Transportation Association of Canada

# Moving Smarter: Exploring energy and greenhouse gas emission reduction solutions for Canadian cities

## TOOLBOX OF MEASURES

April 2016

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**Abstract**

Over the past decade, many governments in Canada have identified ambitious targets for reducing energy use and/or greenhouse gas (GHG) emissions. Since transportation accounts for about one-third of all energy consumed in Canada, significant changes to transportation behavior, modal shares and technology are considered to achieve the targets.

This report seeks to provide readers with ideas for reducing urban transportation GHG emissions and help them identify, weigh and select the most appropriate measures or bundle of measures when policy, program or project level opportunities arise. Readers can use the information provided in this report to:

- Identify a list of measures which are applicable to their jurisdiction based on the size of their municipality and to their area of responsibility (e.g. as a transit agency, municipality, etc.);
- Short list measures for further investigation based on an examination of the GHG reduction potential of measures, costs, technical feasibility and social acceptability;
- Explore options to support or augment the actions already underway in their own jurisdiction;
- Conduct further evaluations of measures within their local context to determine locally specific feasibility issues, budget requirements, GHG reduction potential and constraints;
- Understand benefits and disadvantages of various measures in order to build arguments and support for policy choices;
- Identify constraints and barriers which need to be addressed in their own jurisdiction, or which may remove certain measures from further consideration;
- Build an action plan based on the implementation considerations and timing of application.

**Keywords**

Environment
Traffic and Transport Planning

- Cost benefit analysis
- Emission control
- Energy conservation
- Environment protection
- Greenhouse gas
- Planning
- Policy
- Specifications
- Transport authority
- Urban area

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# Project Steering Committee

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# Executive Summary

In recognition of the significant impacts and risks of climate change, municipalities and regional agencies across Canada are working to reduce energy use and greenhouse gas (GHG) emissions across a broad range of sectors. This report was developed to help municipal and regional agencies understand and assess available options for reducing GHG emissions from the urban transportation sector.

***Urban Transportation and GHG Emissions***

The goal of urban transportation is to facilitate the movement of people and goods in an efficient, affordable, safe and environmentally sustainable manner. However, a heavy reliance on fossil fuels as the dominant source of energy for propulsion has meant that urban transportation has become a significant contributor to Canada's total GHG emissions. In 2011, the Canadian transportation sector accounted for about one quarter of Canada's total GHG emissions (Government of Canada, 2014a). Of these emissions, passenger car, light truck and motorcycles accounted for nearly 52 %, freight by heavy-duty trucks and rail modes accounted for 32 %, and urban transit accounted for less than 4 % in 2011. Municipalities and regional planning and transit agencies, responsible for much of the land use, infrastructure and services which support urban transportation, will have a significant role in reducing this sector's emissions.

Road transportation GHG emissions are a function of numerous factors, including population and demographics, economic activity, travel patterns, vehicle fuel efficiency and the carbon intensity of vehicle fuels. Recent trends suggest that road passenger transportation-based GHG emissions, which have stabilized since 2005, will decrease both in absolute and on a per capita basis by 2030 despite increasing travel demand. Population growth in urban centres where alternative forms of transportation to the automobile are more readily available, retiring baby boomers and the millennial generation tending to drive less, gains in vehicle fuel efficiency, and the adoption of national renewable fuel content regulations in 2010, among other things are contributing to this downward trend in road passenger transportation GHG emissions. While heavy-duty vehicles are also seeing an improvement in vehicle fuel efficiency, the projected economic growth and increased demand for freight movement will outweigh the gains made on heavy-duty vehicle fuel efficiency. Furthermore, based on current federal and provincial policies and measures in place as of 2013, the growth of freight heavy-duty vehicle GHG emissions is projected to off-set anticipated reductions in passenger GHG emissions. Combined ground-based passenger and freight transportation sector emissions are projected to increase marginally from approximately 150 Mt GHG / year[1] in 2011 to 151 Mt GHG / year by 2030 (Government of Canada, 2014a).

***The Toolbox of Measures to Reduce GHG Emissions***

There are three main approaches to reducing urban transportation GHG emissions in urban areas. They are:

- **Reduce Vehicle Kilometres Travelled**: Reducing distances travelled by passengers and goods by vehicle;
- **Improve Transportation System and Driver Efficiency**: Improving the efficiency of the transportation system so that more vehicles travel under more optimal conditions in terms of speed and flow;

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[1] *1 Mt of GHG = 1 megatonne, or 1 million tonnes of $CO_2$ equivalent gases.*

- **Encourage Alternative Vehicle and Fuel Technologies**: Adopting and supporting vehicles that use alternative fuels and technologies which are more energy efficient or use less GHG-intensive energy sources for propulsion.

These approaches can be implemented through a variety of strategies, policies, programs, projects or actions, collectively named “measures” in this report. This report presents a collection of 30 different measures to address transportation-related GHG emissions, organized according to the three approaches. The “Reducing VKT” approach itself comprises a broad range of possible measures that are further divided into five categories. Table ES-1 presents the 30 measures, which are colour coded to facilitate identification. To help readers identify measures which are appropriate to their context, the applicability of measures by size of municipality, responsibility for implementation, timing of implementation, potential reductions in urban transportation GHG emissions, and timeframe when reductions might occur, are presented in Table ES-1. The technical feasibility of implementation and social acceptability of measures are discussed in this report, but are not presented in this summary.

## Table ES 1 – Description of Measures to Reduce Transportation GHG Emissions

| | Measure | Responsibility for Implementation* | Applicability** | Timing of Implementation* | Reduction Potential*** | Reduction Timeframe* |
|---|---|---|---|---|---|---|
| **Reduce Vehicle Kilometres Travelled** | | | | | | |
| | **Land Use** | | | | | |
| **1** | Land Use Planning and Smart Growth | Municipalities, Transit Agencies | All | Immediate, ongoing | 4 | Long |
| | **Transportation Supply-Side Alternatives** | | | | | |
| **2a** | Expand Transit Service | Transit Agencies, Municipalities | All | Short | 3 - 4 | Medium to Long |
| **2b** | Enhance Existing Transit Services | Transit Agencies, Municipalities | All | Immediate, ongoing | 3 - 4 | Medium to Long |
| **3** | Provide Taxibus Transit Service | Taxi Operators, Transit Agencies | S | Short | 1 | Short |
| **4** | Encourage Active Transportation | Municipalities | All | Immediate | 3 | Medium to Long |
| **5** | Provide Carsharing Services | Private Operator, Municipalities | M, L | Immediate | 2 – 3 | Short |
| **6** | Encourage Carpooling | Employers, Local and Regional Agencies | All | Immediate | 2 - 3 | Short |
| **7** | Encourage Telecommuting | Employers | All | Immediate | 2 | Immediate |
| | **Pricing Mechanisms** | | | | | |
| **8** | Implement Toll Roads and Cordon/Area Pricing | All Levels of Government | M, L | Short | 3 | Short |
| **9** | Implement Distance Travelled Fees | Regional or Provincial Agencies | All | Short to Medium | 5 | Short |
| **10** | Charge Distance-based Insurance Costs | Insurance Companies, Provincial Agencies | All | Short to Medium | 3 - 5 | Short |
| **11** | Implement a Fuel Sales or Carbon Tax | Regional or Provincial Governments | All | Short | 5 | Short |
| **12** | Increase Parking Costs | Local Municipality, Private Parking Operators | M, L | Immediate | 2 – 3 | Immediate |
| **13** | Offer Fees in Lieu of Travel, Parking | Employers | M, L | Immediate | 2 – 3 | Immediate |

| | Measure | Responsibility for Implementation* | Applicability** | Timing of Implementation* | Reduction Potential*** | Reduction Timeframe* |
|---|---|---|---|---|---|---|
| | **Parking Mechanisms** | | | | | |
| 14 | Optimize the Use of Existing Parking Spaces | Municipalities, Parking Lot Operators | M, L | Immediate, ongoing | 1 – 2 | Immediate |
| 15 | Reduce Minimum Parking Requirements | Municipalities | M, L | Immediate, ongoing | 1 – 2 | Medium to Long |
| | **Trucking** | | | | | |
| 16 | Enhance Logistics Management | Transport Co., Facility Operators | M, L | Immediate, ongoing | 2 - 3 | Short to Medium |
| 17 | Encourage Modal Shift for Freight | Private Transportation Co. | Limited | Immediate | 1 | Short to Medium |
| 18 | Enhance Truck Inspection and Maintenance | Municipalities, Truck Operators | All | Immediate, ongoing | 1 - 2 | Short |
| **Improve Transportation System and Driver Efficiency** | | | | | | |
| 19 | Increase Infrastructure Capacity | Local, Regional and Provincial Agencies | All | Short | 1 | Short, but Diminish over Long Term |
| 20 | Manage Roadway Capacity Dynamically | Municipalities, Provincial Transport Agencies | All | Immediate, ongoing | 1 – 2 | Short |
| 21 | Implement Speed Change Policies | Municipalities, Provincial Transport Agencies | All | Immediate, ongoing | 3 – 4 | Short |
| 22 | Optimize Traffic Signal Operation and Timing | Municipalities | All | Immediate, ongoing | 2 – 3 | Short |
| 23 | Implement Ramp Metering | Municipalities, Provincial Transportation | M, L | Immediate | 3 – 4 | Short |
| 24 | Improve Traffic Incident Management | Municipalities, Response Agencies | All | Immediate, ongoing | 3 – 4 | Short |
| 25 | Provide Transit Priority Measures | Transit Agencies, Municipalities | All | Immediate, ongoing | 2 | Short |
| 26 | Encourage Eco-driving | Government Agencies, Drivers | All | Immediate, ongoing | 3 - 4 | Short to medium |
| **Encourage Alternative Vehicle and Fuel Technologies** | | | | | | |
| 27 | Encourage Adoption of Efficient Vehicle Tech. | Industry, Government, Local Electrical Co. | All | Immediate, ongoing | 4 – 5 | Medium to Long |

| | Measure | Responsibility for Implementation* | Applica bility** | Timing of Implementation* | Reduction Potential*** | Reduction Timeframe* |
|---|---|---|---|---|---|---|
| **28** | Implement New Transit Vehicle Technologies | Industry, Government, Transit Agencies, Local Electrical Companies | All | Immediate for hybrid, Medium for FCV / EV. | 1 | Medium to Long |
| **29** | Encourage New Heavy-Duty Vehicle Tech. | Trucking Industry, Government | All | Immediate to Medium | 4 - 5 | Medium to Long |
| **30** | Use Low Carbon Fuels | Provincial and Federal Governments | All | Immediate | 2 | Short |

**Definitions are provided in Chapter 3.* ***All – all municipalities, S – small, M – medium, L – large municipalities.* ****Scale of Very Low – 1 to Very High - 5*

***Responsibility for Implementation***

Reducing transportation GHG emissions will require efforts by a wide range of actors. However, as owners and operators of infrastructure and transportation services, municipalities and transit agencies have a significant role to play in the majority of the transportation supply side and transportation system optimization measures described in this toolbox. Land use planning, parking controls, transit provision, active transportation, traffic control and roads and transportation system optimizations are key responsibilities of local and regional agencies, recognizing that some of the funding support may come from upper levels of government.

Measures which typically fall under the jurisdiction of provincial or federal governments include economy wide pricing measures such as carbon taxes and VKT fees, vehicle fuel-economy standards and fuel carbon content. Provincial and federal agencies are also responsible for some of the toll pricing and infrastructure measures applicable to provincial highways or bridges within urban areas.

For several measures, the lead agency responsible for implementation has typically fallen on non-public sector actors, although municipalities and transit agencies may serve as important partners for implementation. Taxi-bus transit or carsharing programs are typically operated by private or not-for profit corporations. Transit agencies or local municipalities can specify operational requirements and facilitate these services through permissive parking regulations. Commuting programs, such as carpooling and offering fees in lieu of travel, or parking cash-out, are the responsibility of public and private sector employers, although public agencies can support awareness and coordination or even provide funding for such programs. Enhancing vehicle fuel efficiencies through vehicle technology development has been led by private vehicle industry, although provincial or federal governments can and have set the regulations and incentives to drive this development. On vehicle and fuel technologies, municipalities can deploy charging infrastructure, allow access to dedicated travel lanes (e.g. HOV lanes), enact supportive parking bylaws and demonstrate leadership through fleet vehicle procurement. Truck logistics management, modal shift and vehicle efficiency developments have typically been led by the trucking industry, although public agencies have played a supporting role in information diffusion, financial subsidies or regulations.

***Applicability of Measures by Size of Municipality***

There are a large number of measures which can apply to municipalities of all sizes. Land use planning and transportation supply alternatives such as transit, active transportation, carpooling and telecommuting can be applied in any size of municipality, although the extent and intensity of implementation may vary (e.g. geography and level of service). Economy wide pricing measures such as carbon taxes, fuel taxes, VKT fees, or distance based insurance costs apply irrespective of size of municipality. Most transportation system and vehicle operation efficiency measures can be applied in all sizes of municipalities, although those with greater congestion issues will tend to see greater benefits from these traffic-flow and congestion relief measures (i.e. medium and large municipalities). Finally, more efficient vehicle technologies are universal and do not depend on municipal size.

