Putting Transportation on Track in the GTHA

A survey of road and rail emissions comparisons

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Sustainable Prosperity

the Pembina Institute

Contents

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Sustainable Prosperity and Pembina share a commitment to local and regional sustainability, and responsible transportation options in the GTHA. For further research see, for example:

- Sustainable Prosperity's reports: Time to get serious: Reliable funding for GTHA Transit/Transportation Infrastructure (co-authored), and Smart Budget Toolkit: Environmental Pricing Reform for Municipalities http://www.sustainableprosperity.ca/Sustainable+Communities+EN+Reports
- Pembina's reports: *Bridging the Gulf,* and *Driving down Carbon* http://www.pembina.org/ontario.

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Executive Summary

There is a new openness to discussing the future of transportation in the Greater Toronto and Hamilton Area (GTHA). This openness is at least partly driven by a growing consensus that continual expansion of roads and motor vehicle traffic is not environmentally sustainable, socially desirable, or economically feasible.

The Ontario Government has created an ambitious program of building new rapid transit infrastructure and shifting car trips onto transit. This work will include expansion of passenger rail, as well as freight rail, in the region.

The discussion around this shift needs to be grounded in fact, rather than rhetoric. There are no studies that directly compare road and rail emissions in the GTHA. Fortunately, there are published studies from a number of locations that do provide head-to-head comparisons between road and rail emissions – for both passenger and freight transportation.

This report provides a survey of those comparison studies. While the studies differ in many ways, overall they paint a clear picture of emissions from road and rail.

Context

Climate change has been termed the defining challenge of our age, and will cause enormous economic losses if not addressed. And transportation is by far the largest source of the greenhouse gas (GHG) emissions in Ontario, as well as the fastest-growing.

Ground-level air pollution is also a serious problem. Although emissions of many criteria air contaminants (CACs) have declined in recent decades, smog still causes thousands of deaths every year in Ontario. Transportation is a significant source of that air pollution, with transportation-based emissions killing hundreds of people every year just in Toronto.

The great majority of transportation in the GTHA takes place on roads. About 80% of passenger trips or passenger-kilometres travelled take place in automobiles (somewhat less in Toronto). Likewise, 70%-90% of freight is moved by trucks. This heavy reliance on roads not only causes higher emissions but also suburban sprawl and its attendant costs (loss of farmland, obesity and other health impacts, and of course further motor-vehicle dependency).

Ontario has set ambitious targets for reducing transportation-based emissions, and the number of car trips taken in the province. The GTHA Regional Transportation Plan (The Big Move) also aims to shift personal and freight transportation from roads to rails.

GHG Emissions

Automobiles contribute the vast majority of Ontario's large and quickly-growing transportation-related GHG emissions. For freight, trucks contribute 12 times as much in GHG emissions as rail does, and for passengers the road-to-rail emissions ratio is even higher. Since 1990, rail-based emissions for both passenger and freight rail have actually declined, while road-based emissions have soared.

Part of the reason for this is the inefficiency of road transportation, which results in higher fuel consumption and thus higher GHG emissions. Studies from across a number of jurisdictions in Canada and beyond indicate that automobiles cause higher intensity of GHG emissions (the emissions per passenger-kilometre travelled, or pkm) than rail – about two to four times as much GHG emissions per pkm. Likewise, freight trucking causes higher levels of GHG emissions per tonne-km than rail – about five times as high.

CAC Emissions

The picture with CAC emissions is more complex, as there are several different CACs. However, in Ontario, transportation overall is a large source of smog-forming volatile organic compounds (VOCs) and nitrogen oxides (NO_x), and the source of 85% of poisonous carbon monoxide (CO). It also contributes about 20% of health-damaging particulate (PM) emissions.

Road transportation is responsible for the majority of those transportation-related CAC emissions in Ontario – about half of sulphur oxides (SO_x), about 70% of PM and NO_x, and over 98% of VOCs and CO. The proportions are similar in the Toronto-Detroit trade corridor.

Considering again the intensity of emissions, for the majority of CACs, automobiles are more polluting per pkm travelled than is rail. For SO_2 and NO_x, levels can be similar depending on fuel and other conditions, but for VOC, PM_{10} and CO, automobile emissions are significantly higher. For freight, the results are similar.

Importantly, regulations requiring emission control devices for fuel-combustion energy sources have resulted in significant CAC emission reductions over the last few decades. Since 1990, both diesel rail and trucking CAC emissions have declined significantly. For example the NO_x, HC and PM10 standards for diesel locomotives have become increasingly stringent, to the point where "Tier 2" engines being used today cause half the emissions of uncontrolled locomotives. Tier 4 engines (available in 2015) will produce a small fraction of emissions of Tier 2 emissions – comparable to those of electric locomotives powered by fairly clean electricity sources.

However, emissions reductions from improved regulatory requirements are undercut by growing numbers of vehicles, bolstering the case for moving passengers and freight to more efficient and less-polluting rail.

The literature is fairly consistent. While more data would always be useful, there is enough information to draw solid conclusions. In the GTHA, as elsewhere, rail transportation causes lower levels of emissions than does road transportation.

There is also enough information to begin to design and implement public policy changes that will shift some of the traffic from road to rail and reduce emissions.

1. Introduction

There is a new openness to discussing the future of transportation in the Greater Toronto and Hamilton Area (GTHA). This openness is at least partly driven by a growing consensus that continual expansion of roads and motor vehicle traffic is not environmentally sustainable, socially desirable, or economically feasible.

The Ontario Government has created an ambitious program of building new rapid transit infrastructure and increasing the number of trips taken by transit. This work will include expansion of passenger rail, as well as freight rail, in the region.

The exact shape of this expansion is yet to be determined, and that determination will rightly entail some public discussion. It is important to ensure that discussions around the shift toward greater rail-based transportation are grounded in fact, rather than rhetoric. One of the key elements of this discussion will be the emissions from rail, as compared to those from cars and trucks.

Transportation is responsible for much of the emissions of pollutants (often called criteria air contaminants - CACs) that cause smog and acid rain, along with its attendant economic and health costs. Likewise, the region's transportation system is a large contributor to greenhouse gas (GHG) emissions that cause climate change, and Ontario has made a commitment to significantly reduce GHG emissions – by 2020 to 15 per cent below 1990 levels, and by 2050 to 80 per cent below 1990 levels.[2]

If some of the road traffic is to be shifted onto rails, it will be useful to have a breakdown of where these GHG and CAC emissions are coming from - which parts of the transportation system contribute to them, and how much.

Fortunately, there are some studies that provide relevant information. A number of publications in recent years have shed light on emissions from road-based and rail-based transportation sources. This report surveys the relevant findings and provides links to the literature.

Scope and Methodology

This report is a survey of the findings of the literature on road-based and rail-based transportation emissions. There are no studies available that directly compare GHG and CAC emissions for rail and road transportation in the GTHA. Hence this report looks at the conclusions of studies from other jurisdictions, both near (Ontario, Toronto) and afar (the rest of Canada and elsewhere in the world), in order to help inform the discussion of emissions in the GTHA.

The various studies differ considerably in methodology, assumptions and other respects. They also differ in underlying data on emissions, which reflect differing regulatory emission standards and policy frameworks, not to mention transportation operating conditions. Thus simply making cross-comparisons of mode emissions numbers between studies could result in significant errors (e.g. comparing automobile emissions intensity from one study against passenger train emissions intensity from another study). This report therefore avoids such comparisons, instead focusing on head-to-head comparisons that are made within single studies.

While this report presents the results of studies, its scope did not extend to revisiting the underlying data sets used in each of the studies in order to verify or re-calculate their results, nor to systematic evaluation of the methodologies or validity of assumptions made across the various studies. An intensive study of that nature could, potentially, enable acceptable comparisons between some studies if the overall data set is rich enough to control for design differences and data differences among studies.

Interestingly, despite the differences among studies, consistent patterns in the results do emerge.

The first section of this report begins by providing context. It reviews overall transportation emissions, and the share of transportation services provided by the different parts of the system (mode share). It also outlines the Ontario and Big Move targets for emissions and mode share.

The next two sections consider GHG emissions and CAC emissions, primarily from passenger transportation, but also from freight transportation, in terms of both total emissions and emissions intensity.

- **Total emissions** by mode is an important measure, as it indicates the overall burden of emissions caused by road and rail modes, and the scale of the problem that needs to be addressed.
- **Emissions intensity** - emissions caused by travel of passengers or freight over a given distance - is a particularly important measure, as it informs the extent to which shifting modes will result in emissions increases or reductions.[3]

This report then summarizes the main conclusions regarding emissions.

2. Context: Emissions, Mode Share, Targets

This section provides context for the later sections on passenger and rail emissions. It explores overall transportation sector emissions, the mode share for road vehicles and rail, and emission and mode share targets.

Overall Transportation Emissions

Transportation emissions in Ontario – both CAC and GHG – are a serious problem.

