VOC, O_3); with five averaging time periods (1-hour, 8-hours, 24-hours, Annual and the 98th Percentile);

11 Corporate City of Toronto Emissions were not modeled separately - in part because the specific location and timing of all corporate emissions were unknown (e.g., corporate vehicular emissions), in part because landfill related emissions occur outside of the modeled domain (as at Keele Valley and in Michigan), and in part because the corporate emissions are very much smaller than, and effectively swamped by the emissions and "resultant concentrations" of the community as a whole. Corporate emissions were effectively included as community emissions but specific bottom-up data was not utilized.

from nine "sources" (Points, Mobiles, Natural Gas from Low, Medium, High and "All Gas" Exhaust Height Locations; Other Areas; Trans-boundary; and Total (All) Sources. The contributions of other source distinctions (e.g., auto passenger vehicles, trucks, trains were modeled collectively, but relative sector contributions are distinguished as originating emissions.

The Air Quality Model "Output"

The output is in the form of tabulated data of predicted "resultant concentrations" which can also be mapped to facilitate the analysis of established Criteria Air Contaminants (CACs). Maps can be produced to show predicted ambient air quality for each and every individual hour of 2004 at computer generated receptors across the City. When the model is run with multi-years of meteorological data, these can also be averaged to show average conditions.[12] However, assessment of general air quality is better accomplished by both averaging the hours over all of the year(s) to determine a generality and by examining the combined worst case (i.e., highest concentrations) of each CAC.

How and Who Does What AQ Modeling?

The first configuration and operation of Toronto's Air Quality Model was undertaken by external consultants (i.e., RWDI) in 2000-2001. That configuration was installed within the Toronto Environment Office (TEO) and was intended to be operated by TEO staff. Subsequently, it was determined necessary to further improve the model, and again this was undertaken with help from external consultants (Earth Tech in 2002-2003); and Golder Associates in 2004-2006). The latest configurations and improvements of the model have been undertaken by a combination of external consultant and internal City staff endeavours.

General Findings

The following major points have been concluded from an analysis of the model output, an analysis of the inherent operational working of the model and from theoretical and analytical understanding of the significance of the prevailing processes and the results obtained.

- Air Quality "issues" relate to certain primary CAC contaminants – not to all of them.
- In Toronto NOx and PM_{10} are problems – $PM_{2.5}$ less so, but SO_2 and CO are not.
- Emissions from local sources are more significant than emissions from trans-boundary sources except on "smog days" when the reverse is true.

12 It is hoped in future to operate the model with a five year meteorological data set but this is currently a hardware limited option.

- Historically "targeted" sources, such as tall industrial smokestacks, are not the City's most problematic sources.
- We should now recognize that "many small sources" are more significant than "fewer large sources" in Toronto.
  - The significant "many small sources" are vehicles and residential natural gas furnaces.
  - The "fewer big sources" (e.g., commercial and industrial natural gas combustion) are less significant.

- Trans-boundary sources pollute our air-shed (where our "air-shed" is a 3-dimensional entity between the ground and the tropopause at a seasonally varying height of 12 to 16 km) – but for all non-smog days in Toronto, trans-boundary sources essentially only pollute the air above our heads – not the air we breathe.

- Smog is caused by weather, but is characterized by pollutant concentrations (on the first-past-the-post principle).

- We cannot change the weather (global warming impacts not withstanding) but the number of smog events and pollutant concentrations that vary from year to year better reflect weather pattern changes rather than source emission changes.

- Air toxics are not addressed here at this time.

- Local contributions to summer smog (i.e., local smog exacerbating emissions) are mostly from vehicles.
  - Impacts of vehicles operating on highways (401, DVP etc) are clear.
  - Impacts of vehicle use in core downtown areas are clear.
  - Impacts of vehicles operating on major arterial are less clearly recognized from results but equally clear if interpreted with theory (i.e., model scale resolution limits clarity – but no other explanation is logical).

- Model results plus established theory indicates downtown urban canyon streets are problem receptor areas at street level (i.e., pollution cannot readily escape confinement of buildings structures – different approaches needed in developing avenues) during the summer in respect to 1-hour and 24-hour exceedances of NO_2 AAQC thresholds (from vehicle emissions).

- Local contributions to winter smog and winter smog-like events (i.e. 1-hour or 24-hour AAQC exceedances) relate to NO_2 from combustion of Natural Gas for heating (as in residential basement furnaces, commercial boilers and non-smoke stack related industrial sources).