The application of some measures will likely be restricted to medium and large municipalities where population densities, travel demand to specific areas and traffic congestion are greater. Carsharing services are likely only to be feasible in areas where a sufficient population base is living in close proximity to vehicle locations to ensure sufficient use and financial viability of maintaining carsharing vehicles. Toll roads, cordon/area pricing, as well as increased parking costs become viable options to reducing GHG emissions where travel demand and congestion around specific areas such as downtowns and major employment centres are high. Furthermore, travel time savings from choosing active transportation or transit is typically only realized where road congestion is present. Higher population densities, travel demand and congestion issues are determining factors in whether certain measures are more appropriate to larger sized municipalities.

***Timing of Implementation***

Most of the measures described in this toolbox can be implemented by the appropriate agencies in the immediate or short term under the assumption that political will and financial constraints (e.g. availability of funding, support from upper levels of government) have been addressed. Generally, there are few overarching knowledge gaps or technical barriers to implementing transportation supportive land use planning, transit, active transportation, carpooling, carsharing, pricing mechanisms, parking and transportation system optimization policies, programs or projects in the immediate or short term. Furthermore, certain measures, such as land use planning, optimizing existing transit services and roadway use, and parking management, require ongoing and sustained implementation over the long term. Site specific planning, design and construction considerations may slow implementation. However, the fact that there are many examples of these measures implemented across North America shows that they are “technically-ready” for adoption and integration within policies and plans when the opportunity arises (e.g. planning review cycle comes up).

Certain measures may not be ready for immediate or short term implementation. Of note, comprehensive or region-wide pricing mechanisms may take a longer timeline for implementation in certain jurisdictions, since they would need to be complemented by viable, attractive, alternative transportation options (e.g. mature transit system) in order to produce significant GHG reductions. Otherwise, travel or economic activity may be penalized, or travellers may have to continue driving. More sophisticated distance based pricing or insurance schemes based on traveller time of day or area of travel may also not be ready for implementation in the short term, as they still require continued technological development of more sophisticated tracking devices and systems to collect fees.

This is also the case with respect to new vehicle propulsion technologies. Light-duty hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), and battery electric vehicle (BEV) models area already commercially available in Canada. However limited vehicle choice options, travel distance constraints, up-front acquisition costs, and limited recharging infrastructure are slowing adoption. Jurisdictions offering financial incentives to offset acquisition costs are seeing greater rates of electrification of their light-duty vehicle fleets. Furthermore, municipalities and other agencies can continue to support the uptake of these technologies through continued monitoring and demonstration of technologies and deployment of electrical charging infrastructure, measures which can be undertaken in the short term.

***GHG Reduction Potential***

The potential of measures to reduce overall urban transportation GHG emissions was scored qualitatively in this report (see Table ES-1). Scores were derived based a review of two key US works comparing GHG emission reduction potentials from transportation, one published in 2009 by the Urban Land Institute, and the other in 2008 by Nelson\Nygaard Consulting Associates. The results of these studies were compared against current Canadian transportation modal share and GHG contributions. Further information about this analysis is explained in Appendix B of this report. Findings from this analysis are presented in order of highest to lowest potential to reduce overall urban transportation GHG emissions:

- Applied provincially or nationally, **economy wide pricing mechanisms** such as carbon pricing, VKT fees, and distance-based insurance costs could have the most significant impact on reducing GHG emissions. In Canada, such measures would target vehicle modes currently contributing to around 150 Mt / year (>80%) of transportation GHG emissions;

- More **regional and local pricing mechanisms** can also have a significant effect on transportation GHG emissions, though not to the extent of economy wide pricing measures. Where high travel demand exists to central or major employment areas, or where there is road congestion along major routes or in certain areas, tolls, congestion pricing and parking pricing can serve as an incentive for other forms of transportation;

- More efficient **light-duty and heavy-duty vehicle technologies** have a significant potential to reduce transportation GHG emissions. Alternative powertrains for light-duty vehicles like plug-in hybrids and fully electric vehicles can significantly reduce or eliminate fossil fuel dependence for most urban transportation purposes in jurisdictions with less GHG intensive energy generation. Similarly, alternative fuels and hybrid systems have the potential to significantly reduce urban truck GHG emissions. Truck aerodynamic improvements and low rolling resistance tires will have a more limited impact for urban transportation as compared to interurban travel due to generally lower vehicle speeds;

- **Eco-driving** strategies applied nationally could have a relatively important impact on transportation GHG emissions. Once again in Canada, wide-scale eco-driving training could target drivers who currently contribute to approximately 150 Mt / year (>80 %) of transportation GHG emissions;

- Comprehensive **transportation-efficient land use developments** can play a major role in reducing VKT, trip length and vehicle transportation GHG emissions, especially when combined with alternative transportation supply measures such as transit and active transportation. In Canada, land use, transit, and active transportation measures would be aimed at passenger vehicle transportation, which currently contributes just over 88 Mt / year (>50%) of transportation sector GHG emissions;

- **Employer-based commute strategies**, which include encouraging carpooling, parking demand management and pricing, and compensating employees for choosing alternative modes of transport were found to have about the same impact as the land-use and eco-driving strategies;

- Individual **transportation supply side initiatives** were ranked in decreasing order of impact in terms of being able to reduce overall transportation GHG emissions: transit expansion, pedestrian strategies, bicycle strategies, car sharing and improving transit levels of service;

- Measures to improve the **transportation system's efficiency** (through reducing congestion and enhancing traffic flow) were ranked in decreasing order of impact: ramp metering, incident management, travel corridor management, and signal control management. In Canada, these system efficiency measures would be targeted at all vehicle modes currently contributing around 150 Mt / year (>80%) of transportation GHG emissions.

- Measures to reduce freight VKT through intermodal transportation were found to reduce overall urban transportation GHG emissions marginally due to limited scope of application within urban areas;

- The Moving Cooler Study found that all road infrastructure capacity expansions, including targeted bottleneck relief, would eventually contribute to a net increase in cumulative GHG emissions. Emissions reductions and smoother traffic flow may result immediately after construction, but induced traffic in the longer term ultimately erases initial reductions in GHG emissions.

The Moving Cooler Study found that the current-upper-bounds of an all-out, economy wide effort to reduce transportation sector GHG emissions in the U.S. were up to **16% cumulative reductions** of US road-based transportation sector GHG emissions over that study's 40 year study horizon (2010 to 2050). In Canada, the estimated road and rail passenger and freight transportation emissions between 2015 and 2030 is approximately 2,415 Mt. If the maximum effort estimated in the Moving Cooler Study were applied to the baseline emissions for the Canadian road sector between 2015 and 2030, it is estimated reductions in GHG emissions would represent approximately 386 Mt of GHG emissions, or an average of 26 Mt GHG / year over the 15 years[2].

***Timeframe for Reductions to Occur***

This report evaluated when GHG reductions would be expected to occur if measures were implemented in the immediate or short term (where possible). Implementing transportation efficient land use patterns may begin to result in some emissions reductions in the short term. However, the maximum potential of land use in reducing VKT and trips is not likely to occur until the long term due to the long time it takes for full build out. Similarly, while encouraging more trips to be made by transit and active transportation can result in immediate reductions in GHG emissions, the full potential of these measures on a region wide scale will likely not be achieved until the medium to long term in conjunction with supportive land use development.

Pricing mechanisms and parking control mechanisms can result in GHG emissions reductions in the short term due to the direct financial impact to drivers. Similarly, transportation system optimizations such as speed control policies, traffic signal and corridor optimization and incident management can improve traffic flow rapidly after implementation. It should be noted that roadway and intersection capacity expansion can lead to immediate improvements in traffic flow and GHG reduction. However, in the absence of other control measures, induced traffic over the long term can negate early gains in terms of GHG reduction.

The full potential of vehicle propulsion and efficiency technologies are not likely to be achieved before the medium to long term due to the long time required before a significant turnover of light-duty, transit and heavy-duty vehicle fleets occur. Technological readiness and energy distribution or charging infrastructure for these new vehicles are also less mature or widespread than current fossil-fuel based systems, thereby slowing adoption rates and significant short to medium term GHG reductions.

***Comparing GHG Reduction Potential Against Cost of Implementation***

The scores for the GHG reduction potential of measures were plotted against cost of implementation (for the agency or agencies who would be responsible for implementation)[3]. Measures which perform

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*[2] This value is calculated by dividing total cumulative emission reductions over 15 years. However, annual reductions in early years are unlikely to be this high, as land use changes and vehicle fleet turnover are not expected to produce significant emission reductions until the medium or long term.*

*[3] The metric, GHG reduction potential / cost of implementation, should not be confused with the term "cost-effectiveness". Cost effectiveness measures the cost of reducing a given quantity, for example 1 tonne of GHG emissions ($ / tonne of GHG). Cost-effectiveness was not evaluated in this report, as the scope of the undertaking was beyond the resources available to this mandate.*

better on this metric are located in the top left (light blue shaded area). The result of this cross comparison is shown in Figure ES-1. The results of this comparison include:

- Transportation efficient land-use planning (1) scores highly in terms of overall GHG reduction potential and modest cost. Implementation costs will vary depending on the scope of the changes to policy, program or regulations being considered. However, compared to some other capital intensive measures such as transit or road capacity expansion, implementing land use policies could generally be considered a lower cost measure;

- In terms of transportation supply side alternatives, public transit optimizations (2b) score well in terms of overall reduction potential at medium cost. Transit expansion (2a) has a similar potential for significant GHG emission reductions, but may require substantial investments to implement. Improving active transportation (4), carpooling (5), carsharing (6), and telecommuting (7) do not generally have the same potential to reduce GHG emissions as transit, but lower costs of implementation mean they generally score well in terms of reduction potential / implementation costs;

- Pricing mechanisms (Measures 8 – 13) generally fall into the top left half of the plot. This is supported by the literature (Cambridge Systematics Inc., 2009), which finds that financial mechanisms can be strong levers for achieving significant GHG reductions. Other than a distance-travelled fee (9) and tolling systems, they are also relatively cheap to implement, as they generally only require programmatic and administrative changes, and capital costs for equipment acquisition are relatively low;

- Parking control measures (14, 15) score moderately low in terms of overall GHG reduction potential / implementation costs. While they are relatively cheap to implement, their effect is limited to central areas where parking demand is high;

- Measures to reduce truck VKT fall into the middle and bottom of the plot. Of the three main measures considered, logistics management (16) scores highest, as optimizations of existing deliveries prove to be relatively low cost. Modal transfer (17) and truck inspections (18) do not result in significant GHG reduction impacts for urban transportation. The former is typically not viable for short distance, intra-urban travel. Both also require moderate costs for operations of trans-shipment centres or inspection facilities;

- Increasing the capacity of the transportation system to reduce congestion and smooth traffic flow score low in terms of GHG reduction potential / implementation costs (Measures 19, 20). While there may be other reasons to increase infrastructure capacity (e.g. economic development) and enhance traffic flow, these measures require more significant capital and operational investments. Furthermore, making driving easier and more fluid acts as incentives to vehicle use and can, in the medium and long terms, induce further vehicle travel;

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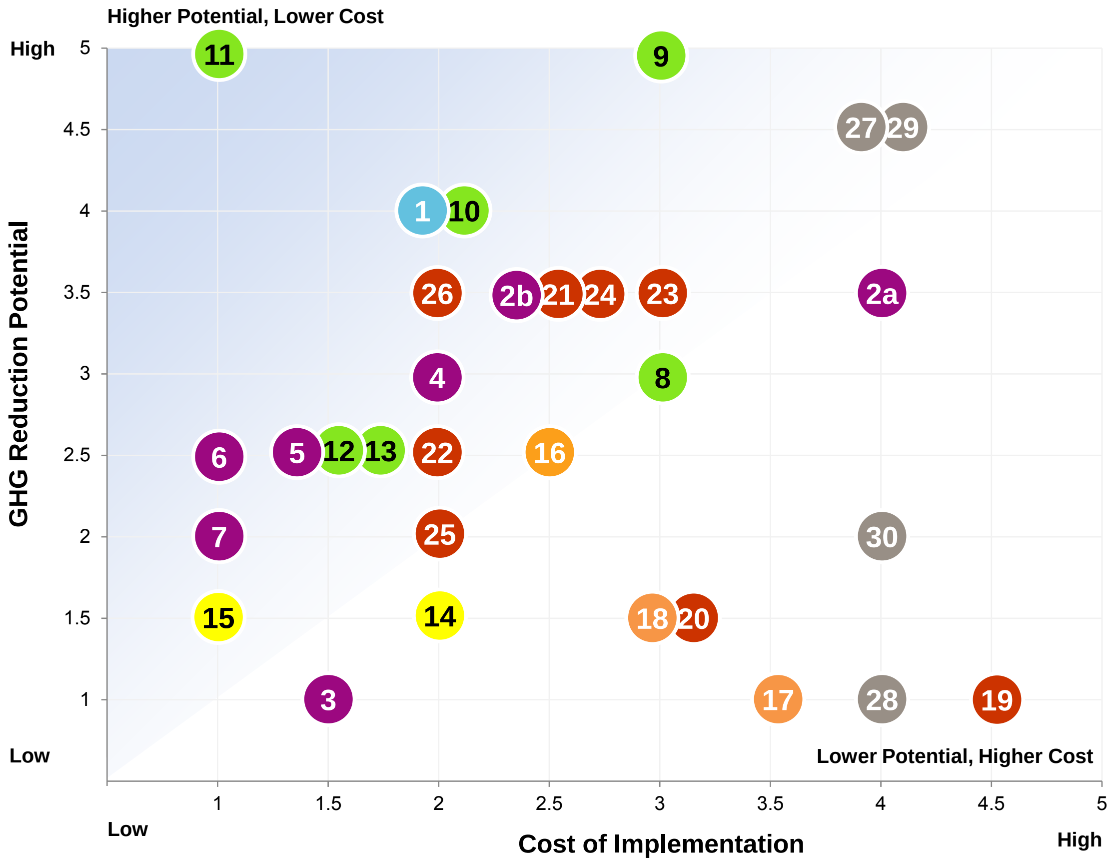
*Information that was found in the literature and document review was not sufficient to support a comparison of cost-effectiveness across all measures. A study completed by Nelson/Nygaard provides some information about the cost-effectiveness of different measures relevant to the Bay Area Rapid Transit System. This information is presented in Appendix B of this report.*