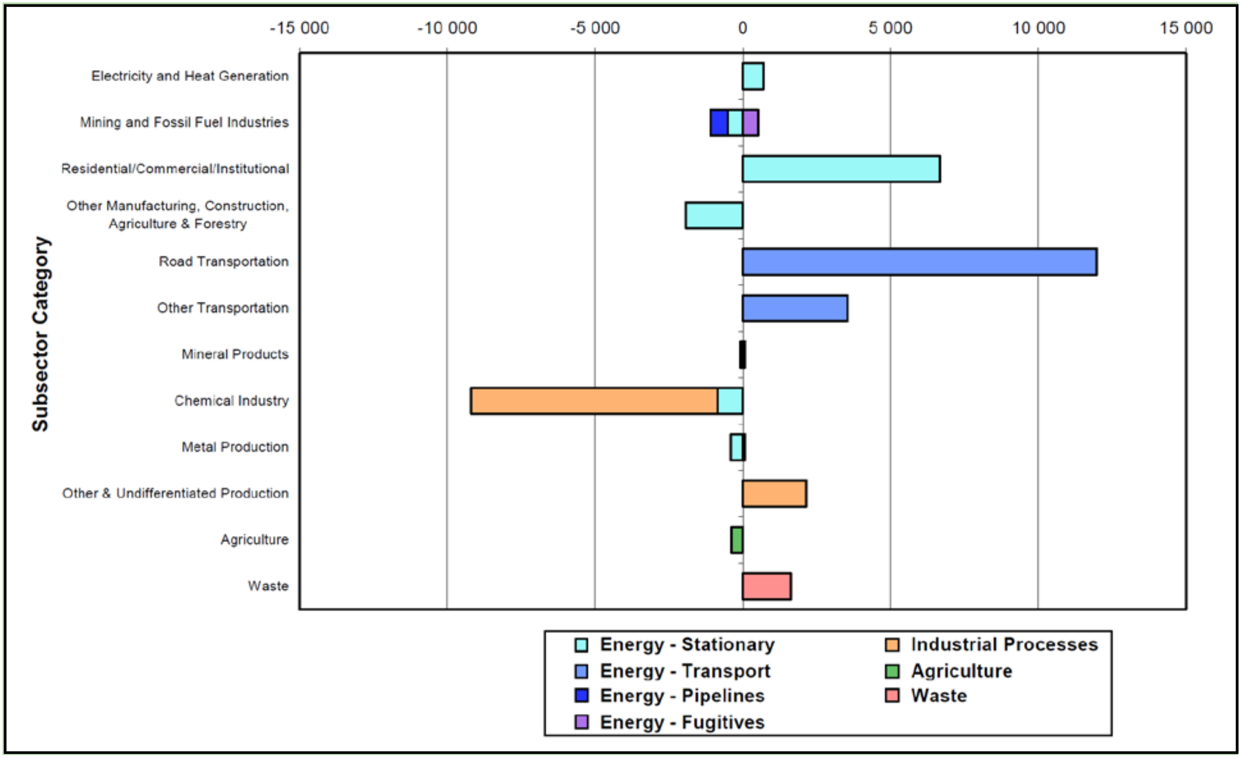
The economic costs of failure to act on climate change have been estimated at 20% of global GDP, although Nicholas Stern more recently noted that he had underestimated the threat.[4] Paul Volcker, former chair of the US Federal Reserve, said that if we don't address climate change, "the economy will go down the drain in the next 30 years."[5] Such economic projections may vastly underestimate the impacts, which range from mass extinctions[6] to global flooding and more.[7] Climate change has been termed the defining challenge of our age,[8] and "perhaps the biggest threat to confront the future of humanity today."[9]

Within Ontario, transportation is by far the largest source of GHG emissions. As noted by Environment Canada, emissions from transportation "made up the largest portion (32%) of the provincial emissions in 2008" – almost double the contribution from the second-largest source, the Residential/Commercial/Institutional Sector (17.3 %).[10]

Transportation also has been the fastest-growing sources of greenhouse gas (GHG) emissions in Ontario. Since 1990, emissions in this sector have increased by more than 30%, or 14,900 kt CO_2e. During the same period, emissions from the rest of the Ontario economy declined by 900 kt CO_2e.[11]

Kt CO2e: kilotonnes of CO_2 (carbon dioxide) equivalent - greenhouse gases that are equivalent in greenhouse effect to one kt of CO_2.

Figure 2.1 Ontario GHG Emissions Changes: 1990 to 2008 (kt CO_2e)



Source of data: Canada's National GHG Inventory[12]

At the same time, transportation contributes significantly to CAC emissions. Although the concentrations of many CACs have been declining over the last few decades,[13] the smog that results from CACs cause an enormous burden of illness and have been estimated to kill 9,500 people per year in Ontario,[14] far more than the number killed by all infectious diseases combined.[15] In Toronto alone, air pollution just from traffic has been estimated to kill 440 people and cost $2.2 billion per year.[16] Despite emission reductions over the decades, CACs clearly remain a serious problem.

The GHG and CAC transportation emissions come from combustion of fossil fuels. In the passenger sector, 99.98% of transportation energy used in Ontario comes from fossil fuel combustion – about 80% from gasoline, 16% from aviation fuels, 3.4% from diesel, and 1% from propane and natural gas. 0.02% of transportation energy in Ontario comes from electricity.[17] In the freight sector, fully 100% is fossil-fuelled, with 72% being diesel, 26% gasoline, and the remainder a mix of other fossil fuels.[18]

As will be seen below, automobile and truck traffic account for the large majority of overall transportation emissions. This is partly due to their relative inefficiency (compared to transit and rail freight transportation), and partly due to their high mode share.

Transportation Mode Shares

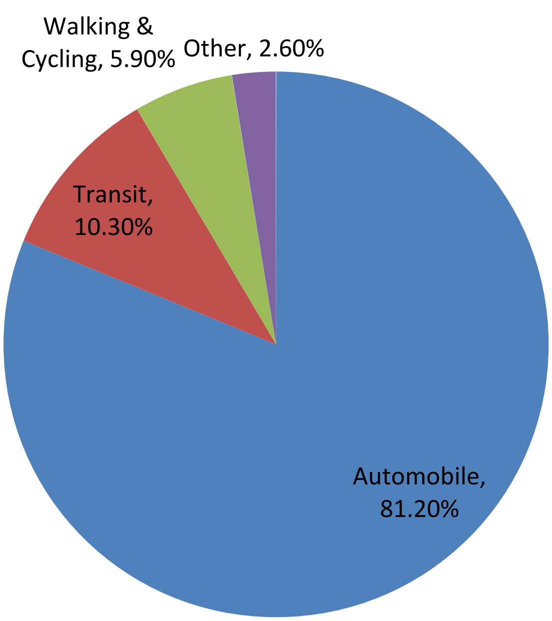
Transportation mode share is a significant factor in the levels of emissions from the transportation sector. See the Appendix for further information and sources.

Currently, the large majority of personal travel in the GTHA takes place in automobiles. Whether measured as the percentage of trips taken (sometimes termed mode share) or the distance travelled (passenger-kilometres travelled, or pkm), about 80% of trips are taken in automobiles (see Figure 2.2). Transit provides most of the remainder, followed by walking and cycling.

GTHA-wide figures mask significant variability across the region; in Toronto, automobiles account for about 75% of travel, and in suburbs and Hamilton up to 90%. In further distant centres and rural areas, automobiles account for 95% of travel.

Likewise, use of alternatives to the automobile also varies across the region. In Toronto, transit accounts for 23% of travel, while it only accounts for 5-7% in suburbs and Hamilton, and less in distant centres and rural areas.

Figure 2.2 GTHA-Averaged Passenger Mode Share



Source of data: DMG[19]

Like personal travel, freight movement is also dominated by road-based transportation. The majority of all freight in the GTHA – 70%-90% depending on location – is moved by truck, and the truck numbers are rising quickly. Truck volumes "have been increasing on the expressway network at a much faster rate than auto volumes."[20]

This extent of reliance on road-based transportation for both personal and freight transportation, along with inadequate rail-based alternatives, comes with a cost. In addition to higher emissions, it contributes to suburban sprawl and its attendant costs (loss of farmland, loss of productivity, obesity and other health impacts, and of course further motor-vehicle dependency).[21]

Transportation and Emission Targets

The Ontario government set the following targets under its Move Ontario 2020 plan:

- 6% GHG emissions reductions from freight and diesel;
- 13% GHG emissions reductions from passenger vehicle and transit; and
- 300 million fewer car trips per year.[22]

The Big Move, the Regional Transportation Plan (RTP) for the GTHA, is the mechanism for implementing Move Ontario 2020, and provides modeling forecasts for what the RTP can achieve by 2033:[23]

- 60% higher morning rush hour transit share;[24]
- the average daily distance travelled by car will be 27% lower;[25]
- annual GHG emissions from passenger transportation per person will be 21% lower;[26] and,
- average time spent commuting will be reduced by 29%.[27]

Achieving the transit mode shift will require a significant movement from automobile-based transportation to regional transit, including commuter rail.

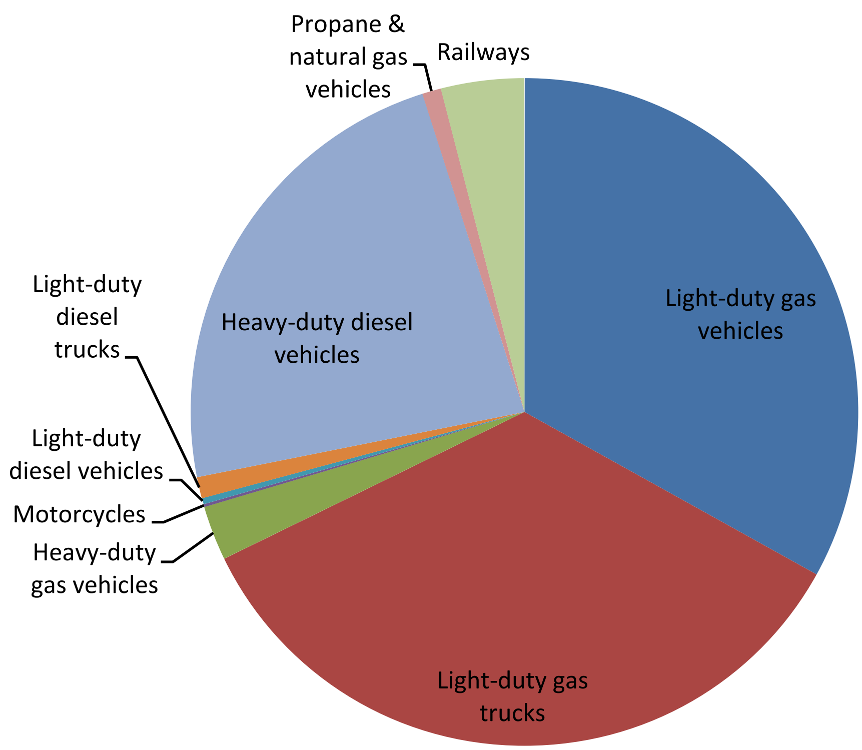
The Big Move also speaks to goods movement in the GTHA. Its prescriptions here are less specific, but still address the need to reduce GHG and other emissions from goods movement, and the need to map goods movements by mode and use the most environmentally sustainable modes.[28]

3. Greenhouse Gas Emissions

As noted above, transportation is the largest and fastest-growing source of GHG emissions in Ontario. Passenger transportation contributes the greater share of this total. According to Natural Resources Canada, Ontario passenger transportation in 2008 accounted for 62% of transportation-related emissions, compared to 34% for freight and 4% for off-road transportation.[29] Another study noted that the emissions fraction from passenger transportation in Toronto was somewhat higher, at 75%, compared to freight at 25%.[30] Total GHG emissions from personal transportation in the Greater Golden Horseshoe region are very substantial, at 16.0 million tonnes per year.[31]

Figure 3.1 shows the relative proportions of emissions from both passenger and freight modes. As can be seen, the proportion caused by railways are very small compared to road-based emissions: road vehicle emissions were approximately 25 times those from railways.[32]

Figure 3.1 – Relative proportions of Ontario road and rail GHG emissions



Source of data: Canada's National GHG Inventory[33]

Data from Natural Resources Canada breaks down the categories further, by function; see figures 3.2A and 3.2B. Freight truck emissions exceed those from freight rail by a factor of 12.[34] Emissions from cars and light trucks exceed those from passenger rail and transit by an even greater degree. Other modes (e.g. air, marine, off-road) are included here to give a further sense of proportion.