- High downtown buildings (commercial and residential) do not typically create ground level pollution (usually NO_2 is the concern – as from combustion of natural gas being exhausted at top of such buildings) other than during smog-events. However, during winter smog and near-smog conditions, exhaust from high buildings is significant in downtown core areas as a function of the high volumes of natural gas normally being combusted.

- Model results plus established theory indicates downtown urban canyon streets are problem receptor areas at street level (i.e., pollution cannot readily escape confinement of buildings structures – different approaches needed in developing avenues) during winter episodes in respect to 1-hour and 24-hour exceedances of NO_2 AAQC thresholds (from building emissions).

A most compelling conclusion is that “doing the met” (i.e. understanding the meteorology) tells us more about locally significant “resultant concentration” issues than assessing the initial, and causative, emissions. Air moves and dilutes and/or concentrates those emissions, or in modelling terms, “three-dimensionally diffuses and disperses” those emissions. As such the resulting concentrations, or what people actually have to breathe, are more important than the amount of a pollutant source that originates from a tailpipe or furnace flue. However, by knowing the amounts and details of the emission sources, air quality modeling can also trace back and identify the cause-and-effect chains behind adverse concentrations, and suggest the best improvement actions required to address the issues.

“Doing the met” tells us that most trans-boundary pollution passes over our heads most of the time – actual smog events being the obvious exception when the meteorology (high pressure and atmospheric stability) pushes the pollution down to the “breathing zone”. “Doing the met” tells us that urban canyons trap particulate pollution most of the time, as when prevailing wind flows are less than 8 km per hour and do not penetrate, or flush out, the pollution between the buildings. “Doing the met” tells us that there will be times when point source smokestacks will fumigate local neighbourhoods. “Doing the met” tells us that odour complaints at a location most frequently relate to specific upwind source releases.

Smog and the occurrence of smog (number and dates of Smog Days) are a function of meteorology (i.e., the weather). Equally, Heat Days are also a function of weather. Climate influences weather, and climate change influences weather changes and air quality changes. A year with a greater number of smog days than is typical may well be followed by a year with fewer smog days. This does not show that the emissions are being reduced (though this may be the case) or that the air quality is meaningfully improved. It does show the need to look at air quality as a trend within a changing set of weather patterns. Examining general conditions from day-to-day changes is perilous from a scientific significance perspective. But examining or predicting maximum likely concentrations and exceedances and setting standards (i.e., the “criteria” in CACs) as well as establishing a cumulative health based index, which can also beneficially be predicted using the AQ Model, appears to be an obvious way forward.

Specific Findings

The two most significant issues are with resultant year round and city-wide concentrations of NOx and PM_{10} (and to a lesser extent $PM_{2.5}$) and with episodic shorter averaging period event concentrations (mostly accompanying smog events, but not exclusively).

The two most significant sources are natural gas burning furnaces and vehicle tailpipes (but vehicles tires, their abrasion of road surfaces, and re-entrainment of road dust are also a major source of PM_{10}).

Oxides of Nitrogen (NOx) as NO_2 (Nitrogen Dioxide)

- High Confidence in Results
- Significant Concentration Issues in Toronto
- Significant Causes: a) Mobiles / Vehicles, &
  b) Natural Gas Burning Furnaces

Vehicles are a year round issue and high concentrations are notably more pronounced adjacent to 400 series highways and equivalent and in the downtown core area where there are many arterial roads within a confined space, but concentrations in proximity to other arterials are theoretically no less significant (but require finer resolution modelling to confirm).

Natural Gas combustion in furnaces is a winter month issue and "fills" the spaces between the highways. Natural Gas is combusted in all land use types (residential, commercial and industrial) but the very high number of low level (i.e. low height) exhausts as from small residential home furnaces, collectively creates a significant problem. Episodic concentrations resulting from high level (downtown office and residential core type area) sources also significantly "fumigate" downtown streets.

Particulate Matter Less Than 10 Microns Diameter (PM_{10})

- High Confidence in Results
- Significant Concentration Issues (even when excluding Construction Dust)
- Significant Causes: a) Fugitive Road Dust
  b) Construction Dust (discussed but not modelled)
  c) Tailpipe Emissions

PM_{10} includes $PM_{2.5}$. The coarser fraction of particles ($<PM_{10}>PM_{2.5}$) is a more local issue whereas $PM_{2.5}$ is much more of a regional issue. The major source of coarser fraction particles is Fugitive Road Dust and Construction Dust.
The major source of finer fraction particles is combustion as in furnaces and vehicles (see below).