- Measures to improve traffic flow and relieve congestion which score well are speed change policies (21), incident management (24), ramp metering (23), and traffic signal operation and timing optimization (22). These measures do not rely on building additional lane capacity, and municipalities can and typically do (with the exception of ramp metering) already implement these measures on an ongoing basis to make the most use out of their existing infrastructure. Similarly, implementing transit priority measures (25) proves to be relatively low cost. The contributions of transit vehicles to overall transportation GHGs are low, but improvements to travel time and service reliability can play an role in encouraging modal transfer;

- Encouraging eco-driving (26) for all drivers through awareness and training scores well in terms of potential GHG reductions and cost of implementation. Awareness and training programs are relatively inexpensive to apply, and can lead to important reductions in fuel consumption if eco-driving achieves widespread adoption;

- Improvements to light-duty and heavy-duty vehicle technologies (27, 29) are generally high-cost/high impact measures. They can yield significant fuel consumption and GHG emission reductions, but require significant investment for technology development by manufacturers, acquisition by truck operators or owners, and deployment of support infrastructure by local or regional agencies. However, note that vehicle operating cost

## Figure ES 1 – GHG Reduction Potential versus Cost of Implementation for Responsible Agency




| | | | | | |
|---|---|---|---|---|---|
| 1 | Land Use | 11 | Fuel / Carbon Tax | 21 | Speed Change Policies |
| 2a | Transit Expansion | 12 | Parking Costs | 22 | Traffic Signal Optimization |
| 2b | Transit Service Optimization | 13 | Fees in Lieu of Travel / Parking | 23 | Ramp Metering |
| 3 | Taxibus | 14 | Parking Optimization | 24 | Traffic Incident Management |
| 4 | Active | 15 | Parking Requirements | 25 | Transit Priority Measures |
| 5 | Carsharing | 16 | Truck Logistics | 26 | Eco-driving |
| 6 | Carpooling | 17 | Modal Shift | 27 | Efficient Vehicle Technologies |
| 7 | Telecommuting | 18 | Truck Inspection Maintenance | 28 | Transit Vehicle Technologies |
| 8 | Tolls | 19 | Road Infrastructure Expansion | 29 | Heavy-Duty Vehicle Technologies |
| 9 | Distance Travelled Fee | 20 | Dynamic Capacity Management | 30 | Low Carbon Fuels |
| 10 | Distance-Based Insurance | | | | |

savings were not estimated or considered in this evaluation. These vehicle operating cost savings to car and truck operators may off-set initial acquisition costs, increasing the attractiveness of these measures;

- Improving transit bus vehicle technologies (28) scores low in terms of overall GHG reduction potential / implementation costs because transit vehicles currently contribute little to overall transportation GHG emissions. These measures are however still relevant to transit agencies to demonstrate environmental leadership and reduce their own GHG emissions;

Reducing fossil fuel consumption, energy use and GHG emissions are not the only benefits to the measures described in this toolbox. Many measures also have co-benefits in terms of increasing the mobility of travellers, improving the livability of urban areas, improving the environment, and enhancing public health and traveller safety. Increasing transportation options and reducing the need for motor vehicles for travel also enhances equity for low-income households.

### *Other Considerations*

This toolbox provides basic information about measures, high level implementation considerations, and a qualitative evaluation of the factors which serve as an initial analysis of the available information. Social acceptability and technical feasibility of implementing measures are also discussed in this report.

While this toolbox attempts to cover a whole range of different actions, it recognizes that there are specific contexts across Canada that make certain measures more applicable to some cases than others. Notably, the state of existing transportation systems and services, political context, budget availability and time horizons for action will determine the kinds of measures that can be implemented. Opportunities for action, such as funding from upper levels of government, plan; policy or infrastructure renewal cycles; or broader planning processes, will also provide context for the identification and selection of measures. The responsibilities of the implementing agency, whether a local municipality, regional government or transit agency, will also determine what measures can be implemented. Each jurisdiction will ultimately need to assess the opportunities and constraints within their own local context to determine the most appropriate set of measures to reduce transportation based GHG emissions.

### *Future Work*

The evaluation of the GHG reduction potential of measures to reduce transportation GHG emissions presented in this report was qualitative in nature, as it was drawn from a review of previous works. Further research and work is required to provide a better determination of the GHG reduction potential of specific measures in the Canadian context. Specifically, a more comprehensive quantitative evaluation of the GHG reduction potentials could be identified for each measure, or groups of measures through a close examination of local conditions and opportunities across the country. A determination of which measures are applicable, and consideration of how they might be implemented, would need to be completed. Hypotheses as to the geographical extents, timing of application, and intensity of the effort would need to be made. The consideration of these parameters would provide more information about economic costs, benefits, cost-effectiveness and implementation considerations of measures. Such an analysis could be carried out for a region, province or across the country.

# 1 – Introduction

In recognition of the significant impacts and risk of climate change, municipalities and regional agencies across Canada are working to reduce energy use and greenhouse gas (GHG) emissions across a broad range of sectors. As the transportation sector accounts for almost one-quarter of GHG emissions in Canada (Government of Canada, 2014a), municipalities and regional planning and transit agencies have placed significant focus on reducing this sector's emissions. Significant changes to land use, travel behavior, travel mode and technology options will be required.

In addition to a changing climate, Canada's municipalities and regions face a diversity of other issues and challenges. For example, increasing population growth increases pressure for land development, infrastructure service provision and the conservation of agricultural and natural areas. Demand for travel and the predominance of the automobile over the last half century has created challenges of congestion, air and noise pollution. Demand for infrastructure and public transit has not ceased, and aging and underfunded infrastructure is leading to degradation in service levels, quality and reliability. A changing energy landscape and fluctuations in energy prices can affect travel costs and affordability. At the same time, municipal governments face constraints such as limited staff resources and funds, and the ability to keep up with best practices and constantly changing technologies. Clearly, municipalities and regions are constantly looking for practical solutions to address multiple objectives and a broad range of issues including climate change.

Opportunities to address these issues can arise on multiple occasions or be triggered by various activities. For example, municipalities and regions may be updating or developing new land use, transportation, parking, sustainability or GHG reduction policies or plans. They may be considering the creation or renewal of programs to deal with mobility, infrastructure renewal, employment or redevelopment. Finally, they may be considering the design, extent, alignment, or level of service of new infrastructure projects. These activities represent key opportunities in which to integrate measures to reduce transportation GHG emissions.

In the context of these challenges and opportunities, this report was developed to help municipal and regional agencies understand and assess available options for reducing GHG emissions from the transportation sector. The objectives of this report are to:

- Provide a framework, whereby municipalities and regional agencies can explore the benefits and costs of available options for reducing transportation-related energy and greenhouse gas emissions within their own local context, which could enhance the regional and municipal decision-making and planning processes aimed at reducing GHG emissions as well as achieving broader sustainability and efficiency goals;
- Help municipalities and regional agencies identify locally-relevant best practices, measures, approaches and options to reduce energy consumption, GHG emissions and mitigate congestion from urban transportation;
- Share and leverage the technical knowledge that many cities and regional agencies are already undertaking in the areas of climate change mitigation and transportation energy efficiency planning;

This report seeks to provide readers with ideas for reducing urban transportation GHG emissions and help them identify, weigh and select the most appropriate measures or bundle of measures when policy, program or project level opportunities arise. Readers can use the information provided in this report to:

- Identify a list of measures which are applicable to their jurisdiction based on the size of their municipality and to their area of responsibility (e.g. as a transit agency, municipality, etc.);
- Short list measures for further investigation based on an examination of the GHG reduction potential of measures, costs, technical feasibility and social acceptability;
- Explore options to support or augment the actions already underway in their own jurisdiction;
- Conduct further evaluations of measures within their local context to determine locally specific feasibility issues, budget requirements, GHG reduction potential and constraints;
- Understand benefits and disadvantages of various measures in order to build arguments and support for policy choices;
- Identify constraints and barriers which need to be addressed in their own jurisdiction, or which may remove certain measures from further consideration;
- Build an action plan based on the implementation considerations and timing of application.

This report is suitable to a wide audience of readers, including planners, policy makers, engineers, sustainability and energy managers, fleet managers, etc. working in small, medium and large municipalities and regions.

## 1.1 REDUCING TRANSPORTATION GHG EMISSIONS

The goal of urban transportation is to facilitate the movement of people and goods in an efficient, affordable, safe and environmentally sustainable manner. However, a heavy reliance on fossil fuels as the dominant energy source for propulsion has resulted in urban transportation becoming a significant contributor to Canada's total GHG emissions (Government of Canada, 2014a). There are three main approaches to reducing transportation GHG emissions. They are:

- **Reduce Vehicle Kilometres Travelled**: Reducing distances travelled by passengers and goods by vehicle;
- **Improve Transportation System and Driver Efficiency**: Improving the efficiency of the transportation system so that more vehicles travel under more optimal conditions in terms of speed and flow;
- **Encourage Alternative Vehicle and Fuel Technology**: Adopting and supporting vehicles that use alternative fuels and technologies which are more energy efficient or use less GHG-intensive energy sources for vehicle propulsion.

The measures presented in this report (toolbox of measures) cover the three approaches to reducing energy efficient, encourage land development patterns which facilitate or reinforce these patterns and behaviours, and optimize the energy efficiency of vehicle travel and vehicle fleets. A full list of measures covered in this report can be found in Chapter 3.

**Sustainable Transportation and Reducing GHG Emissions**

Definitions of sustainable transportation are useful for outlining the broader context for reducing transportation GHG emissions. A comprehensive but succinct definition adopted by the Ministers of Transport of European Union countries is:

> *A sustainable transport system is one that allows the basic access and development needs of individuals, companies and societies to be met safely and in a manner consistent with ecosystem health, and promotes equality within and between successive generations.*
>
> *It is affordable, operates efficiently, offers choice of transport mode, and supports a competitive economy, as well as balanced regional development.*
>
> *It limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation, and uses non-renewable resources at or below the rates of development of renewable substitutes while minimizing the impact on the use of land and generation of noise* (EU Ministers of Transport, 2001).

Another definition adopted by the Transportation Association of Canada is:

> Sustainable transportation is the result of a continuous decision-making process that seeks to achieve a context-specific balance between environmental integrity, social equity, and economic opportunity both within and among transportation systems, now *and in the future.*

## 1.2 ORGANIZATION OF THIS REPORT

This report is divided into eight chapters. **Chapter 1** presents an introduction to this report. **Chapter 2** provides a background on transportation GHG emissions trends in Canada, and the drivers of transportation demand, including recent demographic, economic, energy generation and transportation contexts and trends to 2030. These contexts and trends provide a backdrop against which choices about appropriate measures to reduce transportation related GHG emissions will be made.

**Chapters 3** presents the structure of the toolbox of measures, and how the information about each measure was organized, assessed and evaluated.

Chapter 4 through 6 present the different measures for reducing urban transportation GHG emissions. Specifically, **Chapter 4** presents measures related to reducing vehicle kilometres travelled; C**hapter 5** presents measures related to improving transportation system and driver efficiency; and C**hapter 6** presents measures encouraging alternative vehicle and fuel and vehicle technologies.

**Chapter 7** presents a review of implementation considerations and performance indicators for each of the measures discussed in chapters 4 through 6. A comparative evaluation of the GHG reduction potential of measures, as well as comparisons with costs, technical feasibility and social acceptability of implementation are presented.

**Chapter 8** provides concluding remarks about the toolbox of measures as well as potential future work.

# 2 – Transportation GHG Emissions, Projections and Drivers

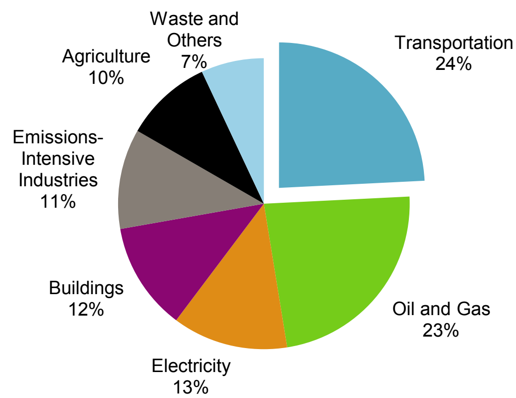
This chapter aims to set the stage for the toolbox of measures to reduce urban transportation GHG emissions by describing some of the considerations and factors influencing such emissions. First, this chapter presents an overview of GHG emissions in Canada, with specific focus on the transportation sector. Transportation GHG emissions projections and Canada's progress towards meeting its 2005 Copenhagen targets are then presented. As discussed in further detail below, Canada is not on track to meet its emissions targets, which highlights the need for and importance of continued efforts to reduce Canada's GHG emissions across all sectors, including transportation.