Figure 3.2A – Relative proportions of Ontario freight GHG emissions

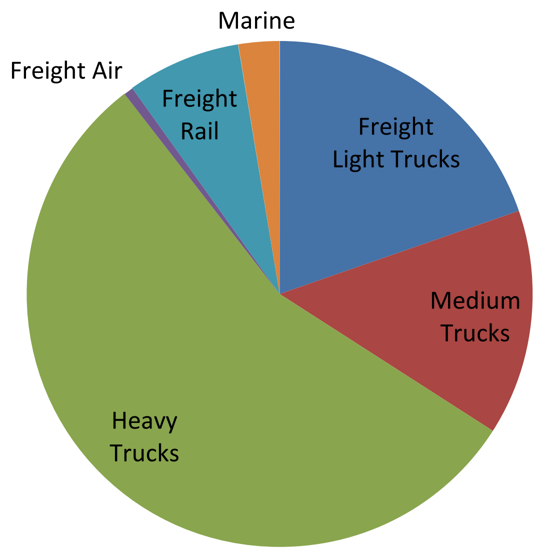
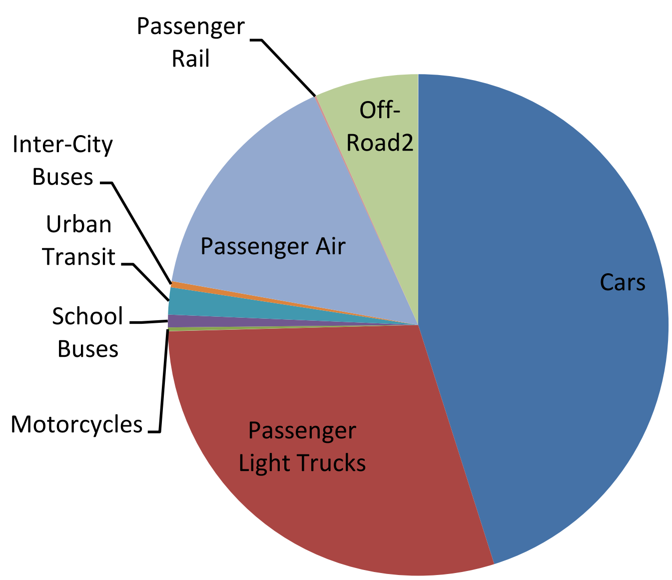


Figure 3.2B – Relative proportions of Ontario passenger GHG emissions



Source of data: Natural Resources Canada[35]

The increases in Ontario transportation GHGs since 1990 are split roughly equally between the passenger and freight sectors. The increase in the passenger sector has been driven largely by the shift toward energy intensive (and thus GHG-intensive) 'passenger light trucks' – pickup trucks and SUVs. Passenger car emissions over the same period actually declined, as light trucks increased in mode share. Indeed the increase in passenger light truck GHG emissions was over 140%, and accounts for almost half of the emissions increase across the entire transportation sector. Over the same period, GHG emissions from passenger rail declined.[36]

This trend also has its parallel in freight transportation. Freight transportation GHG emissions have increased considerably since 1990. Despite improvements in fuel efficiency, particularly for diesel rail, Canadian carbon emissions in this sector rose by 40% between 1990 and 2003 alone. About half of that increase was due to increased levels of freight activity, a primary cause of which was "increased trade with the US following the FTA and the concurrent emergence of 'just in time delivery.'"[37] The other half of the increase was due to a shift from rail toward trucking, which has higher emissions per tonne-kilometer. Emissions from heavy trucking in Canada are approximately seven times as high as those from rail.[38]

Indeed, Ontario freight rail emissions (diesel powers all rail freight in Ontario) declined slightly between 1990 and 2008, while trucking emissions grew dramatically – by 139%.[39] The number of heavy duty diesel vehicles (HDDVs) on Ontario's roads more than doubled between 1990 and 2008.[40]

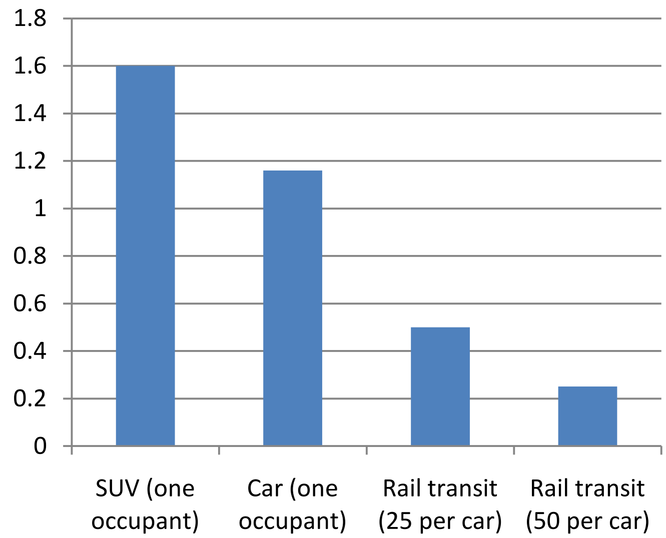
GHG Emissions Intensity

As noted earlier, emissions intensity is the level of emissions caused by a given distance of travel (per passenger, or per unit of freight). Several studies indicate the intensity of GHG emissions caused by rail transportation versus those of road transportation.

As noted earlier, these studies come from different jurisdictions, and vary somewhat. However, the results are generally fairly consistent. They show that automobile travel generally causes greater emissions per passenger-km than rail and other forms of transit. Likewise, freight truck movement causes greater emissions per tonne-km than does freight rail.

One source compared American GHG intensities for passenger travel modes, finding that cars and SUVs generally create twice or more the emissions of rail transit with average rail occupancy (see Figure 3.3).[41] Because a considerably higher proportion of American electricity is sourced from GHG-intensive coal-fired generation, rail emissions in the GTHA (including electricity-powered subway, streetcars, etc.) likely are comparatively lower than suggested in Figure 3.3.

Figure 3.3 US GHG emissions kg/pkm

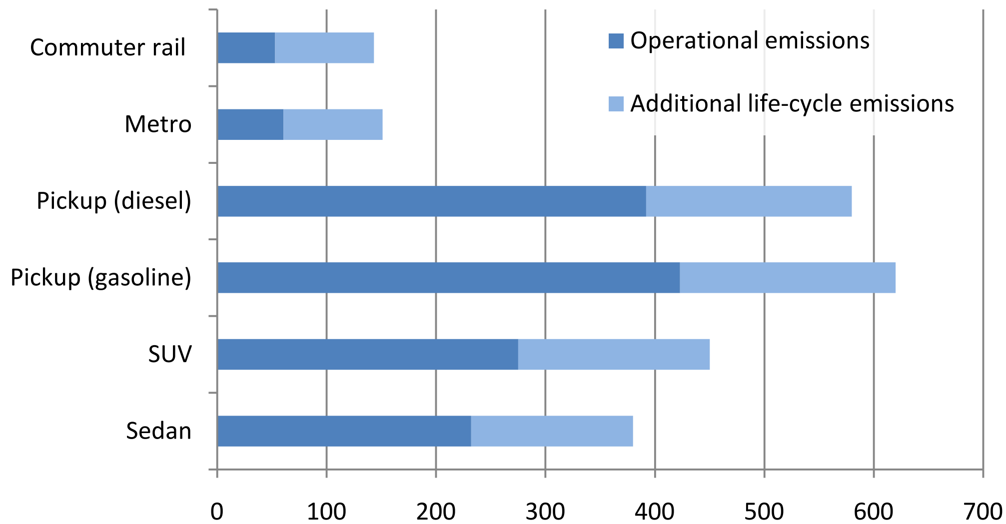


Source of data: Sightline Institute[42]

An international source presented results based on an emissions calculation protocol that uses data provided by the UK government, the US government and the IPCC.[43] The relative emissions intensities are consistent with the US figures; passenger automobile travel contributes double the levels of GHG emissions of rail travel, with light truck emissions being almost double again.[44]

In addition to operational emissions, it is important to consider the emissions caused in the manufacture of vehicles, the construction of infrastructure, etc. One US meta-study considered life-cycle GHG emissions intensities of several modes of transportation. Figure 3.4 presents the operational emissions, as well as the additional life-cycle emissions (emissions from manufacture, infrastructure requirements and fuel production). Rail had significantly lower emissions intensity than cars and trucks (the study considered electric and diesel rail systems in different areas in the US). A European study similarly reported automobile emissions intensities nearly three times as high as those of rail.[45]

Figure 3.4 US GHG emissions intensity (g CO_2e / PMT)



Source of data: M. Chester and A. Horvath[46]

Reported emissions in various studies would be expected to vary due to types of trip studied (inter-city, commuter, urban), GHG-intensity of energy sources (for electric trains and buses), and a number of other factors and assumptions. For example, an older Canadian modeling study conducted for the National Climate Change Strategy reported that inter-city rail transportation would be 12% more GHG-intensive than inter-city automobile, while inter-city bus would have less than a quarter the emissions of automobiles. This study, however, was based on the assumption of an occupancy of 2.1 to 2.2 passengers per automobile.[47] Occupancies in the GTHA are in fact closer to 1.2,[48] which would result in the same data indicating that automobiles are significantly more GHG-intensive than both bus and rail (thus illustrating the sensitivity of modelling results to assumptions and methods). A more recent Canadian publication using Natural Resources Canada data indicated that even small cars are about four times as GHG-intensive as commuter rail, which in turn is more energy-intensive than light rail or subway.[49]