Fugitive Road Dust (from wear down of tires, asphalt and brake linings plus tailpipe emissions) is a major casual factor in the City's PM_{10} concentration exceedances.

Emissions from Mobile Sources alone (Fugitive Road Dust plus Vehicle Tailpipe emissions $<PM_{2.5}$) generate sufficient emissions to create concentrations that exceed AAQC values.

Construction Dust has been excluded from the latest model runs (due to dubious values of available data) pending resolution of apportionment issues (in progress). But when included it will add significantly to the resultant PM_{10} concentration issues, especially in West, North and East Districts. [TEO has obtained and is about to utilize Toronto's annual development footprint data, and other related data, across Toronto, as an alternate spatial apportionment factor to Environment Canada's employment based factor to indicate where construction dust originates. Estimating the amounts of construction dust to be included and apportioned is more problematic but also underway. Rationalization of all such source components and the relative apportionment due to each will be forthcoming.]

Particulate Matter Less Than 2.5 Microns Diameter ($PM_{2.5}$)

- High Confidence in Results
- Both Direct & Indirect Sources Included as Total
- Significant Concentration Issues in Toronto
- Significant Causes: a) Mobiles (esp. Vehicle Tailpipes),
  b) Natural Gas Burning Furnaces, &
  c) Trans-boundary Inputs

$PM_{2.5}$ is a more significant health issue than PM_{10}. $PM_{2.5}$ is also much more of a regional issue than PM_{10}. $PM_{2.5}$ rises higher and travels horizontally much further than PM_{10}. As such $PM_{2.5}$ is much more impacted and is an issue at those times when trans-boundary inputs are significant – as during smog episodes.

During smog events, and at all other times of the year, $PM_{2.5}$ production from tailpipes and from stationary combustion furnaces is significant and contributes significantly to the PM_{10} situation.

When all sources are totalled together, $PM_{2.5}$ displays exceedance issues only when smog episodes or high pressure type stability meteorological conditions prevail.

Carbon Monoxide (CO)

- High Confidence in Results
- Not a Significant Issue In Toronto

No further comment necessary.

Oxides of Sulphur (SOx) as SO_2 (Sulphur Dioxide)

- Low Confidence in Results
- Model Shows Isolated but Significant Concentrations in Toronto
- Analysis Suggests Input Reapportionment Likely to Change Conclusions

SO_2 concentration exceedances are an apparent issue in some parts of the City over the shorter averaging periods. The causes of the issue are thought to be lawnmowers in residential areas and motor boating (inboard and outboard motors) along the waterfront.

Further research and analysis is required to improve understanding and confidence in results.

Volatile Organic Compounds (VOCs)

- Low Confidence in Results
- Major Source (90+ percent) is Natural Vegetation (Biogenic)
- But apparent concentration issue over downtown core appears contradictory

Clearly, there is a problem with the "top-down" apportionment of area data. The subject requires further investigation of Environment Canada relevant apportionment factors.

Ozone (O_3)

- Medium Confidence in Results
- Significant Concentration Issues in Toronto
- Significant Causes: a) Mobiles (esp. Vehicle Tailpipes),
  b) Natural Gas Burning Furnaces,
  c) Biogenic Inputs, and
  d) Trans-boundary Inputs

A "river of O_3" passes overhead every day of the year. The MOE's CN Tower O_3 monitoring data consistently indicates much higher concentrations than their ground level stations. Theoretically, if similar stations could be located at still greater heights – even higher concentrations would be monitored. Such concentrations result from sunshine acting on the ozone precursors that travel to Ontario from trans-boundary sources.

The local contribution of smog precursors (NOx, VOCs etc.) from local vehicles and even furnaces (as during winter smog events) appears as a significant source of additional ozone, and hence smog events.

When the "river of overhead trans-boundary ozone" is pushed down to the ground, as during certain meteorological conditions, or smog events, then ozone becomes an obvious issue.

Smog is caused by weather but it is typically characterized by the presence of O_3 or $PM_{2.5}$.

Ozone was modeled using CALPUUF output of CACs and these were then in turn modelled with a proprietary macro add-on, as by external consultants, to suggest the resultant ozone concentration distribution.

Smog (O_3 plus $PM_{2.5}$)

- Low Confidence in Results
- Significant Concentration Issues in Toronto
- Significant Causes: Weather
- Significant Inputs: a) All Local Emissions
  b) All Trans-boundary Inputs

Low confidence in the results relates to present estimates of the trans-boundary contribution rather than to the local contribution, but also to the model's chemistry handling capability.