This chapter then presents some of the factors which influence travel demand. These factors include population and demographics, economic activity, travel patterns, vehicle fuel efficiency and the carbon intensity of vehicle fuels. Understanding these factors helps illustrate the drivers of transportation GHG emissions, since current transportation practices are predominantly powered by fossil fuels.

## 2.1 GHG EMISSIONS AND PROJECTIONS FOR THE TRANSPORTATION SECTOR IN CANADA

As shown in Figure 2-1, GHG emissions from the transportation sector (i.e. passenger and freight on road, air, rail, marine and non-industrial off-road travel) accounted for the largest portion (24%) of total Canadian emissions in 2011 (Environment Canada, 2014b). Of all the modes of transportation, road-based passenger and freight transportation accounted for the largest portion of GHG emissions (i.e. over 80% in 2011) within the sector[4].

**Figure 2-1 – Share of GHG Emissions by Economic Sectors in Canada, 2011**




Between 1990 and 2005, GHG emissions from the transportation sector grew from 128 Mt / year to 168 Mt / year (a 31 % increase). This growth is attributed to a strong period of economic growth coupled with low oil prices, which led to an increase in the number and proportion of light-duty trucks (e.g. pickups, SUVs and minivans) in the vehicle fleet, as well as an increase in freight activity. Since 2005, transportation emissions have remained relatively stable around 170 Mt / year. Fuel efficiency improvements for all vehicles has contributed to this trend, despite continued population growth, an increased number vehicles on the road and more VKT (see Section 2.2 for further details). Table 2-1 below presents a breakdown of GHG emissions from the transportation sector broken down by passenger and freight modes up to 2011.

[4] *At the time of writing, national GHG emissions data is available for Canada up to 2013. However, the only available GHG emissions projections to 2030 are based on 2011 national GHG emissions data. To ensure a consistent basis of comparison between current and projected GHG emissions, the 2011 GHG emissions data is presented in this report.*

Road and rail based passenger and freight transportation accounted for approximately 88 % (~150 Mt / year) of all transportation sector emissions in Canada in 2011. Passenger car, light truck and motorcycles accounted for 52 % (88 Mt / year) of that total, while urban bus and urban rail passenger transportation (e.g. transit service) accounted for less than 4 % (< 7 Mt / year)[5]. Freight by heavy-duty trucks and rail modes accounted for 32 % of emissions (54 Mt / year) in 2011.

The Government of Canada has developed GHG emissions projections across all sectors, including transportation, which are based on current federal and provincial policies and measures that were in place or announced as of May 2013 (see Government of Canada, 2014 for more details). As shown in Table 2-1, overall transportation sector emissions are projected to increase to 176 Mt by 2020, and 179 Mt by 2030, an increase of 7% between 2005 and 2030.

Road and rail based passenger and freight transportation is projected to account for approximately 84% of all transportation sector emissions in Canada in 2030 (151 Mt / year). Passenger car, light truck and motorcycles are projected to account for 39 % of that total (70 Mt / year). However, freight by heavy-duty trucks and rail modes are projected to account for 40% of emissions in 2030 (71 Mt / year). Total road and rail based passenger and freight transportation is projected to increase by 4% between 2005 and 2030. Figure 2-2 presents the same data graphically.

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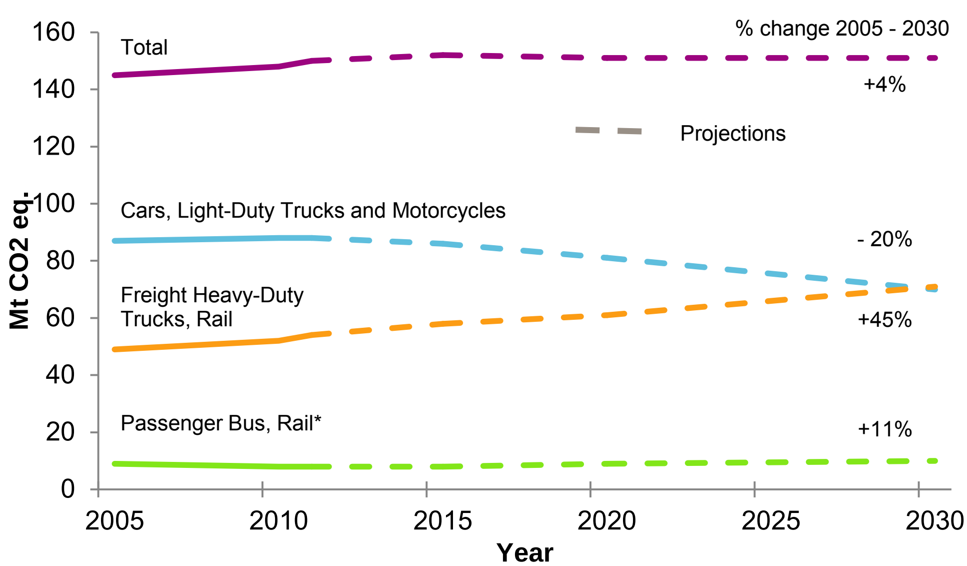
[5] *The category, Passenger Transportation by Bus, Rail and Aviation comprises emissions from domestic aviation, and urban and interurban passenger bus and rail service totalling 5 % of transportation emissions (8 Mt) in 2011. The contributions of domestic aviation can estimated based on Environment Canada's 2014 National Inventory Report. It reported that domestic aviation accounted for nearly 1 % of transportation GHG emissions in Canada in 2011 (Environment Canada, 2014).A specific breakdown of the contribution between interurban and urban passenger transportation was not available. Nonetheless, it is reasonable to hypothesize that urban bus and rail passenger transportation, or transit service, is likely to have contributed to less than 4 % of GHG (< 7 Mt) emissions in 2011.*

**Table 2-1 GHG Emissions from the Transportation Sector for 1990 to 2011, and Projections for 2020 and 2030 (Mt $CO_2$ eq.)**

| | 1990 | 2005 | 2010 | 2011 | % of 2011 emissions | 2020 | 2030 | % of 2030 emissions | % change 2005 - 2030 |
|---|---|---|---|---|---|---|---|---|---|
| Passenger transportation | n/a | 96 | 97 | 96 | 56% | 90 | 80 | 45% | -17 % |
| *Cars, Trucks and Motorcycles* | - | *87* | *88* | *88* | *52%* | *81* | *70* | *39%* | *-20 %* |
| *Bus, Rail and Aviation* | - | *9* | *8* | *8* | *4.7%* | *9* | *10* | *6%* | *11%* |
| Freight Transportation | n/a | 57 | 60 | 61 | 36% | 70 | 81 | 45% | 42 % |
| *Heavy-Duty Trucks, Rail* | - | *49* | *52* | *54* | *32%* | *61* | *71* | *40%* | *45 %* |
| Aviation and Marine | - | *8* | *8* | *7* | *4%* | *9* | *10* | *6%* | *25 %* |
| Other[6] | n/a | 14 | 11 | 13 | 8% | 15 | 18 | 10% | 29 % |
| Sub-total Passenger and Freight Road and Rail Transportation | n/a | 145 | 148 | 150 | 88% | 151 | 151 | 84% | 4% |
| **Total Transportation** | 128 | 168 | 167 | 170 | 100% | 176 | 179 | 100% | 7 % |

Source: (Government of Canada, 2014a)

**Figure 2-2 – GHG Emissions and Projections for Passenger and Freight Road and Rail Transportation, 2005 to 2030**




* Data for disaggregation unavailable. Includes passenger aviation emissions. Source: (Government of Canada, 2014a)

[6] *Includes recreational, commercial and residential transportation subsectors.*

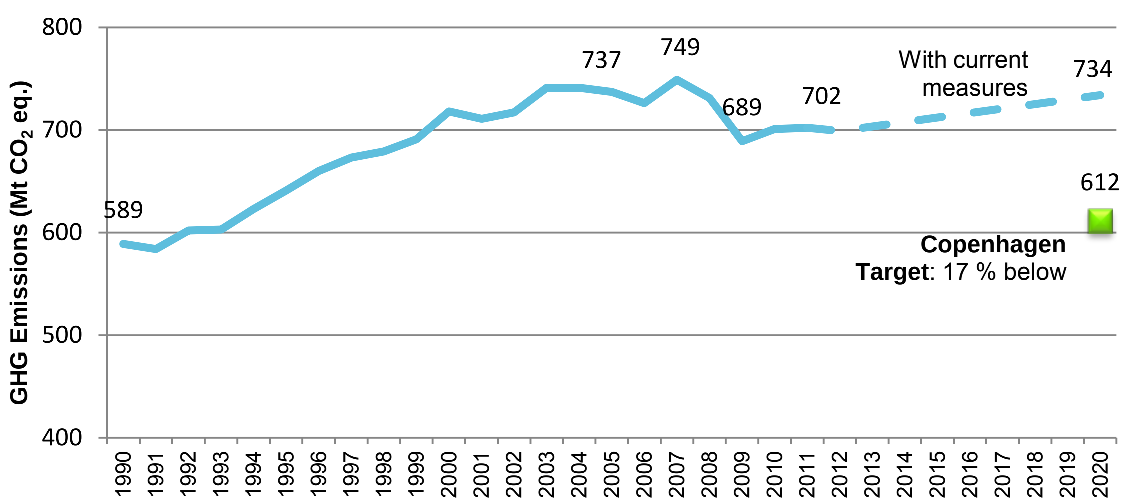
While GHG emissions from passenger transportation have largely been stable between 2005 and 2011 (around 96 Mt), they are projected to drop to 80 Mt by 2030 (a 17 % decrease between 2005 and 2030). This reduction is anticipated to come in large part from increasing fuel efficiency for light-duty vehicles such as cars and motorcycles (resulting in a 20% reduction in GHG emissions related to light-duty vehicles between 2005 and 2030). On the other hand, freight transportation, especially by heavy truck, is projected to increase its overall contribution to transportation sector GHG emissions. The heavy-duty truck and rail subsector (though primarily heavy-truck) is projected to emit 71 Mt of GHG emissions by 2030, up from 49 Mt in 2005 (increase of 45 %). This increase in freight-based GHG emissions is attributed to anticipated economic growth in spite of increasing fuel economy improvements for these vehicles. The contributions of urban bus and rail transportation to overall transportation GHG emissions is projected to increase only slightly, going from <7 Mt in 2011 to <10 Mt by 2030 (an increase of <11% between 2005 and 2030) (Government of Canada, 2014a).

### 2.1.1 Canada's GHG Emissions Target

Canada committed to reduce its GHG emissions to 17 % below 2005 levels by 2020 when it joined the Copenhagen Accord in January 2010. Despite this target, Canada's overall progress on GHG emissions to date, coupled with the Government of Canada's projections, show that Canada is not on track to meet its commitments. The Government's current projection of 734 Mt by 2020, a mere 0.5 % below 2005 levels, is some 122 Mt above its Copenhagen target of 612 Mt (Figure 2-3). They are projected to reach 815 Mt by 2030, an increase of 11% above 2005 levels.

**Figure 2-3 – Canadian GHG Emissions Trends, All Sectors (1990 – 2011) and Projection to 2020**

Source: (Government of Canada, 2014a)



## 2.2 DRIVERS OF TRANSPORTATION GHG EMISSIONS

Road transportation GHG emissions are a function of numerous factors, including population and demographics, economic activity, travel patterns, vehicle fuel efficiency and the carbon intensity of vehicle fuels. The rest of this chapter explores some of the patterns and trends with respect to these factors.

### 2.2.1 Population and Demographics

In general, population growth is a driver for increased travel demand. The Canadian population reached 35.1 million people in 2013. Together, Ontario (13.5 million) and Quebec (8.1 million) account for 62% of the country's total population, while British Columbia and Alberta count for approximately 10% (4 million) each (Statistics Canada, 2014a). Canada's population is projected to grow by 8% between 2013 and 2020 to over 38 million[7]. By 2030, the population is projected to reach 41.7 million, a 17 % increase relative to 2013. Table 2-2 presents Canadian population counts and population growth by province to the 2030 horizon (Statistics Canada, 2014a; 2014b).