The location of the transportation is also an important factor. Figures 3.5A and 3.5B illustrate that comparable forms of transportation emit more in the city than between cities (of course not all modes can be used in both settings). Nonetheless, even more pronounced is the difference between transit and automobile in either setting. Only a compact car with an occupancy of three – more than double the existing rates in the GTHA – would be comparable to per-passenger diesel train emissions. Note that emissions for electric train, subway and tram are based on Quebec's electricity generation, which produces extremely low levels of GHG emissions due to the predominance of hydro (Quebec burns no GHG-intensive coal, and only a third of the natural gas that Ontario burns.[50])

Figure 3.5A Quebec Intercity Passenger CO_2 Emissions (g / pkm)

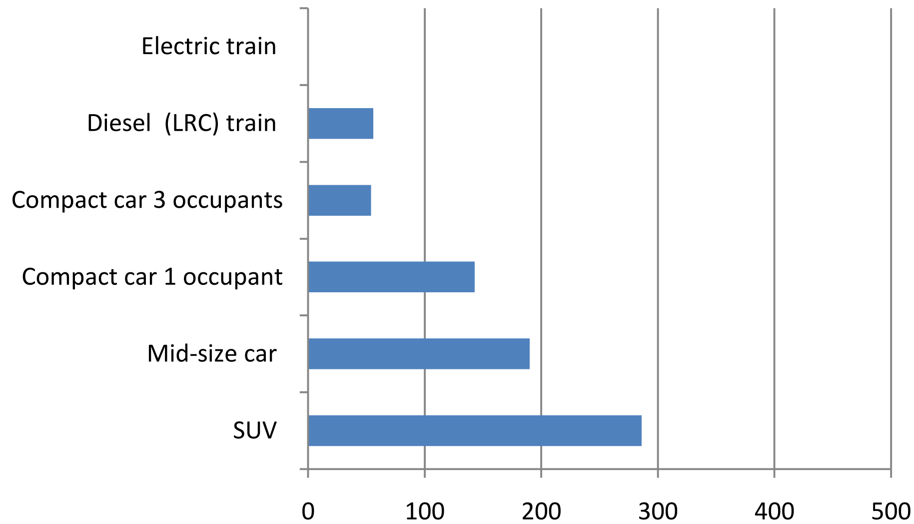
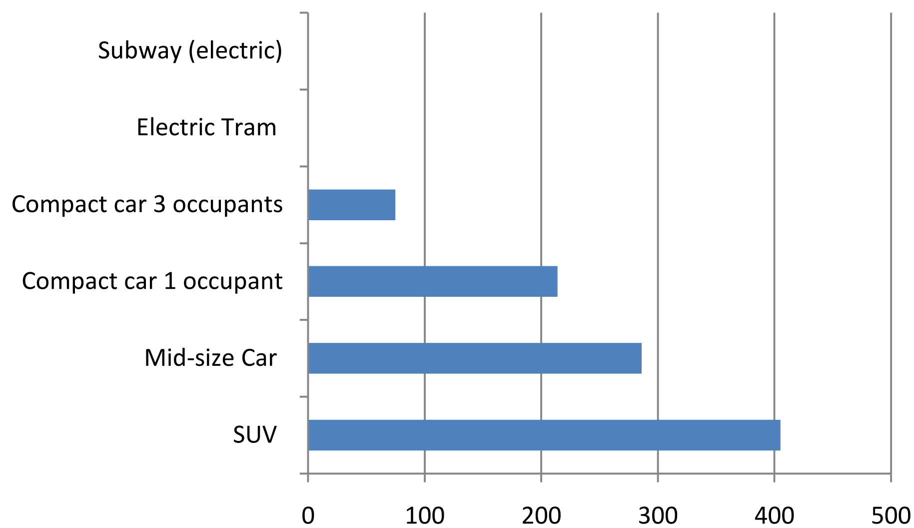


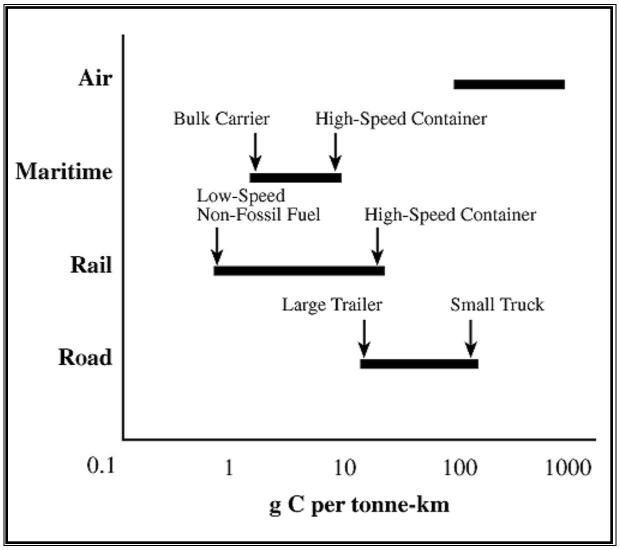
Figure 3.5B Quebec Urban Passenger CO_2 Emissions (g / pkm)



Source of data: L. Gagnon, "Greenhouse Gas Emissions from Transportation Options"[51]

As with passenger transportation, freight transportation GHG intensities vary considerably, depending on a number of factors. An IPCC report provides ranges of GHG-intensities world-wide for freight transport, taking into account various factors such as fuel source and vehicle configuration (figure 3.6). Note that the scale in 3.6 is logarithmic, not linear; the road freight emissions intensity range shown is roughly ten times higher than the range of rail freight.

Figure 3.6 Global freight GHG-intensity

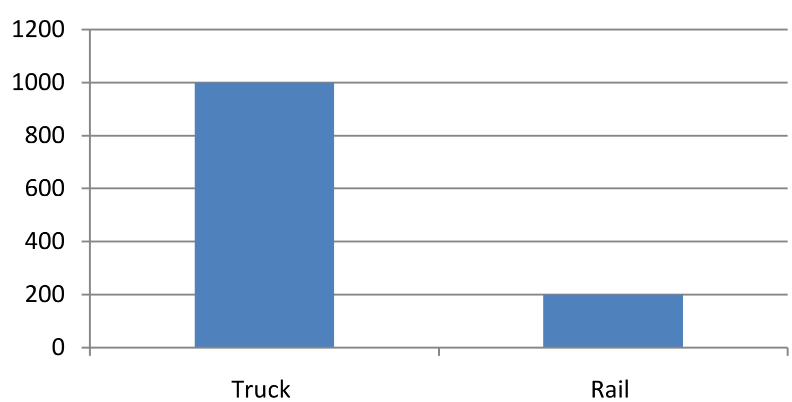


Source of figure: IPCC[52]

These global figures also hold in Ontario, where studies suggest the ratio of truck to rail freight GHG intensity is about five to one,[53] and in the Great Lakes Region (see Figure 3.7). Environment Canada figures suggest the ratio nationally is eight to one. [54]

This significant emissions advantage of freight rail over trucking is due to the fuel efficiency differences; GHG emissions are proportional to fuel consumption and rail is two to five times as fuel-efficient as trucking.[55]

Figure 3.7 Emissions (g/TEU-mile) in Great Lakes Region container shipping



Source of data: J. Winebrake, "Intermodal Freight Transport in the Great Lakes"[56]

> *"[M]oving freight by truck is one of the most emission-intensive ways of moving freight."*
>
> \- Environment Canada [57]

Conclusions - GHGs

As expected, the data on GHG emissions varies between studies. Several factors can make a significant difference in GHG emissions, including the location and type of transportation, the characteristics of the vehicle, occupancy / load, and the source of the energy.

On this latter point, as Ontario moves away from GHG-intensive coal combustion for electricity generation, rail transportation that relies on electricity (subways, streetcars, LRT and inter-city or freight rail if electrified) will become even less GHG-intensive.

Despite the variations between studies, important patterns do emerge. Although there is variation, road-based passenger travel is more GHG-intensive than rail-based passenger travel; the literature suggests road is roughly two to four times as GHG intensive as rail. Likewise trucking is on the order of five times as GHG-intensive than rail-freight transportation.

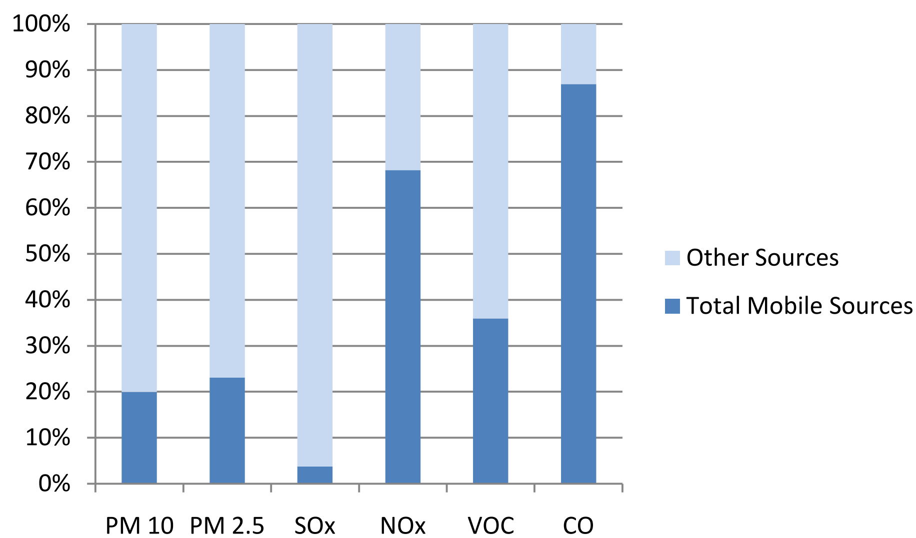
Furthermore, because of the superior efficiency of rail, and because of the high mode share of automobiles and trucking compared to rail, overall GHG emissions from road-based transportation are far higher than those from rail.

4. Criteria Air Contaminant Emissions

As noted earlier, criteria air contaminants (CACs) are a group of pollutants that cause air issues, such as smog and acid rain,[58] and have major health impacts. Transportation makes a significant contribution toward overall CAC levels.