CALPUFF is not typically used to model smog chemistry. An adjunct chemical model, CALGRID, from the CALPUFF suite of models, was evaluated but found to be too cumbersome and experimental for immediate use. It so hoped that is will change in the near future. In the meantime, and for the future, using CHRONOS and, or AURAMS data (from Environment Canada) and modeling it with the aforementioned proprietary macro should provide the needed level of confidence in trans-boundary inputs in future runs.

Obviously, and especially in years with high numbers of smog days, smog is a significant issue in Toronto. As has been described above, weather is the cause of smog but it is typically characterized by notably high concentrations of O_3 and $PM_{2.5}$.

Significant Inputs: a) All Local Emissions
b) All Trans-boundary Inputs

Recommended Future Technical Work

Future technical work relating to data collection and information creation (through modelling) is advised to improve the confidence in conclusions already reached and to facilitate conclusions and actions being formulated in respect to aspects not fully addressed as yet.

- Trans-boundary Data
- Construction Dust (apportionment factor resolution)
- VOC (apportionment factor resolution)
- Expanded Meteorological Time Domain

- Smog Event Modelling
- Expanded "Bottom-Up" Local Area Source Data Inputs
- Urban Canyon Modelling
- Transportation Data
- Monitoring and Model Verification

Trans-boundary Data Improvements

The trans-boundary data as used in the latest model runs were derived from remote sensing (by satellite) of average monthly CAC concentrations within the modeled meteorological domain – effectively this meant adjacent low elevation trans-boundary inputs could be incorporated. (The meteorological domain of CALMET encompasses a considerably larger geography than the CALPUFF domain.) These calculated general trans-boundary "inputs" were considered adequate to depict the contribution of trans-boundary inputs for general air quality but should be recognized as inadequate to depict smog day events concentrations.

Chemistry model based trans-boundary data should be used as input to the City's CALPUFF based AQ Model. Environment Canada is willing to provide the City with continental trans-boundary estimates (as modeled under CHRONOS) but the City must provide the technical staff required to "download" the information at Environment Canada's offices. The City has not had sufficient resources to undertake this necessary improvement as yet.

Improved understanding of trans-boundary sources will help to improve "technical findings" and subsequent improvement actions in respect to smog events in Toronto.

Construction Dust

Resolution of how important the Construction Dust source of PM_{10} is in Toronto requires an internal study of development location and intensity as it effects the amount of soil exposure and construction dust creation and its distributive apportionment based on the geography of development applications and assessment of the amount of affected land impacted. (This is underway with help from City Planning Division staff.) The final result will be to develop more appropriate bottom-up "apportionment factors" to replace the "top-down" Environment Canada provided estimates.

This will permit the inclusion of the Construction Dust portion of local sources of PM_{10}. Improved understanding of Construction Dust sources of PM_{10} will also be used to "close the gap" between modeled estimates and monitored estimates of PM_{10} found in Toronto's streets and neighbourhoods. Currently, modelled estimates are lower than monitored estimates of PM_{10} in the City due to the deliberate exclusion of Construction Dust.

Volatile Organic Compounds (VOCs)

VOCs are released very largely (approximately, at least 90 percent)[13] from biogenic area sources (parks and gardens etc) and the present findings that show high concentrations around non-biogenic source areas, need to be re-examined.[14] This will require checking apportionment factors as embedded in the computer code and checking with Environment Canada as to their recommended resolution. CALPUFF modeled VOC output is also used as input to chemistry modules to depict ozone and smog.

Improvement will permit for greater confidence in reporting VOC issues and will permit its more confident use in estimating ozone concentrations across the City.[15]

Expanded Meteorological Record

To date, CALMET has been used to meteorologically model one year of data at a time (due to the limitations of available computer hardware). The current model application operates with 2004 meteorological data. TEO has meteorological data for the years 1996-2000 plus 2004 and 2005. Expanding the modelled time domain to include the last five (or ideally 10) years of data will allow greater confidence in predicting "general" conditions. This is anticipated to occur in 2007.

Smog Event Modelling

Using a longer meteorological record (see above) will also permit a more detailed examination of a greater number of previous smog events to better allow generalized findings about the sources of pollution that typically characterize smog events in Toronto.