**Table 2-2 – Population (2013) and Population Projections for Canada and Provinces (in thousands)**

| | 2013 | 2020 | Variation (2013-2020) (% change) | 2030 | Variation (2020-2030) (% change) |
|---|---|---|---|---|---|
| **Canada** | **35,158** | **38,025** | **8%** | **41,740** | **17%** |
| **British Columbia** | 4,582 | 5,243 | 14% | 5,947 | 25% |
| **Alberta** | 4,025 | 4,243 | 5% | 4,703 | 16% |
| **Saskatchewan** | 1,108 | 1,102 | -1% | 1,168 | 5% |
| **Manitoba** | 1,265 | 1,367 | 8% | 1,501 | 17% |
| **Ontario** | 13,538 | 15,000 | 11% | 16,744 | 21% |
| **Quebec** | 8,155 | 8,509 | 4% | 9,022 | 10% |
| **New Brunswick** | 756 | 785 | 4% | 811 | 7% |
| **Prince Edward Island** | 145 | 155 | 7% | 168 | 14% |
| **Nova Scotia** | 941 | 991 | 5% | 1,035 | 9% |
| **Newfoundland and Labrador** | 527 | 512 | -3% | 515 | -2% |
| **Yukon** | 37 | 36 | -3% | 38 | 2% |
| **Northwest Territories** | 44 | 47 | 8% | 51 | 15% |
| **Nunavut** | 36 | 36 | 1% | 39 | 8% |

Source: (Statistics Canada, 2014a; 2014b)

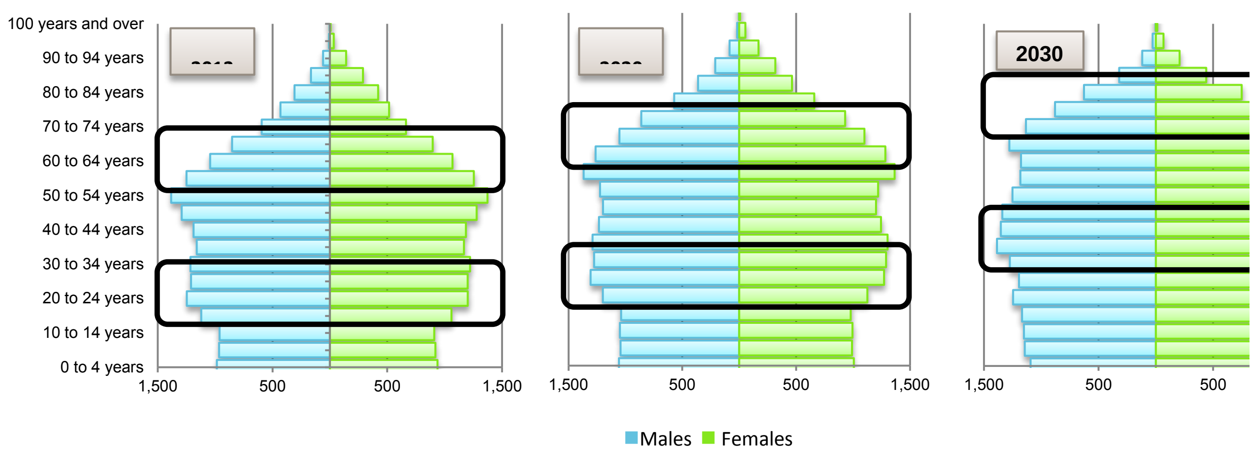
[7] Statistics Canada develops national population growth projections under low, medium and high growth rate scenarios. Scenarios take into account the following factors: 1) Natural population growth: births, deaths, gradually increasing life expectancy and improving health conditions; 2) Migration: Immigration to Canada, Canada emigration and interprovincial migration; 3) Population projections for each of the individual provinces take into account the same factors, but also include trends in interprovincial migration. The figures used in this section are for the medium growth scenario.

Population growth projections vary significantly between provinces. For example, British Columbia and Ontario are expected to see their population grow by 25% and 21%, respectively, between 2013 and 2030, while the population of Newfoundland and Labrador is expected to decline by 2% over the same period. The populations of Saskatchewan and Yukon are expected to decline between 2013 and 2020 by 1% and 3%, respectively, but grow by 6% between 2020 and 2030, which offsets the initial decline for a positive overall growth rate over the 2013-2030 period. The other provinces (Alberta, Manitoba, Quebec, New Brunswick, Prince Edward Island, Nova Scotia, Northwest Territories and Nunavut) are projected to have population growth rates that vary between 7% and 17%.

While continued population growth suggests that travel demand will increase, demographic changes and the characteristics of specific age cohorts also influence travel patterns. Specifically, research suggests that baby boomers (i.e. persons born between 1945 and 1964 and who currently represent a large cohort in Canadian society) will be retiring over the next several decades and will drive less as a result. Furthermore, the millennial generation (i.e. persons with birth years ranging from the early 1980s and to the early 2000s) is also showing a tendency towards driving less, owning fewer vehicles, and getting a driver's licence later in life, thereby placing downward pressure on travel demand by vehicle (McGuckin, 2014; Pickrell, 2014; State of Oregon, 2014).

Figure 2-4 shows a demographic breakdown of the Canadian population in 2013, as well as projections to 2020 and 2030. The baby boomer generation and the millennial generation are shown as black rectangles on the age pyramids. It is predicted that while VKT in Canada will continue to rise to 2030, a range of factors including the driving tendencies of retiring baby boomers and the millennial generation are expected to slow VKT growth going forward (McGuckin, 2014; Pickrell, 2014; State of Oregon, 2014).

**Figure 2-**4 – Age **Pyramids (in thousands) of the Canadian Population, 2013, 2020 and 2030**



Canada's population is mostly urban. According to Statistics Canada, more people have lived in urban areas[8] (defined as centres with 1000 or more people) than rural areas since the 1930s. Furthermore, the proportion of people living in urban areas has continued to increase (Statistics Canada, 2011). In 2011, 81 % of Canada's population lived in urban areas (Statistics Canada, 2011).

Data from 33 census metropolitan areas (CMA) from 1996 to 2006 showed that larger cities are growing faster than smaller cities in both absolute and percentage terms (TAC, 2010)[9]. Over those 10 years, approximately 3.4 million people were added to those 33 CMAs, 42 % of which were captured by Toronto, Montreal and Vancouver (TAC, 2010).

The tendency of population growth to be focused in urban centres suggests that urban transportation issues such as infrastructure capacity constraints, traffic congestion and air pollution, which are already significant challenge facing medium and large urban centres, will likely continue into the future as urbanization and suburbanization is projected to intensify (Transport Canada, 2011b). However, urban areas will also be key to mitigating transportation GHG emissions, as they provide greater opportunities for the development of transportation-efficient land use, which in turn makes alternative forms of transportation such as transit, active transportation and carpooling possible and feasible (Kamal-Chaoui & Robert, 2009). In fact, the greater use of alternative forms of transportation in larger Canadian urban areas is a circumstance that has been demonstrated statistical data (see **section 2.2.3** below for further details).

### 2.2.2 Economic Outlook

Economic growth will also be a contributing factor to travel demand. As shown in Table 2-3, the Canadian economy is projected to expand by 2.3% per year on average from 2014 to 2019 and by 1.6% for the 2020-2030 period (Government of Canada, 2014c). Economic growth is partly a result of increased domestic, cross-border and global trade, as well as demand for goods and commodities. This will drive freight transportation demand across the country (Transport Canada, 2011b).

**Table 2-3 – Average Annual Growth Rates in GDP in Canada**

| | 1970-2013 | 2014-2019 | 2020-2030 |
|---|---|---|---|
| **Real GDP growth** | 2.8 % | 2.3 % | 1.6 % |

Source: (Government of Canada, 2014c)

Demand for commodities such as oil and other natural resources will favour goods movements to export gateways (such as Vancouver, Montreal and Halifax) from resource-based regions such as Alberta,

[8] *While Statistics Canada's exact definition of an urban area has varied over time, it has generally referred to centres with 1000 or more people. In 1981, this definition was specified to mean areas with 1000 or more people AND with 400 or more persons per square kilometre. In 2011, the term urban area was replaced by the term population centre, and is broken down into three types: small population centres, with a population of between 1,000 and 29,999; medium population centres, with a population of between 30,000 and 99,999; and large urban population centres, consisting of a population of 100,000 and over.*

[9] *The 33 CMAs included in the Transportation Association of Canada's Urban Transportation Indicators 4th Survey were Abbotsford, Barrie, Brantford, Calgary, Edmonton, Greater Sudbury, Guelph, Halifax, Hamilton, Kelowna, Kingston, Kitchener, London, Moncton, Montreal, Oshawa, Ottawa-Gatineau, Peterborough, Quebec City, Regina, Saguenay, Saint John, Saskatoon, Sherbrooke, St-Catherine's-Niagara, St. John's, Toronto, Thunder Bay, Trois-Rivieres, Vancouver, Victoria, Windsor and Winnipeg.*

Saskatchewan, Ontario, Quebec and Newfoundland and Labrador. At the same time, the development of these resource industries will also spur freight transport through the development of their industrial supply chains. The weak Canadian dollar and the economic recovery in the USA are also expected to benefit the manufacturing and service sectors and contribute to increased cross-border trade (Conference Board of Canada, 2015). This is especially significant for road transportation, as 45 % of Canadian exports to the USA were made by truck in 2011 while 73 % of imports from the USA were similarly transported (Government of Canada, 2014a). Trade agreements with Europe, China and other potential trans-Pacific trade partners will also open up new markets to Canadian exporters and thus result in increased freight movements across the country (Government of Canada, 2014b).

### 2.2.3 Transportation Patterns

According to the 2011 National Household Survey (NHS), nearly four out of five Canadian commuters used private vehicles to get to work (74% of Canadian workers drive and an additional 5.6% travel as passengers). 12% of Canadians used public transit for the longest part of their commute in 2011. Of public transit users, 63.5% commuted by bus, 25% by subway/elevated rail, 11.2% by light rail, streetcar or commuter train, and 0.3% by ferry. Active modes of transportation accounted for 7.0% of all commutes, with 5.7% of workers walking to work and 1.3% cycling. Table 2-4 below illustrates changes in transportation modal shares, as reported by Statistics Canada, between 2001 and 2011.

**Table 2-4 Transportation Mode Trends (2001-2011)**

| Mode of Transportation | Proportion of Total Commutes | | |
|---|---|---|---|
| | 2001 | 2006 | 2011 |
| **Car, Truck or Van – as Driver** | 73.8% | 72.3% | 74.0% |
| **Car, Truck or Van – as Passenger** | 6.9% | 7.7% | 5.6% |
| **Public Transit** | 10.5% | 11.0% | 12.0% |
| **Walked or Bicycled** | 7.8% | 7.7% | 7.0% |
| **Other** | 1.1% | 1.2% | 1.2% |

While the proportion of commuters travelling by private vehicle has decreased slightly from 2001 (80.7%) to 2011 (79.7%), the proportion of carpoolers also decreased, going from 7.7% in 2006 to 5.6% in 2011. Conversely, the proportion of commuters travelling via public transit has increased through each Census year, rising from 10.5% in 2001 to 12.0% in 2011. Census data also indicates that the proportion of workers using active transportation to get to work decreased from 7.7% in 2006 to 7.0% in 2011, primarily due to a decrease in the number of commuters who walked to work (Statistics Canada, 2014a).

2011 NHS data for 33 census metropolitan areas (CMAs)[10] was analysed to examine how the transportation modal share during the commute to work may vary between cities of different sizes (Table 2-5). The results of the analysis indicated that the proportion of workers using a private vehicle to commute to work generally decreases as the population of the CMA increases. Furthermore, commuters living in the largest CMAs were much more likely to take public transit to work. This is partially due to longer trip distances, increased transit availability and service levels, as well as constraints such as road congestion. The proportion of commuters that walked or bicycled to work was generally consistent regardless of the size of the CMA, although Victoria had a substantially higher proportion (15.9%) than other CMAs (Statistics Canada, 2013). That city's mild year-round climate compared with the rest of the country is a contributing factor.

**Table 2-5 Mode of Transportation by CMA (2011)**

| Number of People | % of Total Commutes | | |
|---|---|---|---|
| | Car, Truck or Van | Public Transit | Walked or Bicycled |
| **Over 2M** | 70.1% | 22.2% | 6.6% |
| **500K – 2M** | 78.1% | 14.2% | 6.6% |
| **190K – 500K** | 85.0% | 6.5% | 7.2% |
| **Under 190K** | 88.7% | 3.8% | 6.1% |

### 2.2.4 VKT and Vehicle Ownership

VKT in Canada has been increasing along with demographic and economic growth. The amount of light-duty[11] VKT from 1990 to 2012 grew from 264 billion to 354 billion VKT (an increase of 34 %), while heavy-duty[12] vehicle freight activity grew from 115 billion tonne-km[13] to 295 billion tonne-km (an increase of 157%) over the same time period. In terms of average distance travelled each year, Canadians drove their vehicles less in 2012 on average compared to 1990. Average annual VKT per light-duty vehicle went from 17,787 km in 1990 to a peak around 2005 of 18,116 km, before decreasing to 16,481 km in 2012. Annual average VKT for all heavy-duty vehicles has remained relatively stable between 1990 to 2012 (around 27,000 to 30,000 km / vehicle), although annual VKT of long-haul heavy

[10] *The CMAs analysed were: Toronto, Montreal, Vancouver, Ottawa-Gatineau, Calgary, Edmonton, Quebec, Winnipeg, Hamilton, Kitchener-Cambridge-Waterloo, London, Halifax, St. Catharines-Niagara, Oshawa, Victoria, Windsor, Saskatoon, Regina, Sherbrooke, St. John's, Barrie, Kelowna, Abbotsford-Mission, Greater Sudbury, Saguenay, Kingston, Trois-Rivieres, Guelph, Moncton, Brantford, Saint John, Thunder Bay, and Peterborough.*

[11] *Light-duty vehicles comprise all passenger vehicles, passenger light trucks and motorcycles ( < 4 500 kg)*

[12] *Heavy duty vehicles comprise all light, medium and heavy trucks used for freight transport*

[13] *Tonne-kilometre is an activity measure used in freight transportation describing the transportation of one tonne over a distance of one kilometre.*

trucks have increased from 72 000 to 81 000 km / vehicle (an increase of 12 %) over the same time period.