Canada's National Pollutant Release Inventory breaks down pollutants by province and source (see Figure 4.1). In Ontario, transportation was a significant source of particulate emissions and smog-forming volatile organic compounds (VOCs) and nitrogen oxides (NO_x), and the source of more than 85% of poisonous carbon monoxide (CO). A study of Toronto's emissions of these six contaminants yielded similar results.[59] That study also noted that in Toronto NO_x and PM_{10} (particulate matter, of size 10 micrometers or smaller) are at "significant" levels compared to established standards - also noting that standards for any and all contaminants may need to be improved in light of epidemiological evidence.[60] The same study pointed out that the small sources (vehicles and residential furnaces) collectively are more important than the few large sources (commercial and industrial sources), and that local contributions to summer smog are mostly from vehicles.[61]

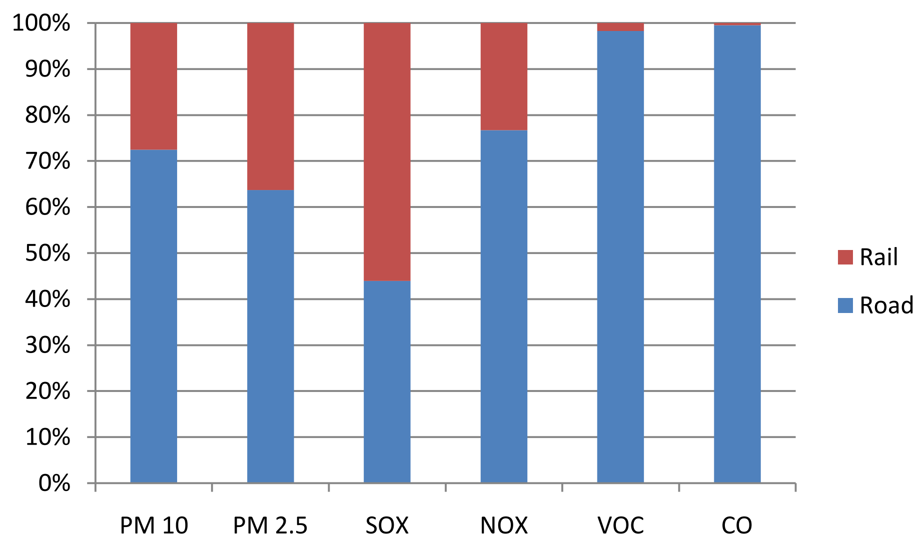
Figure 4.1 Proportion of Ontario CAC Emissions due to Transportation, 2008



Source of data: National Pollutant Release Inventory[62]

NPRI data also breaks out the relative contributions of rail and road transportation to these CACs. As shown in Figure 4.2, road transportation is responsible for the majority of CAC emissions. For SO_x, rail contributes fractionally (one-fifth) more emissions, Ontario-wide (diesel emissions depend on fuel sulphur content, which is low in GTHA passenger trains[63]) while for $PM_{2.5}$ road emissions are nearly double those of rail, and for PM_{10} and NO_x road emissions are roughly triple those of rail (the largest source of NO_x being heavy trucks). For VOC and CO road transport contributes, respectively, 57 times and 199 times as much as rail. Sustainable Development Technology Canada data echo these results.[64]

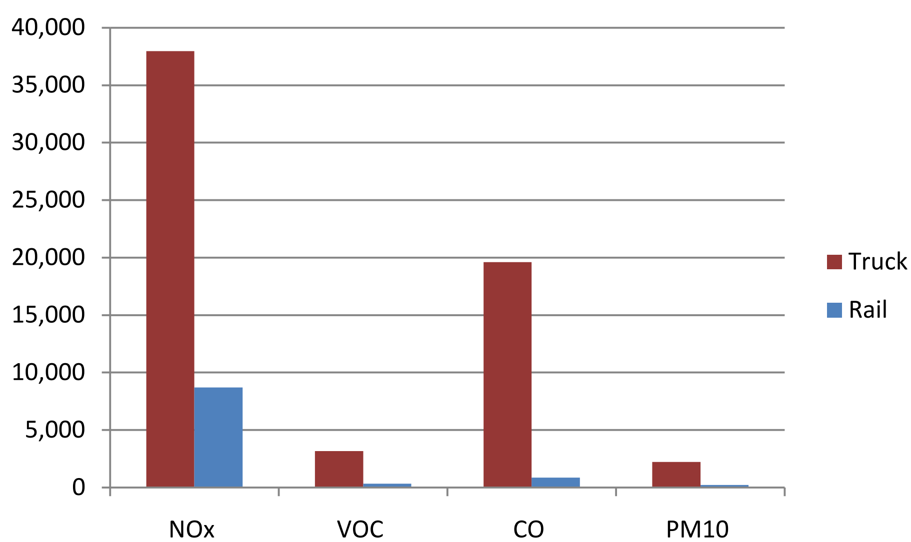
Figure 4.2 Combined passenger and freight emission proportions in Ontario, 2008



Source of data: National Pollutant Release Inventory[65]

Closer to the GTHA, within the Toronto-Detroit trade corridor, the figures are similar. Trucking produced substantially higher NO_x, SO_x, VOCs and PM emissions than rail. See figure 4.3.

Figure 4.3 Toronto-Detroit Corridor Trade Emissions (kg/day)



Source of data: ICF Consulting, "North American Trade and Transportation Corridors: Environmental Impacts and Mitigation Strategies"[66]

CAC Emissions Intensity

The emissions intensity picture is more complex for criteria air contaminants (CACs) than it is for GHGs. This is partly because there are several different CACs, and circumstances that cause emissions of one to be higher can cause another to be lower.

For example, emissions of VOCs – smog-forming volatile organic chemicals – tend to be lower for diesel than for comparable gasoline engines. However, particulate matter emissions tend to be higher in diesel engines than in comparable gasoline engines.[67] Nevertheless the results are generally consistent as between modes: other things being equal, the CAC emissions for rail and other forms of transit are lower than for automobiles.

Once again considering the full life-cycle analysis in the Chester and Horvath study,[68] the following broad observations can be made:

- SO_2: rail emissions intensity can be lower or higher than for passenger automobiles, depending in part on energy source[69] (as noted above, for diesel this depends on fuel sulphur content, and passenger rail in the GTHA uses ultra low sulphur fuel);
- NO_x: rail emissions intensity is, with a few exceptions, significantly lower than for passenger automobiles;[70]
- VOC: rail emissions intensity is significantly lower than for passenger automobiles, with no exceptions;
- PM_{10}: rail emissions intensity is significantly lower than for passenger automobiles, with no exceptions;
- CO: rail emissions intensity is more than an order of magnitude (ten times) lower for rail than for passenger automobiles (except for diesel passenger automobiles, which are about two to four times as intensive as passenger rail).

Closer to the GTHA, in container freight in the Great Lakes Region, trucking is more emissions-intensive than rail for both NO_x and PM_{10}, and less intensive for SOx.[71]

> *"[T]ravel by public transportation produces, on average, 95 percent less carbon monoxide, 90 percent less volatile organic compounds, and about 45 percent less carbon dioxide and nitrogen oxide, per passenger mile, as travel by private vehicles."*
>
> \- Shapiro, Hassett, and Arnold[72]

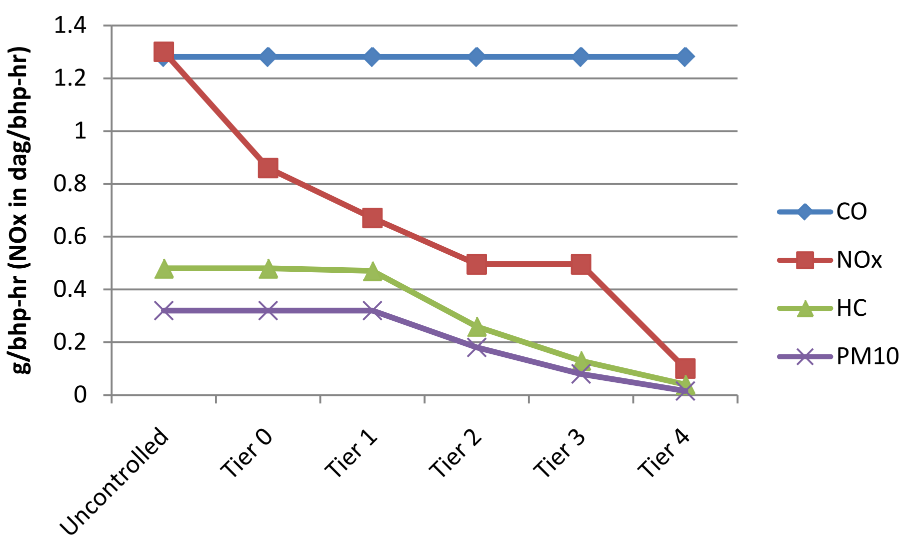
Importantly in the discussion of CACs, emission control devices required to be added to fuel-combustion energy sources (in vehicle engines or combustion-based electricity generators) can be very effective at reducing some CAC emissions. (This is not the case with GHG emissions, which vary directly with the amount of energy consumed, and cannot be reduced effectively by add-on emission control devices.[73])

Since the late 1960s and early 1970s, regulatory initiatives worldwide have set CAC emission standards that have resulted in significant reductions in CAC-intensity from combustion engines. Between 1990 and 2006 both diesel rail and trucking emissions intensities for some CACs declined significantly.[74] For example the NO_x, HC and PM10 standards for Tier 2 diesel locomotives, which GO Transit is currently meeting[75], are about half those of uncontrolled locomotives (see Figure 4.4).[76]

Tier 4 locomotives, expected to be commercially available as of 2015, will produce dramatically lower emissions, particularly NO_x and PM – the most significant emissions for diesel locomotives (locomotives are not a major source of CO or HC emissions).[77] Even compared to Tier 2 locomotives, Tier 4 locomotives will produce only 20% of the NO_x emissions and 8% of the PM_{10} emissions (see Figure 4.4).[78]

One study concluded that new diesel emission standards will result in PM and NO_x emissions from diesel multiple-unit trains being nearly as low as those of electric trains powered by a fairly clean electricity grid.[79] Electric trains produce near-zero emissions at the site of usage, but some electricity generation sources (including coal and natural gas currently used in Ontario) create emissions elsewhere.[80]

Figure 4.4 Emissions intensity standards for line-haul diesel locomotives



Source of data: US EPA[81]

While emissions regulation is another reason for variability in results among studies (by jurisdiction and over time), it is also reason to hope that CAC emission intensity can be even further reduced in the future.