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13 Elsewhere, Environment Canada's "Canada–wide" estimates suggests 42 percent of VOC emissions come from the transportation sector and 28 percent comes from solvents in consumer and commercial products. Utilizing that 42:28 ratio suggests that Toronto's solvent contribution is less than 3 percent and that biogenic emissions are 97 percent of the area emissions, or 93 percent of total VOC emissions – but given the present reliance on approximations, it is considered safer, as here, to only suggest that biogenic emissions are at least 90 percent of total VOC emissions.

14 The VOCs from trees (mostly isoprene and monoterpenes) can also come from artificial sources, but more importantly, both naturally sourced and industrially sourced VOCs can contribute to ozone formation. However, this does not in any way imply that tree removal would be beneficial. In fact it can be readily argued that the opposite is true. The chemistry of ozone formation involves nitrogen oxides (mostly artificially created) and VOCs (mostly but not exclusively naturally created) being present in the atmosphere and being subjected to incoming short-wave radiation (i.e., insolation or sunshine) such that ozone is formed. It is argued that without the presence of artificially emitted NOx, any naturally emitted VOCs would not be able to participate in the formation of ozone. Further, and although counter-intuitive, it can be reasonably argued that if more trees were present to emit even more VOCs that the amount of ozone would be reduced rather than be increased. Not only does the NOx come from anthropogenic sources, but when NOx levels are low (as with reduced anthropogenic NOx release), VOCs in a low NOx environment act to reduce ozone concentrations, and it is now considered possible (pending further study) that further releases of biogenic VOC in the present high NOx environment are "likely" to decrease ozone as well. Ozone improvement is, therefore, also more likely to come from changes in anthropogenic NOx which are likely to be much larger than changes in response to changes in VOCs. Looking at this from a purely inventory based perspective, suggests tree removal as a potential solution. But such tree removal can be shown to lead to increased ozone production. From an air quality perspective, as defined here, ozone concentrations are the important issue – not VOC emissions!

15 The distribution of any specific toxic VOCs has not been modelled as part of the present air quality exercise.

Smog event modeling will be a combined meteorological and source of contamination exercise. It will lead to a better recognition of the nature and significance of both trans-boundary and local source inputs during smog episodes, and will subsequently help to identify local actions that may be effective in reducing the local severity of smog.

Expanded "Bottom-Up" Local Area Source Data Inputs

Having seen the great value added by adopting a bottom-up approach based on local data replacing top-down national estimates in respect to natural gas combustion especially. A study that evaluates employing other local data sources and/or local data to better help with estimating other area sources is viewed as potentially beneficial.

The greater the use of local data to generate findings, the greater the likelihood of improved relevance and accuracy in the findings.

Urban Canyon Modelling

The City's data and CALPUFF have previously been used in a pilot study (based around Bay Street) to investigate the ability of a modified CALPUFF to address urban canyon pollution entrapment variation with local wind direction and wind speed. The pilot was successful and the model can be confidently expanded to examine downtown, and other core area, urban canyon air quality issues. This should also be linked with more detailed data as to street specific traffic controls, traffic flow and traffic characteristics data. This has also been successfully modeled in a pilot study. Bringing both models together will be a new and worthwhile endeavour.

Findings from the work can be used to inform future issue limitation or avoidance policies (e.g., future "avenues" of intensification developments) and future mitigation measures (e.g., improved street sweeper operational practices). The modelled inclusion of improved traffic flow regime data also provide opportunity to develop air quality aiding flow pattern changes where appropriate.

Transportation Data

City Data Improvements: Given the very apparent significance of vehicle emissions, improved fleet composition data and/or estimation techniques are needed as AQ model inputs. Vehicle numbers are known for all roads and times but the compositional breakdown of different vehicle types (each with different fuel efficiencies and emission profiles) is needed.

Discussions with appropriate City staff in order to facilitate the collection of such meaningful data or developing best estimation techniques are proposed.

Regional and Behavioural Transportation Data Improvements: Participate in University of Toronto led study (with Transport Canada support) to assess regional transportation patterns and the decision-making behaviours that control them and might be influenced to improve them from an air quality perspective.

Monitoring & Model Verification

AQ Model results can be calibrated against point station data as from MOE AQ stations (as is routinely done as part of the City's modelling) but further monitoring and verification is advisable especially where "hot spots" may be identified, to confirm their presence and significance. The City can undertake local monitoring on a mobile basis. The work is pending future approvals.

Such monitoring could also be linked to a network of City supported local AQ stations and readings distributed in real time on a City web-site. This concept needs further investigation.