Rates of light-duty vehicle ownership are increasing in Canada, going from 536 vehicles per 1000 inhabitants in 1990 to 618 vehicles per 1000 inhabitants by 2012 ( an increase of 15 %). Furthermore, the composition of the light-duty vehicle fleet is changing towards more light trucks (e.g. SUVs and pickups); the proportion of passenger cars among all light-duty vehicles fell from 75 % in 1990 to 56 % by 2012. The number of heavy-duty vehicles across Canada increased from 1.8 million in 1990 to 4.3 million in 2012 (an increase of 129 %). Table 2-6 summarizes these road transportation patterns from 1990 to 2012.

**Table 2-6 Light- and Heavy-Duty Vehicle Usage Statistics in Canada, 1990 to 2012**

| Item | 1990 | 2005 | 2012 | % change 1990 - 2012 |
|---|---|---|---|---|
| **Light-duty Vehicles** | | | | |
| Vehicle-km travelled (millions) | 264,234 | 333,152 | 353,938 | 34 % |
| Number of Light-duty Vehicles (thousands) | 14,856 | 18 390 | 21,476 | 45 % |
| Number of Light-duty Vehicles per 1000 inhabitants | 536 | 570 | 618 | 15 % |
| % of passenger cars among Light-duty Vehicles | 75 % | 60 % | 56 % | -26 % |
| Average Distance Travelled per year, per vehicle (km) | 17,787 | 18,116 | 16,481 | -7 % |
| **Heavy-duty Vehicles** | | | | |
| Tonne-kilometres (millions) | 114,952 | 275,277 | 295,225 | 157 % |
| Number of Heavy-duty Vehicles (thousands) | 1,874 | 3,072 | 4,293 | 129 % |
| Number of Heavy-duty Vehicles per $ GDP | 2,497 | 2,870 | 3,309 | 33 % |
| Average Distance travelled per year per vehicle (km) All Heavy-duty Vehicles | 29,902 | 29,462 | 26,971 | -10 % |
| Average Distance travelled per year per vehicle (km) Heavy Trucks Only | 72,005 | 88,743 | 80,943 | 12 % |

Source: (Office of Energy Efficiency, 2015)

### 2.2.5 Vehicle Fuel Efficiency

While total vehicle ownership and total VKT increased between 1990 and 2012, average vehicle fuel consumption has decreased due to improving vehicle fuel efficiency. As shown in Table 2-7, average fuel consumption for light-duty vehicles in Canada has been dropping steadily since 1990, going from 11.1 L/100 km to 10.0 L/100 km in 2012. Fuel efficiency gains have also been seen for heavy-duty vehicles, as average heavy-duty vehicle fuel consumption fell from 26.7 L/100 km in 1990 to 20.6 L/100 km in 2012 (a reduction of 23 %). This tendency also held true for heavy trucks[14], which saw average fuel consumption drop from 42.5 L/100 km to 32.6 L/100 km (a decrease of 23%) in the same time period.

**Table 2-7 Average Fuel Consumption for Light and Heavy-duty Vehicles, 1990 to 2012**

| Item | 1990 | 2005 | 2012 | % change 1990 - 2012 |
|---|---|---|---|---|
| **Light-duty Vehicles** | | | | |
| Average Fuel Consumption (L/100 km) | 11.1 | 10.1 | 10.0 | -10 % |
| **Heavy-duty Vehicles** | | | | |
| Average Fuel Consumption (L/100 km) All Heavy-duty Vehicles | 26.7 | 23.5 | 20.6 | -23 % |
| Average Fuel Consumption (L/100 km) Heavy Trucks only | 42.5 | 34.7 | 32.6 | -23 % |

In the near term, the transportation sector's demand for energy will continue to be largely met by fossil fuels, as all modes of transportation in Canada are highly dependent on petroleum-derived fuels (Transport Canada, 2011). However, the Government of Canada adopted the Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations in 2010, which prescribes increasingly stringent fuel efficiency requirements for light-duty vehicles from 2011 and onward (Government of Canada, 2014). These regulations are expected to result in a decrease of up to 50 % of light-duty vehicle GHG emissions for 2025 model year vehicles compared to 2008 model year vehicles. Similarly, in complement to the passenger and light-duty vehicle emission regulations, the Government Canada adopted the Heavy-Duty Vehicle and Engine Greenhouse Gas Emission Regulations in 2013. These regulations apply increasing stringent emissions standards to all new on-road heavy-duty vehicles and engines in Canada to 2018 and cover full-size pickup trucks, semi-trucks, buses, and vocational vehicles such as garbage trucks. It is expected that 2018 model year heavy-duty vehicles will emit 23% less GHG emissions than 2014 year vehicles (Government of Canada, 2014a). Further advancements in vehicle technology and increased adoption of hybrid and electric vehicle and battery technologies, as well as further development and deployment of heavy-duty vehicle aerodynamic, vehicle and engine technologies will likely to contribute to current and projected improvements in vehicle fuel efficiency.

The production of electricity required to power hybrid and electric vehicles is also becoming less GHG intensive. The *Canada's Energy Future 2013* report projects that electricity in Canada will increasingly be produced from non-fossil fuel based sources such as hydroelectricity and solar. Furthermore, GHG intensive coal contributions to electricity production will continue to decline, while production by less GHG intensive natural gas will expand (see **Appendix A** for a full summary of energy generation and GHG trends) (National Energy Board, 2013). Of all economic sectors[15] in Canada, the electricity generation

[14] *Heavy trucks are defined as vehicles with gross weight >15 000 kg*

[15] *As listed in Section 2.1: Agriculture, Waste, Transportation, Oil and Gas, Electricity, Buildings and Industry.*

sector is the only one where total GHG emission contributions are projected to decline by 2030 (from 121 Mt in 2005 to 59 Mt in 2030, a 51% decline) (Government of Canada, 2014a).

#### 2.2.6 Carbon Content of Vehicle Fuels

The carbon content of vehicle fuels will also influence GHG emissions from the transportation sector, as the amount of carbon dioxide ($CO_2$) produced when a fuel is burned is a function of the carbon content of the fuel. In 2010, Canada adopted national Renewable Fuels Regulations, which require petroleum fuel producers and importers to blend an average of 5 % renewable fuel content into gasoline as of December 15, 2010, and 2 % renewable fuel content in diesel fuels as of July 1, 2011 (Government of Canada, 2014a).

## 2.3 Summary

Canada's transportation GHG emissions, which currently account for about a quarter of the country's total emissions, are projected to increase to 2030. Road-based transportation accounts for most of the transportation sector's GHG emissions, and total light-duty and heavy-duty VKT are increasing. However, emissions from road-based passenger transportation, which started leveling off around 2005, are projected to go down going forward in spite of increased vehicle travel. This is largely due to recent gains and continued improvements in light-duty vehicle fuel efficiency. Furthermore, population growth in urban centres, where alternatives to vehicle travel are possible and effective, as well as demographic changes, will likely contribute to decreased emissions from road-based transportation. While heavy-duty vehicles are also seeing an improvement in vehicle fuel efficiency, the projected increases in economic growth and demand for freight movement will outweigh the gains made on heavy-duty vehicle fuel efficiency. In light of current policies and measures put in place, Canada is not on track to meet its Copenhagen target of reducing its total emissions by 17 % below 2005 levels, highlighting the need for and importance of continued efforts to reduce Canada's GHG emissions across all sectors of the economy, including transportation.

#### 2.3.1 Other Factors Influencing Travel Demand

There may be other factors which contribute to travel demand that have not been explored in this chapter. They include the relative costs of personal vehicle ownership and travel (e.g. increased costs of vehicle maintenance, fuel and insurance), economic challenges (e.g. recessions, unemployment, downward pressures on worker wages), employment characteristics (e.g. work schedule, telecommuting, enhanced information and communications technology), growth of online retail, freight requisites (e.g. just-in-time delivery, multiple destinations, logistics), lifestyle preferences and choices of urban and suburban dwellers, and patterns of land use development (e.g. densification, concentration and consolidation in some cases and suburban, peripheral and exurban development in others). Investigation of these factors is not within the scope of the current mandate. However, future work by local jurisdictions may be warranted to explore how these factors may affect local travel demand characteristics and allow for more informed selections of appropriate transportation GHG reduction measures.

# 3 – Toolbox of Measures

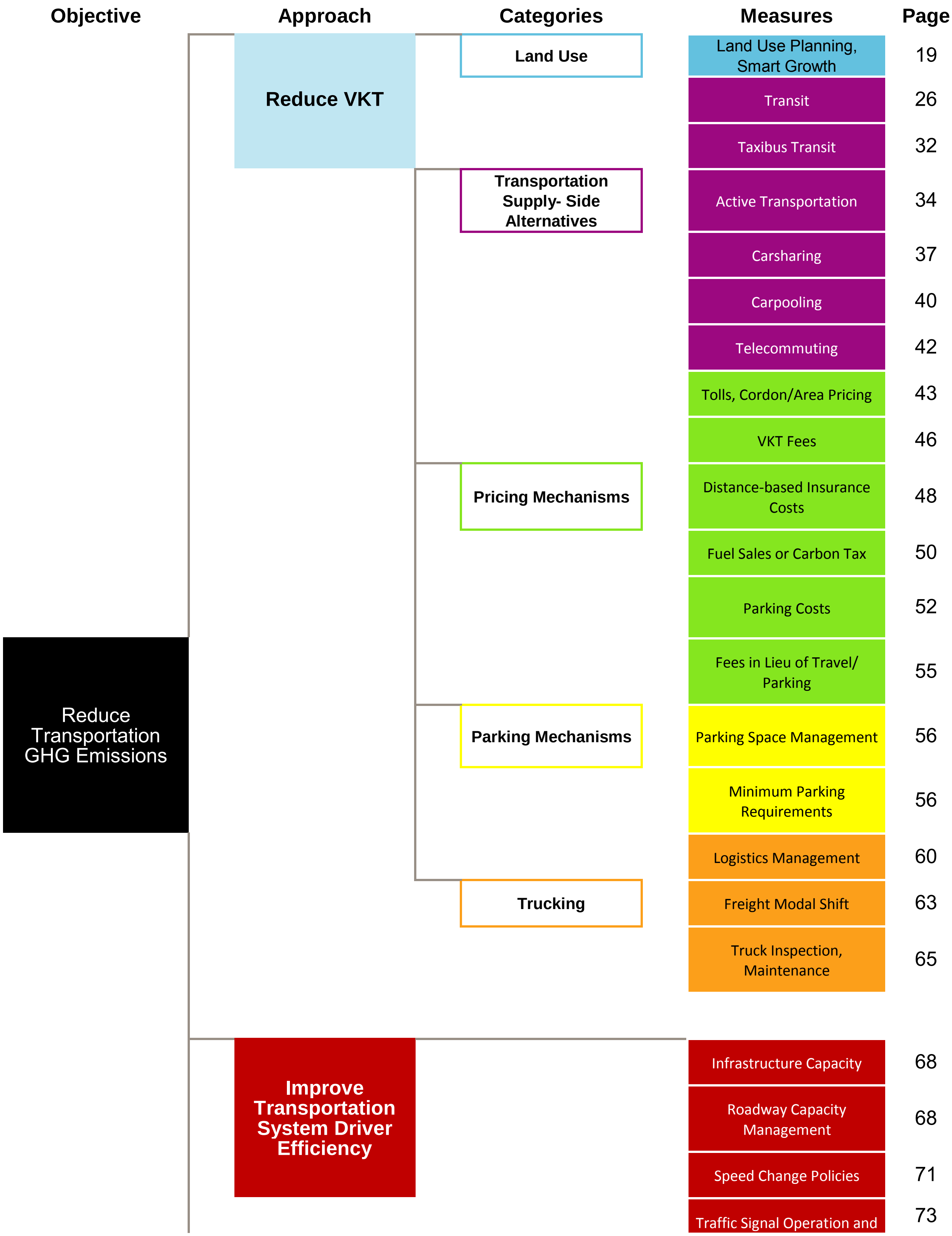
Reducing transportation GHG emissions can be achieved through the three following complementary approaches:

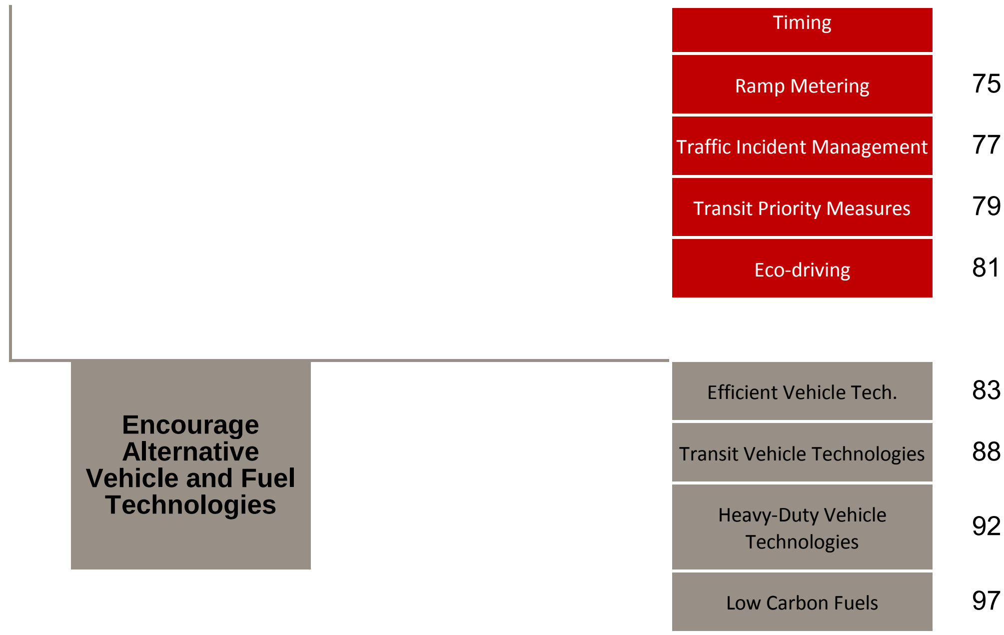
- **Reduce Vehicle Kilometres Travelled (VKT)**: Reducing distances travelled by passengers and goods by vehicle;
- **Improve Transportation System and Driver Efficiency Operations**: Improving the efficiency of the transportation system so that more vehicles travel under more optimal conditions in terms of speed and flow;
- **Encourage Alternative Vehicle and Fuel Technologies**: Adopting and supporting vehicles that use alternative fuels, and technologies that use energy more 4efficiently or use less GHG-intensive energy sources for vehicle propulsion.