Of course emissions intensity improvements on roads and on rail are undermined by large increases in numbers of motor vehicles. Thus shifting transportation to cleaner modes will be an important component of reducing overall emissions.

Conclusions - CACs

CAC emissions are even more variable than those of GHGs, due to the number of CACs and their differences. However, some conclusions can be drawn.

First, transportation is an important contributor to overall CAC pollution levels, which have an enormous negative impact - including causing billions of dollars of costs and thousands of deaths every year in Ontario.

Second, while rail transportation can cause somewhat more SO_x transportation emissions than road transportation, depending on fuel, road transportation contributes more of PM_{10}, $PM_{2.5}$ and NO_x, and the vast majority of VOCs and CO.

Third, public policy and regulatory change can mandate reductions in CAC emissions from fossil fuel combustion sources. The decline in emissions from uncontrolled locomotives to Tier 4 locomotives is dramatic.

Fourth, because of rail's low and rapidly declining CAC emissions intensity, shifting some passenger and freight movement from roads to rail would reduce emissions from the transportation sector.

5. Conclusions

The new openness to discussing the future of transportation in the GTHA could result in significant improvements in transportation, while reducing transportation-related emissions.

There are plans to shift some automobile passengers onto trains (urban and inter-urban) and some freight movement onto freight trains. The details of that shift have yet to be determined, which will require some discussion, including a discussion of emissions.

Fortunately, there are already studies available that give guidance on the types and amounts of emissions caused by various transportation modes. This survey has provided an overview of the major conclusions of those studies.

While there are significant variations between the studies, as is always the case, there are some conclusions that can be drawn.

First, transportation-related emissions constitute a large proportion of overall emissions in the GTHA. This is in part due to the mode share: automobiles and truck traffic make up the vast majority of passenger and freight movement respectively, and rail transportation has a much smaller mode share.

In relation to GHG emissions, a number of factors play a role in determining emissions from a given mode – including the source of energy used. However, it appears that rail-based passenger travel is less GHG-intensive than automobile-based passenger travel. Likewise rail-based freight transportation is less GHG-intensive than trucking. Furthermore, overall emissions from road-based transportation are much higher than those from rail.

In relation to CAC emissions, there are more factors at play, including the differing natures of the individual CACs themselves, and public policy initiatives that have driven down CAC emissions over the last few decades. However, CAC emissions from transportation are still very considerable, and entail enormous economic and human health costs.

While rail transportation can contribute somewhat more SO_x emissions than road transportation, depending on fuel, road transportation contributes the majority of all other CACs, with significantly higher levels of PM_{10}, $PM_{2.5}$ and NO_x, and vastly higher levels of VOCs and CO.

The literature is fairly consistent. While more data would always be useful, there is enough information to draw solid conclusions. In the GTHA, as elsewhere, rail transportation causes lower levels of emissions than does road transportation.

There is also enough information to begin to design and implement public policy instruments that will shift some of the traffic from road to rail and reduce emissions.

Appendix - Transportation Mode Shares

Mode share, the proportion of transportation taken by various modes of transportation, varies across the GTHA. However, the large majority of personal and freight transportation is by motor vehicles on roadways.

Mode share can be measured in two ways: percentage of trips taken by the mode, or total length of travel taken by the mode.

Passenger Transportation

Passenger transportation mode shares for the Greater Toronto Area are set out in table A.1 below. Toronto mode shares (daily and peak hour) are set out in tables A.2 and A.3.

Toronto has significantly higher transit mode share than the larger area. However, even in Toronto, automobile transportation outweighs all other modes combined.

Table A.1 GTHA / GTA Transportation Mode Share

	DMG (Weighted Avg)[82]	Toronto City Summit Alliance[83]
Automobile	81.2%	78%
Transit	10.3%	15%
Walking & Cycling	5.9%	7%
Other	2.6%	-
TOTAL	100%	100%

Note: The DMG source includes Hamilton in its transportation mode shares. The Toronto City Summit Alliance defines the "Greater Toronto Area (GTA)" as the City of Toronto together with the regional municipalities of Durham, Halton, Peel and York (does not include Hamilton).

Table A.2 City of Toronto Transportation Mode Share – Daily

	DMG[84]	City of Toronto[85]	Toronto City Summit Alliance[86]	Pembina Insitute[87]
Automobile	67.1%	65%	68%	55%
Transit	23.2%	25%	-	35%
Walking & Cycling	8.2%	9%	-	9%
Other	1.5%	1%	-	1%

Table A.3 City of Toronto Transportation Mode Share – Peak Hours

	City of Toronto[88]	Toronto Environmental Alliance[89]	City of Toronto[90]
Automobile	55%	-	55%
Transit	32%	28%	32%
Walking & Cycling	13%	-	13%
Other	-	-	-

Freight Transportation

Surface freight transportation is comprised of longer distance carriage of goods and shorter trips. Shorter trips are generally road-based, delivered by trucks or other vehicles.

Comparisons between rail freight and truck freight can be made for longer-distance trips. In the Toronto-Detroit Corridor, trucking accounts for 71% of all freight.[91] Within the GTHA, 89% of freight movements are by truck. [92] For both imports and exports, table A.4 shows the dominance of freight trucking by value of goods shipped across the Ontario/US border.

Table A.4 Ontario/US Exports and Imports Mode Share (% by value), 2001[93]

	Exports	Import
Air	8.2	6.8
Rail	25.1	8.5
Road	61.1	83.3
Marine	3.6	0.8
Other	2.0	0.6

Endnotes

[1] David Thompson is Director of Sustainable Communities for Sustainable Prosperity. He co-authored Sustainable Prosperity's "Smart Budget: A Background Paper on Environmental Pricing Reform for Local Governments," and was the principal researcher for "The Smart Budget Toolkit". He has also prepared briefing documents on EPR for the City of Edmonton and the Toronto City Summit Alliance. He has worked as a lawyer in government and in the civil society sector, in management, and as a small business owner. He has postgraduate degrees in law and environmental economics.

[2] "Go Green: Ontario's Action Plan on Climate Change", (Government of Ontario, August 2007) p.6, http://www.ene.gov.on.ca/publications/6445e.pdf.'

[3] Using intensity as an indicator of whether road or rail is more efficient (i.e. produces lower emissions levels per unit of travel) is helpful in determining which way to shift modes in order to reduce overall emissions. In addition to shifting modes, it is also useful to make each mode more efficient, and reduce total distances travelled. Note that measuring emissions intensity in order to compare relative efficiency across modes is fundamentally different from the use of the term "intensity" in the context of setting jurisdiction-wide GHG emissions targets. Setting GHG emission reduction *targets* on the basis of GHG intensity is pointless, as the only thing that matters regarding climate is overall emissions; climate change is caused by emissions, not emissions intensity. Because intensity-based emissions targets are likely misleading to some members of the public, they should be avoided.

[4] D. Adam, "I underestimated the threat, says Stern" (Guardian, April 18, 2008) http://www.guardian.co.uk/environment/2008/apr/18/climatechange.carbonemissions.

[5] AFX, "Volcker: Global warming bad for economy" (ABC Money, February 6, 2007) http://www.abcmoney.co.uk/news/06200718912.htm.

[6] P. Ward, *Under a Green Sky: Global Warming, the Mass Extinctions of the Past, and What They Can Tell Us About Our Future* (Smithsonian, 2007). See also D. Beillo, "Mass Extinctions Tied to Past Climate Changes: Fossil and temperature records over the past 520 million years show a correlation between extinctions and climate change" (Scientific American, October 24, 2007) http://www.scientificamerican.com/article.cfm?id=mass-extinctions-tied-to-past-climate-changes; S. Connor, "Climate change is linked to mass extinctions of past" (The Independent, October 24, 2007), http://www.independent.co.uk/news/science/climate-change-is-linked-to-mass-extinctions-of-past-397707.html.

[7] Peter Ward, "The Flooded Earth: Our Future in a World Without Ice Caps" (Basic Books, 2010) http://floodedearth.com/. See also J. Owen, "The planet's future: Climate change 'will cause civilisation to collapse': Authoritative new study sets out a grim vision of shortages and violence – but amid all the gloom, there is some hope too" (The Independent, July 12, 2009) http://www.independent.co.uk/environment/climate-change/the-planets-future-climate-change-will-cause-civilisation-to-collapse-1742759.html.

[8] UN Secretary-General Ban Ki-Moon: United Nations, "Slowing -- and Reversing -- Climate Change Threat 'Defining Challenge of Our Age', Says Secretary-General, Following Release of United Nations Panel Report" (19 Nov 2007) http://www.un.org/News/Press/docs/2007/sgsm11283.doc.htm.

[9] Stephen Harper: Office of the Prime Minister, "Prime Minister Stephen Harper calls for international consensus on climate change" (June 4, 2007), http://pm.gc.ca/eng/media.asp?id=1681.

[10] Environment Canada, "National Inventory Report - Greenhouse Gas Sources and Sinks in Canada – Part 3" p.73, http://www.ec.gc.ca/publications/492D914C-2EAB-47AB-A045-C62B2CDACC29/NationalInventoryReport19902008GreenhouseGasSourcesAndSinksInCanadaPart3.pdf.

[11] Environment Canada, "National Inventory Report - Greenhouse Gas Sources and Sinks in Canada – Part 3" p.113, http://www.ec.gc.ca/publications/492D914C-2EAB-47AB-A045-C62B2CDACC29/NationalInventoryReport19902008GreenhouseGasSourcesAndSinksInCanadaPart3.pdf.

[12]Environment Canada, "National Inventory Report - Greenhouse Gas Sources and Sinks in Canada – Part 3" p.76, http://www.ec.gc.ca/publications/492D914C-2EAB-47AB-A045-C62B2CDACC29/NationalInventoryReport19902008GreenhouseGasSourcesAndSinksInCanadaPart3.pdf

[13] "Air Quality in Ontario - 2008 Report" (Ontario Ministry of Environment) http://www.ene.gov.on.ca/publications/7356e.pdf.

[14] CBC News, "Ontario's smog causes 9,500 deaths per year, medical association says" (June 6, 2008) http://www.cbc.ca/health/story/2008/06/06/smog-deaths.html.