Conclusions

The two most significant air quality concentration issues are with resultant year round and city-wide concentrations of NOx and PM_{10} (and to a lesser extent $PM_{2.5}$) and with episodic shorter averaging period event concentrations (mostly accompanying smog events, but not exclusively).

The two most significant combustion sources are natural gas burning furnaces and vehicle tailpipes. Both of these produce NOx and $PM_{2.5}$. Vehicles also produce PM_{10} (as from vehicles tires, their abrasion of road surfaces, and re-entrainment of road dust) and the other major source (subject to further confirmation) is construction.

As such the obvious "solutions" to the most pressing air quality issues in Toronto rests with reduced numbers of vehicle kilometres travelled and ensuring sufficient street ventilation that NOx contaminants are not trapped in urban canyons; reducing construction related dust and sweeping the streets to remove PM_{10}; and encouraging the eventual replacement of individual residential and commercial unit heating furnaces (for both new developments and established neighbourhood installations) with district energy based solutions. Centralizing the burning of the same amount of natural gas in district boilers but emitting its NOx contaminants from a greater height will markedly improve local air quality!)

The great advantage that an air quality model provides the City is that such proposed solutions can, once detailed and specified, be entered into the air quality model and assessed for their effectiveness as air quality improvements.

Appendix C

City of Toronto Operations Top Ten Emissions Sources

Prepared by Philip Jessup, Executive Director, Toronto Atmospheric Fund

Table C-1 • Corporate eCO2 Emissions from All Sources—Top 10 Rankings

Corporate eCO_2 Emissions Sources	% of all sources	Tonnes eCO_2
Landfills (waste in place, except Thackeray)	42%	668,872
Toronto Community Housing Corporation	20%	315,781
Toronto Water (water pumping & treatment)	10%	159,315
Toronto Transit Commission	4%	71,007
Fleet vehicles (diesel & gasoline)	4%	63,859
Parks and Recreation	2%	58,119
Thackeray landfill	3%	52,678
Facilities and Real Estate	2%	35,994
Michigan Waste Transport	2%	35,438
Toronto Hydro (streetlighting only)	2%	29,203
TOTAL TOP 10 RANKINGS	**92%**	**1,490,267**

Table C-2 • Corporate eCO_2 Emissions from Energy Sources—Top 10 Rankings

Corporate eCO_2 Emissions Sources	% of all sources	Tonnes eCO_2
Toronto Community Housing Corporation	36%	315,781
Toronto Water (water pumping & treatment)	18%	159,315
Toronto Transit Commission	8%	71,007
Fleet vehicles (diesel & gasoline)	7%	63,859
Parks and Recreation	7%	58,119
Facilities and Real Estate	4%	35,994
Michigan Waste Transport	4%	35,438
Toronto Hydro (streetlighting only)	3%	29,203
Homes for the Aged	2%	14,753
Police Services	1%	12,949
TOTAL TOP 10 RANKINGS	**91%**	**796,418**

Table C-3 • Corporate NOx Emissions from Energy Sources—Top 10 Rankings

Corporate NOx Emissions Sources	% of all sources	Kg of NOx
Toronto Community Housing Corporation	22%	316,887
Michigan Waste Transport	19%	283,614
Toronto Water (water pumping and treatment)	15%	213,627
Fleets – Class 8 heavy diesel trucks	12%	170,578
Toronto Transit Commission	5%	74,518
Parks and Recreation	4%	65,398
Fleets – Gas light duty vehicles	4%	59,929
Facilities and Real Estate	3%	45,632
Toronto Hydro (streetlighting only)	3%	41,673
Fleets – Class 4 medium gas/diesel trucks	2%	25,328
TOTAL TOP 10 RANKINGS	**69%**	**1,013,570**

Table C-4 • Corporate TPM Emissions from Energy Sources—Top 10 Rankings

Corporate TPM Emissions Sources	% of all sources	Kg of TPM
Toronto Community Housing Corporation	31%	39,466
Toronto Water	29%	36,793
Toronto Transit Commission	8%	9,899
Parks and Recreation	8%	9,486
Toronto Hydro (streetllighting only)	6%	7,534
Facilities and Real Estate	6%	7,486
Michigan Waste Transport	5%	5,802
Fleets – Diesel trucks (all classes)	4%	5,417
Exhibition Place	2%	2,291
Homes for the Aged	2%	2,265
TOTAL TOP 10 RANKINGS	**89%**	**126,439**