These approaches can be implemented through a variety of strategies, policies, programs, projects or actions, collectively named "measures" in this report. This report presents a collection of about 30 different measures to address urban transportation GHG emissions, organized according to the three approaches. The Reducing VKT approach itself comprises a broad range of possible measures. In this report, they are further divided into five categories which group similarly themed methods for reducing urban transportation GHG emissions. A list of categories and measures discussed in this report is presented in Figure 3-1. Page reference numbers where measures are presented are located on the right side of Figure 3-1. A brief description of the categories and measures is then presented in Table 3-1.

Information about the measures contained in this report was developed through a document and literature review of national and international practices covering all major modes of urban transportation, discussions and exchanges with TAC project partners, and a review of programs, regulations, and examples from Canadian municipalities regarding their current efforts to reduce transportation GHG emissions.

**Figure 3-1 Overview of Measures to Reduce Urban Transportation GHG Emissions**






### Table 3-1 Description of Measures to Reduce Transportation GHG Emissions

| | Approach, Description of Category (Reduce VKT only) and Measures |
|---|---|
| | **Reduce Vehicle Kilometres Travelled** |
| | **Land Use**<br>Planning for urban growth and development to support efficient transportation. |
| 1 | **Land Use Planning and Smart Growth:** Transportation-efficient land use patterns can help reduce the need to make trips by vehicle, or reduce the length of the trip that has to be made by vehicle. Land use development requires policies, plans, programs and regulations that promote intensification, provide complete living environments, enhance connectivity for active transportation, support transit and other transportation alternatives, and reduce environmental impacts. |
| | **Transportation Supply-Side Alternatives**<br>Providing alternatives to single occupant vehicle travel by getting more people to travel together in fewer vehicles, by active transportation or by avoiding travel completely |
| 2 | **Enhance Transit Services:** Transit services provide an important, energy-efficient alternative to travel by automobile. Increasing or expanding transit supply, improving service quality and reliability, enhancing access and improving transit passenger facilities and transit vehicle amenities can make them competitive, viable, and attractive for urban passenger travel. |
| 3 | **Provide Taxibus Transit Service:** Taxibus transit is a form of demand-response public transit suitable to areas with low population density. Installing taxi-bus services provides mobility and energy efficient alternatives to driving alone in areas that do not warrant higher order transit service. |
| 4 | **Encourage Active Transportation:** Active transportation is any form of human-powered travel that results in no GHG emissions. Enhancing the coverage, safety, comfort of infrastructure and routes dedicated to active transportation, as well as enhancing accessibility, intermodality, and supportive land use development can encourage active transportation. |
| 5 | **Provide Carsharing Services:** Carsharing is an alternative method vehicle ownership. Promoting carsharing use can have benefits for |

| | |
|---|---|
| | reducing parking space requirements and private vehicle travel. |
| 6 | **Encourage Carpooling:** Carpooling reduces VKT and GHG emissions through shared trips. Carpooling practices can be encouraged and promoted through employer programs and incentives, coordination and reservation systems, use of HOV lanes, designated pickup and drop-off points, and revised parking policies. |
| 7 | **Encourage Telecommuting:** Employer based telecommuting programs and compressed work schedules can allow employees to reduce or avoid trips to and from work. |
| | **Pricing Mechanisms**<br>Increasing the costs of vehicle travel to influence travellers' transportation choices in terms of mode or time of travel |
| 8 | **Implement Toll Roads and Cordon/Area Pricing:** Tolls or cordon/area pricing can increase the cost of vehicle travel along certain roads, in certain areas, or at certain times of day. |
| 9 | **Implement Distance Travelled Fees:** Drivers are charged a fee based on the distance they travel by vehicle. Unlike toll and cordon/area pricing, distance travelled fees apply at all times. |
| 10 | **Charge Distance-based Insurance Costs:** Distance-based insurance costs charge drivers an insurance premium based upon how far they drive their vehicle. |
| 11 | **Implement a Fuel Sales or Carbon Tax:** Fuel sales and carbon taxes increase the cost of vehicle travel by increasing costs to fuel producers and distributors, which in turn pass down the increased costs to the end user. |
| 12 | **Increase Parking Costs:** Increasing parking costs can be used to discourage car use to certain, specific congested areas. Municipalities can increase the rates it charges for public parking while taxes or fees can be imposed on private parking operators. Differential fees can also be offered to encourage carpooling or carsharing. |
| 13 | **Offer Fees in Lieu of Travel and Cash in Lieu of Parking:** Financial compensation can be offered to employees to choose alternative ways of commuting to work than by car. Compensation can be offered to employees to give up a parking space, or to pay for transit passes or carpooling. |
| | **Parking Mechanisms**<br>Constraining parking supply as a means to influence travel choices and support more transportation-efficient land-use development |
| 14 | **Optimize or Reduce Existing Parking Spaces, Implement a Dynamic Parking Guidance System:** Parking management seeks to optimize the use of existing parking spaces while dynamic parking guidance systems help drivers find available spaces more quickly. They can limit the need to create new parking spaces. |
| 15 | **Modify Parking Bylaws to Reduce Minimum Parking Requirements:** Restricting the number of new parking spaces that are built as part of new developments can serve as a disincentive to car ownership and vehicle travel, all while supporting the densification of the urban environment, transit and active transportation. |
| | **Trucking**<br>Enhancing freight logistics management or encouraging modal shift to decrease the number and length of truck VKT |
| 16 | **Enhance Logistics Management:** Enhancing logistics management can involve optimizing truck routing, loads, package sizing, and use of information technology for organization, tracking and enhancement of deliveries. The implementation of urban distribution centres can help consolidate deliveries in urban areas. Optimizing freight logistics can reduce transportation costs, improve service quality, accelerate delivery, enhance competitiveness and improve environmental performance. |
| 17 | **Encourage Modal Shift for Freight:** Diversion of freight from trucks to marine and rail modes can reduce GHG emissions. However, intermodal freight is typically only advantageous for long distance travel and is likely less relevant to urban transportation. |
| 18 | **Enhance Truck Inspection and Maintenance Programs:** Enhanced inspection and maintenance programs can be employed to detect mechanical problems, limit pollutant emissions and optimize vehicle operating efficiency. Inspection and maintenance programs can be |

| | |
|---|---|
| | deployed or subsidized by government agencies. |
| **Improve Transportation System and Driver Efficiency** | |
| **19** | **Increase Infrastructure Capacity:** Specific infrastructure capacity can be added at intersections or along road segments to relieve congestion. Additional capacity can be added through physical expansion. |
| **20** | **Manage Roadway Capacity Dynamically:** Congestion can be reduced through a more optimal and dynamic management of existing space. Dynamic management of existing road space requires the use of cameras, detection and signalling equipment. |
| **21** | **Implement Speed Change Policies:** Decreasing maximum speeds can reduce GHG emissions by reducing aerodynamic drag. Dynamic speed controls can delay vehicles entering congested zones or bottlenecks to allow more time for congestion to clear. |
| **22** | **Optimize Traffic Signal Operation and Timing:** Reducing vehicle stops and starts through enhanced traffic signal management can promote smoother traffic flow along travel corridors. This can involve adjusting and updating signal timing and phasing along corridors and adapting signals to time of day and traffic conditions. |
| **23** | **Implement Ramp Metering:** Ramp metering controls the number and timing of vehicles entering a highway via on-ramps to ensure fluid traffic flow on the highway. |
| **24** | **Improve Traffic Incident Management:** Incident management is a systematic, multi-agency effort to improve and facilitate the clearance of roadway incidents that can cause bottlenecks and congestion. Use of monitoring and reporting equipment, enhanced interagency coordination, and clear response procedures can facilitate rapid incident identification, response and clearance. |
| **25** | **Provide Transit Priority Measures:** Transit vehicle travel times and reliability can be improved through use of reserved lanes, intersection signal priority measures, stop location optimization, express or limited stop service, and on-board real-time tracking and information systems. Making transit faster and more reliable makes it a more attractive alternative for urban passenger travel. |
| **26** | **Encourage Eco-driving:** Implementing eco-driving training programs can help teach drivers how to drive more fuel efficiently. Drivers can be taught how to avoid rapid acceleration and braking, reduce speeds, limit idling, and conduct routine vehicle maintenance checks such as tire pressure and basic engine monitoring to ensure their vehicle is running optimally. |
| **Encourage Alternative Vehicle and Fuel Technologies** | |
| **27** | **Encourage Adoption of More Efficient Vehicle Propulsion Technologies:** Facilitating the adoption of hybrid and electric vehicle propulsion systems can reduce fossil fuel dependence. Offering incentives, rebates and charging infrastructure; providing access privileges to HOV lanes or parking; and continuing vehicle testing and demonstration can facilitate the uptake of these new vehicle technologies. |
| **28** | **Implement New Transit Vehicle Technologies:** The use of alternative hybrid, fuel-cell, and alternative fuel transit vehicles can reduce fossil fuel dependence of transit fleets. |
| **29** | **Encourage New Heavy-Duty Vehicle Technologies:** Heavy-duty vehicle engine technologies, electric auxiliary power units, tractor and trailer aerodynamic measures and low-rolling resistance tires can improve vehicle fuel efficiencies. Provincial or federal governments can provide incentives and funding to support the testing and adoption of these technologies by trucking operators and municipal fleets. |
| **30** | **Use Low Carbon Fuels:** Blending low carbon fuel alternatives into gasoline and diesel and reduce the quantity of fossil fuel used for transportation. |

## 3.1 Toolbox Layout

Chapters 4 through 6 provide more detailed information about each of the measures to reduce urban transportation GHG emissions. Each section begins with a table summarizing implementation considerations and performance indicators of each measure as described in Table 3-2.

**Table 3-2 Description of Implementation Considerations and Performance Indicators**

| Description of Implementation Consideration or Performance Indicator | Evaluation |
|---|---|
| Responsibility | |
| The implementing agency or agencies that would generally be responsible for the planning, implementation and operation of the measure. Other levels of government and the private sector are identified where they may be involved in implementation or as a partner to the implementation agency. | Examples: local, regional municipal governments, provincial governments, transit agencies, employers, private transportation companies |
| Applicability | |
| Applicability of a measure to the size of a municipality. Note that the guidance provided may not always correlate with size, but more closely with density of land use, travel demand, traffic congestion, availability of transit, parking demand and presence of paid parking. Larger communities tend to have denser urban environments, greater traffic congestion, greater supply of transit, higher parking demand and paid parking, conditions which make certain measures appropriate. However, smaller municipalities may have central areas, zones or town centres which exhibit some of the characteristics which can make measures applicable. | Size of municipality by population:<br><br>S < 50,000<br>M 50,000 < 500 000<br>L >500,000 |
| Cost | |
| Costs relate to implementation costs such as planning, capital and operational costs. Costs do not take into account amounts that the end user (e.g. transit user, driver) may be required to pay. Costs are presented from the perspective of the agency which would be responsible for implementation. | $ - Inexpensive<br>$$ - Somewhat Inexpensive<br>$$$ - Moderately Expensive<br>$$$$ - Expensive<br>$$$$$ - Very expensive |
| GHG Reduction Potential | |
| Describes qualitatively the cumulative reduction potential of the measure over a period of 10 – 20 years from implementation (notionally 2025 to 2035). Further detail as to how measures were rated are described in **Appendix B**. | 1 – Very Low<br>2 – Low<br>3 – Moderate<br>4 – High<br>5 – Very High |
| Technical Feasibility | |

| Description of Implementation Consideration or Performance Indicator | Evaluation |
|---|---|
| Indicates the technical feasibility of implementation, and describes prerequisites such as space and engineering designs which may be important. Technical feasibility is evaluated from the perspective of the agency which would be responsible for implementation. | 1 – Very Difficult<br>2 – Difficult<br>3 – Moderate<br>4 – Easy<br>5 – Very Easy |
| Social Acceptability | |
| Indicates social acceptability of implementing a measure. It is evaluated from the potential perspective of the community (e.g. general population, neighbourhood, district, municipality or region) or user groups (e.g. drivers, transit riders) which would be affected by the measure. | 1 – Very Low<br>2 – Low<br>3 - Neutral<br>4 - Good<br>5 - Excellent |
| Timing | |
| Describes when a measure can be implemented, and depends on the technical feasibility and technological readiness of the measure. The term "ongoing" is listed when the application of a measure is done on a continual basis versus a one-off action (e.g. traffic signal timing adjustments versus building new infrastructure). | Immediate (~ within a year)<br>Short Term (~ 1 – 3 years)<br>Medium Term (~ 3 – 10 years)<br>Long Term (~10+ years) |
| GHG Reductions Timeframe | |
| Describes when significant GHG reductions can be expected to accumulate. | Immediate (~ within a year)<br>Short Term (~ 1 – 3 years)<br>Medium Term (~ 3 – 10 years)<br>Long Term (~10+ years) |

Each section then provides the following information for each measure:

**Description**

Describes the measure or series of measures and the means by which they help to reduce GHG emissions, and provides some examples, best practices, and reference materials for further information.