[15] Nearly 4,900 Ontarians are killed by infectious disease per year: J. Kwong, N. Crowcroft, M. Campitelli, S. Ratnasingham, N. Daneman, S. Deeks and D. Manuel, "Ontario Burden of Infectious Disease Study (Institute for Clinical Evaluative Sciences and Ontario Agency for Health Protection and Promotion, December 2010) p.5. http://www.ices.on.ca/file/ONBOIDS_FullReport_intra.pdf.

[16] 440 out of a total of 1,700 from air pollution: M. Campbell, K. Bassil, C. Morgan, M/Lalani, R. Macfarlane, and M. Bienfeld, "Air Pollution Burden of Illness from Traffic in Toronto – Problems and Solutions" (Nov 2007, Toronto Public Health) http://www.toronto.ca/health/hphe/pdf/air_pollution_burden.pdf.

[17] Natural Resources Canada, Office of Energy Efficiency "Transportation Sector, Ontario, Table 2, Passenger Transportation Secondary Energy Use by Energy Source" http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablestrends2/tran_on_2_e_4.cfm?attr=0.

[18] Natural Resources Canada, Office of Energy Efficiency "Transportation Sector, Ontario, Table 3, Freight Transportation Secondary Energy Use by Energy Source" http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablestrends2/tran_on_3_e_4.cfm?attr=0.

[19] Data Management Group, "2006, 2001, 1996 and 1986 TRAVEL SURVEY SUMMARIES FOR THE GREATER TORONTO AND HAMILTON AREA" (University of Toronto, Department of Civil Engineering, October 2008) http://www.dmg.utoronto.ca/pdf/tts/2006/travel_summaries_for_the_gtha/TTS_Report5_full.pdf, also reported at C. Burda, A. Bailie & G. Haines, "Driving Down Carbon: Reducing GHG Emissions from the Personal Transportation Sector in Ontario" (The Pembina Institute, April 2010) p.64-65 http://pubs.pembina.org/reports/driving-down-carbon-report.pdf. These averages were weighted by distances travelled in Greater Golden Horseshoe Region (Toronto, Hamilton, Inner Suburbs, Outer Suburbs, Outer Centres and Rural Suburbs).

[20] Ministry of Transportation of Ontario, "Goods Movement in Central Ontario: Trends and Issues", (iTRANS Consulting, Technical Report, December 2004) p.113, 173&ff http://www.itransconsulting.com/Papers/paper_goods.aspx.

[21] For a further discussion of the social, economic, and environmental impacts of motor-vehicle dependency and sprawl, see T. Litman, "Evaluating Transportation Land Use Impacts: Considering the Impacts, Benefits and Costs of Different Land Use Development Patterns" (Victoria Transportation Policy Institute, August 6, 2010), http://www.vtpi.org/landuse.pdf.

[22] Government of Ontario, "MoveOntario 2020" http://news.ontario.ca/opo/en/2007/06/moveontario-2020.html; Government of Ontario, "Go Green: Ontario's Action Plan on Climate Change" (August 2007) pp. 9, 10 http://www.ene.gov.on.ca/publications/6445e.pdf.

[23] Metrolinx, "The Big Move: Transforming Transportation in the Greater Toronto and Hamilton Area" (Greater Toronto Transportation Authority, November 2008) pp. 58, 59. http://www.metrolinx.com/Docs/big_move/TheBigMove_020109.pdf.

[24] 26.3% of trips, compared to 16.6% baseline.

[25] 19km, compared to 26km baseline.

[26] 1.7 tonnes, compared to 2.2 tonnes baseline.
[27] 77 minutes, compared to 109 minutes baseline.

[28] Metrolinx, "The Big Move: Transforming Transportation in the Greater Toronto and Hamilton Area" (Greater Toronto Transportation Authority, November 2008) p.55 http://www.metrolinx.com/Docs/big_move/TheBigMove_020109.pdf.

[29] Natural Resources Canada, Office of Energy Efficiency "Transportation Sector, Ontario, Table 8, GHG Emissions by Transportation Mode" http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablestrends2/tran_on_8_e_4.cfm?attr=0.

[30] M. Campbell et al., "Air Pollution Burden of Illness from Traffic in Toronto – Problems and Solutions" (Toronto Public Health, November 2007) p.19, http://www.toronto.ca/health/hphe/pdf/air_pollution_burden.pdf, reported in: ICF International, "Greenhouse Gases and Air Pollutants in the City of Toronto: Towards a Harmonized Strategy for Reducing Emissions" (Toronto Atmospheric Fund and Toronto Environment Office, June 2007) http://www.toronto.ca/legdocs/mmis/2007/pe/bgrd/backgroundfile-4991.pdf.

[31] C. Burda, A. Bailie & G. Haines, "Driving Down Carbon: Reducing GHG Emissions from the Personal Transportation Sector in Ontario" (The Pembina Institute, April 2010) p.13, http://pubs.pembina.org/reports/driving-down-carbon-report.pdf.

[32] Environment Canada, "National Inventory Report - Greenhouse Gas Sources and Sinks in Canada – Part 3" p.113, http://www.ec.gc.ca/publications/492D914C-2EAB-47AB-A045-C62B2CDACC29/NationalInventoryReport19902008GreenhouseGasSourcesAndSinksInCanadaPart3.pdf

[33] Environment Canada, "National Inventory Report - Greenhouse Gas Sources and Sinks in Canada – Part 3" p.113, http://www.ec.gc.ca/publications/492D914C-2EAB-47AB-A045-C62B2CDACC29/NationalInventoryReport19902008GreenhouseGasSourcesAndSinksInCanadaPart3.pdf

[34] Another source remarked that "[e]missions from trucking account for approximately 89 per cent of GHG emissions from goods movement in Ontario:" "The Big Move Backgrounder: Climate Change and Energy Conservation" (Metrolinx, Dec. 2008) http://www.metrolinx.com/Docs/big_move/RTP_Backgrounder_Climate_Change_%20Energy_Conservation.pdf, citing Transport Canada, Environment Canada, Natural Resources Canada, Department of Finance Canada, Industry Canada, and Marbek Resource Consultants.

[35] Natural Resources Canada, Office of Energy Efficiency "Transportation Sector, Ontario, Table 8, GHG Emissions by Transportation Mode" http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablestrends2/tran_on_8_e_4.cfm?attr=0.

[36] Natural Resources Canada, Office of Energy Efficiency "Transportation Sector, Ontario, Table 8, GHG Emissions by Transportation Mode" http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablestrends2/tran_on_8_e_4.cfm?attr=0.

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[39] Natural Resources Canada, Office of Energy Efficiency "Transportation Sector, Ontario, Table 8, GHG Emissions by Transportation Mode" http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablestrends2/tran_on_8_e_4.cfm?attr=0.

[40] Environment Canada, "National Inventory Report - Greenhouse Gas Sources and Sinks in Canada – Part 3" p.74, http://www.ec.gc.ca/publications/492D914C-2EAB-47AB-A045-C62B2CDACC29/NationalInventoryReport19902008GreenhouseGasSourcesAndSinksInCanadaPart3.pdf.

[41] 25 occupants per rail car is a US-wide average combining light, heavy, and commuter rail. C. Williams-Derry, "How Low-Carbon Can You Go: The Green Travel Ranking" (Sightline Institute, Feb 8, 2008) http://www.sightline.org/maps/charts/climate-CO2byMode/?.

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[43] World Resources Institute, "GHG Protocol tool for mobile combustion, Version 2.0" (2008) http://www.ghgprotocol.org/calculation-tools/all-tools, sourced at Greenfiniti, "Calculation Method" http://www.greenfiniti.com/static/calculation_methods.aspx.

[44] Automobile and light truck factors averaged over a range of vehicle sizes and fuel types. World Resources Institute, "GHG Protocol tool for mobile combustion, Version 2.0" (2008) http://www.ghgprotocol.org/calculation-tools/all-tools, sourced at Greenfiniti, "Calculation Method" http://www.greenfiniti.com/static/calculation_methods.aspx.

[45] G. Mellios & M. Giannouli, "Overall energy efficiency and specific CO2 emissions for passenger and freight emissions" (European Environment Agency, November 2005) p.10, http://www.eea.europa.eu/data-and-maps/indicators/overall-energy-efficiency-and-specific-1.

[46] M. Chester and A. Horvath, "Life-cycle Energy and Emissions Inventories for Motorcycles, Diesel Automobiles, School Buses, Electric Buses, Chicago Rail, and New York City Rail" (UC Berkeley Center for Future Urban Transport, 2009) www.its.berkeley.edu/publications/UCB/2009/vwp/UCB-ITS-VWP-2009-2.pdf. Full life cycle includes active operation (dark blue) and several other non-operational components, the largest of which vary by mode, but include vehicle manufacturing, infrastructure construction and operation, and fuel production (pale blue). Metro and commuter rail numbers are averages of four studies and three studies respectively. Operational emissions for trains varies significantly based on occupancy; this study used average occupancies from the National Transit Database (Chester and Horvath, page 11).

[47] Transportation Table of the National Climate Change Strategy Development 1999 Report, cited in "Chapter 11: Ferries, Intercity Buses and Passenger Trains" (Canadian Transportation Act Review Panel, 2001), http://www.reviewcta-examenltc.gc.ca/english/pages/final/ch11e.htm. Similarly Environment Canada used implicit vehicle occupancies of 1.6 (automobile) and 1.7 (light truck) in reporting equivalent GHG emission intensities for rail and car, with light trucks being 29% higher than either: Table 2-12, passenger activity / vehicle activity, Environment Canada, "National Inventory Report - Greenhouse Gas Sources and Sinks in Canada – Part 1" p.73, http://www.ec.gc.ca/publications/492D914C-2EAB-47AB-A045-C62B2CDACC29/NationalInventoryReport19902008GreenhouseGasSourcesAndSinksInCanada.pdf.

[48] C. Burda, A. Bailie & G. Haines, "Driving Down Carbon: Reducing GHG Emissions from the Personal Transportation Sector in Ontario" (The Pembina Institute, April 2010) p.37, http://pubs.pembina.org/reports/driving-down-carbon-report.pdf. Occupancy may be even lower for commuters: "During rush hour, the average Toronto-area car carries about 1.15 people" "GO Transit Green Initiatives - Quick Facts" (November 2009), http://www.gotransit.com/public/en/docs/publications/Quick_Facts_GO_Transit_Green_Initiatives.pdf.

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57 Environment Canada, "National Inventory Report - Greenhouse Gas Sources and Sinks in Canada – Part 1" p.74, http://www.ec.gc.ca/publications/492D914C-2EAB-47AB-A045-C62B2CDACC29/NationalInventoryReport19902008GreenhouseGasSourcesAndSinksInCanada.pdf.

58 Environment Canada, "Criteria Air Contaminants and Related Pollutants" http://www.ec.gc.ca/Air/default.asp?lang=En&n=7C43740B-1.

59 In the Toronto-focussed study, a different methodology was used. Some transportation proportions were higher (notably PM10) and others were lower (notably VOC). ICF International, "Greenhouse Gases and Air Pollutants in the City of Toronto: Towards a Harmonized Strategy for Reducing Emissions" (Toronto Atmospheric Fund and Toronto Environment Office, June 2007) p.64 http://www.toronto.ca/legdocs/mmis/2007/pe/bgrd/backgroundfile-4991.pdf.

60 ICF International, "Greenhouse Gases and Air Pollutants in the City of Toronto: Towards a Harmonized Strategy for Reducing Emissions" (Toronto Atmospheric Fund and Toronto Environment Office, June 2007) p.35, note 20. http://www.toronto.ca/legdocs/mmis/2007/pe/bgrd/backgroundfile-4991.pdf.

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62 National Pollutant Release Inventory , "2007 Air Pollutant Emissions for Ontario" (Environment Canada, May 2009), http://www.ec.gc.ca/pdb/websol/emissions/ap/ap_query_e.cfm.

[63] SOx emissions of trains depends on the sulphur content of fuel used. GO Transit uses ultra-low sulphur fuel. Transport Canada, "Locomotive Emissions Monitoring Program 2007" http://www.tc.gc.ca/eng/programs/environment-ecofreight-about-voluntary-racemissions2007-7-342.htm.
[64] Sustainable Development Technology Canada, "Transportation - Industrial Freight Transportation", (Sustainable Development Business Case Report, November 2009), pp. 30-32, 99-101, http://www.sdtc.ca/uploads/documents/en/BC_TRANS.pdf.

[65] National Pollutant Release Inventory , "2007 Air Pollutant Emissions for Ontario" (Environment Canada, May 2009), http://www.ec.gc.ca/pdb/websol/emissions/ap/ap_query_e.cfm. According to Environment Canada, "the air pollutant emissions data was compiled in collaboration with provincial, territorial and regional environmental agencies using the latest emission estimation methodologies. It represents the most comprehensive information on emissions of key air pollutants available in Canada."

[66] Source: ICF Consulting, "North American Trade and Transportation Corridors: Environmental Impacts and Mitigation Strategies", (Prepared for the North American Commission for Environmental Cooperation, August 2001) p.18, http://www.cec.org/Storage/41/3313_Trade_Corridors_Final-e1_EN.PDF.

[67] B.C. Government, "Air Pollution and Greenhouse Gases from Different Commuting Options" http://www.env.gov.bc.ca/epd/bcairquality/topics/emissions-transportation-options.html.

[68] M. Chester and A. Horvath, "Life-cycle Energy and Emissions Inventories for Motorcycles, Diesel Automobiles, School Buses, Electric Buses, Chicago Rail, and New York City Rail" (UC Berkeley Center for Future Urban Transport, 2009), pages 14-19, www.its.berkeley.edu/publications/UCB/2009/vwp/UCB-ITS-VWP-2009-2.pdf. Full life cycle includes active operation and several other non-operational components, the largest of which vary by mode, but include vehicle manufacturing, infrastructure construction and operation, and fuel production. Metro and commuter rail numbers are averages of four studies and three studies respectively. Operational emissions for trains varies significantly based on occupancy; this study used average occupancies from the National Transit Database (Chester and Horvath, page 11).

[69] Unlike the other CACs discussed, for SO2 the proportion of emissions intensity attributable to vehicle operations (as opposed to non-operational life-cycle emissions) was very low.

[70] Although diesel engines are more NO_x intensive than comparable gasoline engines with equivalent loads, trains are more efficient than cars.

[71] J. Winebrake, "Intermodal Freight Transport in the Great Lakes: Development and Application of a Great Lakes Geographic Intermodal Freight Transport Model", (Great Lakes Maritime Research Institute and Rochester Institute of Technology, October 2008) p.14, http://www.glmri.org/downloads/winebrake08a.pdf.

[72] R. Shapiro, K. Hassett, and F. Arnold, "Conserving Energy and Preserving the Environment: The Role of Public Transportation" (American Public Transportation Association, 2002) p.9 http://www.publictransportation.org/pdf/reports/shapiro_report.pdf.

[73] Some hope that, in the future, CO2 streams will be able to be captured from large stationary emission sources, compressed, and sequestered underground. However, despite extensive and discussion of carbon capture and storage, there are as yet no industrial-scale, integrated installations anywhere in Canada.

[74] Sustainable Development Technology Canada, "Transportation - Industrial Freight Transportation", (Sustainable Development Business Case Report, November 2009), pp. 30-32, 99-101 http://www.sdtc.ca/uploads/documents/en/BC_TRANS.pdf. Transport Canada, "Locomotive Emissions" (2008) Table 11, http://www.tc.gc.ca/eng/programs/environment-ecofreight-about-voluntary-voluntaryagreementsrail-1853.htm.

[75] GO is currently acquiring Tier 2 locomotives, and meeting the Tier 2 standard voluntarily: GO, "Electrification Study, Rolling Stock Basics: Diesel Locomotives" http://www.gotransit.com/estudy/en/info/fact_sheets.aspx.

[76] The US EPA did not set lower CO standards because CO emissions from diesel engines are low compared to other types of engines, locomotives are low compared to trucks per unit of power (1/10th the emissions), and other engine improvements will reduce CO emissions without need for standards: US Federal Register, “Control of Emissions of Air Pollution From Locomotive Engines and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder” (05/06/2008) http://www.federalregister.gov/articles/2008/05/06/E8-7999/control-of-emissions-of-air-pollution-from-locomotive-engines-and-marine-compressionignition-engines#h-65.

[77] D. Brann, “Compliance won't come cheap: what EPA's Tier 3 and Tier 4 locomotive emissions standards mean for manufacturers and railroads” (Railway Age, Sept 2008) available at http://findarticles.com/p/articles/mi_m1215/is_9_209/ai_n30916412/.

[78] The Tiers are determined by the US EPA; at present, Canada has no emission standards.

[79] C. Messa, “Comparison of Emissions from Light Rail Transit, Electric Commuter Rail, and Diesel Multiple Units” (Transportation Research Record: Journal of the Transportation Research Board of the National Academies) vol. 1955, 2006, p.31 http://trb.metapress.com/content/24t5707k6pt40741/.

[80] Metrolinx is currently conducting a study on electrification of the entire GO system. Go Transit, “Electrification Study” http://www.gotransit.com/estudy/en/default.aspx.

[81] US Environmental Protection Agency, “Emissions Factors for Locomotives” (Office of Transportation and Air Quality, April 2009) http://www.epa.gov/oms/regs/nonroad/locomotv/420f09025.pdf. See above note regarding CO emissions and standards.

[82] Data Management Group, “2006, 2001, 1996 and 1986 TRAVEL SURVEY SUMMARIES FOR THE GREATER TORONTO AND HAMILTON AREA” (University of Toronto, Department of Civil Engineering, October 2008) http://www.dmg.utoronto.ca/pdf/tts/2006/travel_summaries_for_the_gtha/TTS_Report5_full.pdf, also reported at C. Burda, A. Bailie & G. Haines, "Driving Down Carbon: Reducing GHG Emissions from the Personal Transportation Sector in Ontario" (The Pembina Institute, April 2010) p.64-65 http://pubs.pembina.org/reports/driving-down-carbon-report.pdf. These averages were weighted by distances travelled in Greater Golden Horseshoe Region (Toronto, Hamilton, Inner Suburbs, Outer Suburbs, Outer Centres and Rural Suburbs).

[83] "Greening Greater Toronto" (Toronto City Summit Alliance, June 2008) p.36, http://www.greeninggreatertoronto.ca/pdf/June2008Report.pdf.

[84] Op. cit.

[85] A Transportation Vision for the City of Toronto Official Plan" (City of Toronto - Urban Development Services, April 2000) p.19, http://www.toronto.ca/torontoplan/trans_vision.pdf. [Details for this table taken from *Transportation Tomorrow Surveys*]

[86] Greening Greater Toronto" (Toronto City Summit Alliance, June 2008) p.9, http://www.greeninggreatertoronto.ca/pdf/June2008Report.pdf. Note that transit, cycling and walking data are not broken out in this source.

[87] Canada's Coolest Cities: Toronto & CMA" (The Pembina Institute) p.3, http://pubs.pembina.org/reports/coolest-cities-case-study-toronto.pdf.

[88] A Transportation Vision for the City of Toronto Official Plan" (City of Toronto - Urban Development Services, April 2000) p.19, http://www.toronto.ca/torontoplan/trans_vision.pdf. [Details for this table taken from *Transportation Tomorrow Surveys*]

[89] Toronto Environmental Alliance, "Transit Facts" (2008), http://www.torontoenvironment.org/campaigns/transit/facts

[90] Great City, Great Living - Five Campaigns of Action", p.101, http://www.toronto.ca/torontoplan/crossroads3.pdf. [From the City of Toronto report, The Official Plan for the City of Toronto, "Toronto at the Crossroads: Shaping Our Future", http://www.toronto.ca/torontoplan/crossroads_change.htm.]

[91] ICF Consulting, "North American Trade and Transportation Corridors: Environmental Impacts and Mitigation Strategies", (Prepared for the North American Commission for Environmental Cooperation, August 2001), p.16, http://www.cec.org/Storage/41/3313_Trade_Corridors_Final-e1_EN.PDF.

[92] Metrolinx, "The Big Move: Transforming Transportation in the Greater Toronto and Hamilton Area" (Greater Toronto Transportation Authority, November 2008) p.54 http://www.metrolinx.com/Docs/big_move/TheBigMove_020109.pdf.

[93] Source: Ministry of Transportation of Ontario, "Goods Movement in Central Ontario: Trends and Issues", (iTRANS Consulting, Technical Report, December 2004) p.43, http://www.itransconsulting.com/Papers/paper_goods.aspx. See table "Truck and Total Volumes at GTA Boundaries, 1991 and 2001" (p.175).