**Measures to Encourage**

Describes the methods and actions that can be taken by local and regional agencies, as well as other levels of government to encourage the implementation or enhance the effectiveness of measures to reduce GHG emissions.

**Pros and Cons**

Describes the advantages, disadvantages and co-benefits of measures for individuals, organizations and the community with respect to the implementation of measures.

**Impacts**

Provides an overview of impacts, where information is available, on transportation patterns, energy consumption and GHG emissions.

**Constraints and Barriers to Implementation**

Presents a list of constraints and barriers to implementation, and commentary on how some of these may be overcome.

Despite the information, high level considerations, and qualitative evaluations collected in this toolbox, study authors recognize that there may be specific conditions across Canada that may lead to different conclusions and evaluations than those presented in this document. City size, layout, density of land uses, infrastructure, availability of alternative modes of transportation, natural features, as well as municipal budgets, population characteristics, objectives and challenges will influence the types of measures which may be appropriate to a given context. Readers should use the information contained in this toolbox as guidance, but evaluate for themselves the appropriateness and performance of measures within their own context.

# 4 – VKT Reduction

This chapter presents a range of measures that seek to reduce the distances travelled by passengers and goods in road based fossil-fuel powered vehicles. In general, VKT reduction measures can have the most significant and long lasting impacts on energy, fuel consumption and GHG emissions (Cambridge Systematics Inc., 2009), as they seek to bring about long lasting changes in travel patterns and behaviour. Measures discussed do not seek to eliminate travel altogether, but to encourage people and transporters to reduce the distance travelled in fossil-fuel powered vehicles, reduce the number of trips made, or to choose more energy efficient modes of travelling or transporting goods. Furthermore, VKT reduction measures also discourage car ownership, a key factor in VKT, by providing supply alternatives, incentives or constraints to vehicle use.

This chapter covers land use planning, public transit, taxibus transit, active transportation, carsharing, carpooling, telecommuting, pricing mechanisms, parking mechanisms and measures for truck transport. Denser, more compact and well-designed urban environments are key to facilitating the use of alternative forms of transportation like transit and active transportation. Public transit, active transportation, carpooling, carsharing, and telecommuting can be considered supply side measures for achieving VKT reductions, since they offer alternatives to single occupant vehicle use. In the case of telecommuting, physical travel can be avoided altogether. On the other hand, pricing and parking control measures use financial, regulatory or restrictive mechanisms to encourage travellers to choose modes of travel other than the automobile, or to travel at less congested times.  Lastly, measures are proposed to move goods and freight more efficiently within cities as a means to reducing truck.

## 4.1 Land Use Planning

Land use planning policies and strategies seek to promote urban development that encourages more sustainable transportation modes and practices (i.e. transportation-efficient land use).  These policies and strategies are formulated at a range of spatial levels and include regionally-led initiatives such as Smart Growth principles, as well as more locally-led initiatives such as Transit-Oriented Development (TOD), Transit-Oriented Communities (TOC), Ecodistricts and Compact Development.  Overall, land use planning policies and strategies seek to, among other objectives, reduce the need to make trips by vehicle, or reduce the length of the trip that has to be made by vehicle.

| | | |
|---|---|---|
| **Responsibility** | | Local and Regional Municipalities and Transit Agencies. |
| **Applicability** | S, M, L | Appropriate for all sizes of municipalities. |
| **Cost** | $ - $$$ | Costs for policy and regulatory changes at municipal and regional level will depending on scope of application, but generally lower in cost relative to other capital intensive measures. |
| **GHG Reduction Potential** | 4 | Can result significant changes in travel habits |
| **Tech Feasibility** | Variable | Depends on scope of policy, program or project |
| **Social Acceptability** | Variable | Depends on scope of policy, program or project |
| **Timing** | Immediate, ongoing | Land use planning laws, policies and programs can be implemented and/or amended immediately to support transportation-efficient land use development. |
| **GHG reductions Timeframe** | Long term | Changes in land use planning approaches are slow to yield tangible results and significant emissions reductions would only be realized in the long term. |

**Description**

Sound land use planning is key to encouraging more energy-efficient forms of transportation. Transportation-efficient land use planning approaches generally seek to:

- Promote intensification and infill development, including higher density housing and employment areas;
- Provide a complete living environment comprising a mix of densities and land uses (e.g. residential, commercial, employment, and institutional);
- Enhance integration and connectivity with adjacent neighborhoods;
- Support a range of transportation alternatives, including public transit and active transportation;
- Reduce the impacts of the built environment on the natural environment, and optimize infrastructure and municipal services to reduce the costs of construction, operation, maintenance and replacement;
- Enhance accessibility and connected street networks with sidewalks and bicycle paths; and,
- Encourage citizen participation in the decision-making process.

Smart Growth planning approaches are generally applied at the regional level, while New Urbanism, TOD / TOC, Ecodistricts and Compact Development represent smaller, neighbourhood-scale (i.e. community) interventions.

### *Regional Growth Management*

Smart Growth is a broad collection of land use and development principles that aim to contain and/or reduce urban sprawl. As urban sprawl is often a problem that transcends municipal boundaries, Smart Growth generally takes the form of long-term, high-level policies aimed at managing regional growth and guiding decisions on how land is developed, resources are managed and public dollars are invested. A common practice in Smart Growth policies involves concentrating future development in strategically located growth centres (e.g. central business district, town centres, employment hubs, transportation hubs, etc.) and placing limits on growth outside of designated areas through the use of urban expansion boundaries. Neighbourhood-scale planning interventions are then employed within the growth centres to help ensure that more efficient and sustainable land use patterns and urban designs are developed (see Community Planning below for examples). However, regional land use policies also recognize that activity is not limited to each growth centre, as trip origins and destinations can vary across a wider geography. Therefore, Smart Growth policies often also include guidance for developing or strengthening a regional network of growth centres. They also highlight the need for coordination with regional transportation planning and investments in transit that provide more travel options within and between each growth centre as well as across the region.

Examples of regional Smart Growth policies include:

- In Ontario, the Growth Plan for the Greater Golden Horseshoe (i.e. a regional growth management plan) is being deployed in conjunction with Metrolinx's The Big Move (i.e. a regional transportation plan);
- The measures adopted by the Province of British Columbia to protect farmland (i.e. designation of an Agricultural Land Reserve in 1974) with leadership from both municipal and the private sectors in British Columbia; and
- The urban containment boundaries or equivalent used by several regional districts and their partner municipalities to limit the extent of urban growth in their regional growth strategies in B.C., including Metro Vancouver, the Capital Regional District (Greater Victoria) and the Regional District of Nanaimo.

### *Community Planning*

New Urbanism, Transit-Oriented Development (TOD) and Transit-Oriented Communities (TOC) are all planning concepts that seek to create denser and more compact communities. All of these concepts promote the development and consolidation of existing urban areas, focus on creating mixed-use living environments, and encourage high quality urban design to promote public and active transportation and lively public spaces.

TOD attempts to focus compact, mixed use development around transit stations as a means to support more sustainable urban growth, increased transit ridership, and reduced automobile use, congestion and GHG emissions. TOD can be characterized as an urban environment focused around a commercial core and services as well as a major transit station that can all be easily accessed by foot (approximately 800 metres or a 10 min walk). Its ultimate goal is to provide residents and workers with transportation mode choices other than cars to access employment, services or leisure activities safely, conveniently and quickly, whether they are within their local TOD or in other TODs on the major transit infrastructure network. To help ensure the successful planning and development of TODs, other specific guidelines and strategies may also be developed. For example, the Metrolinx Mobility Hub Guidelines are intended to work in conjunction with the overall regional transportation plan (i.e. the Big Move) to address topics such as transit station design, station circulation and access, wayfinding, land use and urban design surrounding transit stations, funding and implementation.

The TOC approach is broader in nature than the TOD model, wherein it is not just focused on physical development around rapid transit stations. Rather, TOCs are defined as various locations (regions, cities, districts) adapted or developed to facilitate the reduction in car dependency: high density, mixed use, structuring transportation networks accessible through short walking distances, etc. For example, TOC in Metro Vancouver is focused on development that is planned near the Frequent Transit Network, which consists of bus lines with high levels of service and the SkyTrain rapid transit system.

The six principles of TOCs are (6 D's): Destination, Distance, Design, Density, Diversity and Demand Management (Translink, 2012). These principles should be implemented in harmony within all planning levels (regional, city, district and site).

- Destination: the various areas (centres) are located near a structured or higher order transportation network;
- Distance: Walking distance from the major transit service is minimized by a well-defined design scale and tight street grid;
- Design: an urban design on the human scale including pedestrian routes as well as safe and user-friendly bicycle paths;
- Density: high density buildings with a diversity of uses;
- Diversity:  mix of uses;
- Demand Management: measures to discourage automobile use and unnecessary trips.

Another community level planning concept is the Ecodistrict, which also aims to reduce car dependency by promoting mixed-use development and public and active transportation. However, this concept differs slightly from other community level planning concepts due to its emphasis on incorporating best practices in environmental performance and energy efficiency in the built environment as a means to reduce a neighbourhood’s ecological footprint. All of the above concepts are often derived from and/or supported by broader Smart Growth principles.

Finally, the concept of Compact Development is primarily related to gross density and compactness. Gross density is defined by the number of units within a given area. Compactness is the physical and spatial relationship between the built and unbuilt areas, and how the space is designed to minimize unattractive, empty spaces and discontinuities. New urbanism, TOD /TOC, and Ecodistrict type developments generally integrate some form of compact development within their planning concept as a means to achieving higher density, mixed-use high quality urban environments.

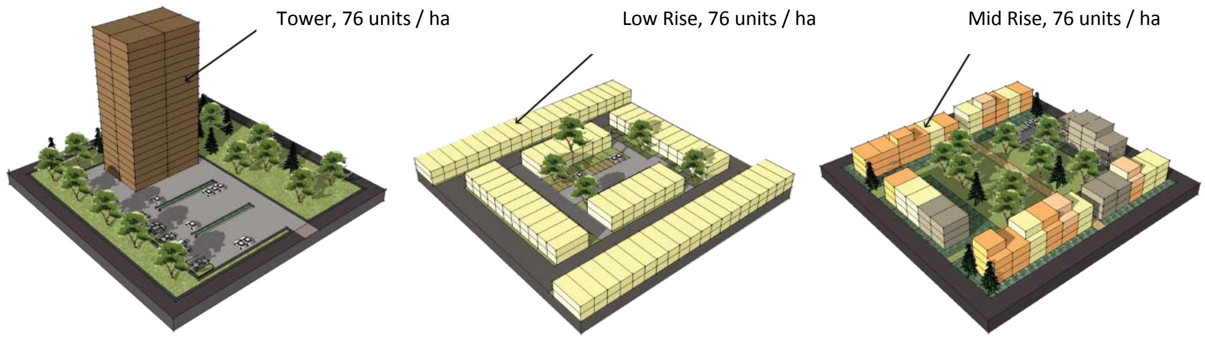
**Examples**


TOD (The Bridges, Calgary, Alberta)


Ecodistrict (Dockside Green, Victoria, B.C.)


TOD, New Urbanism (Bois-Franc, Québec)

**Compact Development**

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**Grid Streets**

The aforementioned planning concepts are often realized through grid street design, which is comprised of a hybrid street network that promotes active transportation while discouraging the use of cars for short distance trips. The concept is characterized by quadrants or neighbourhoods that can be crossed by a 10 minute walk (approximately 800 m by 800 m in size). Arterial and collector roads border each quadrant and provide connectivity to neighboring quadrants. Transiting vehicles are mostly restricted to these corridors, as the street network within each neighbourhood is composed of loops and cul-de-sacs which discourage through traffic. However, walking and cycling paths, parks and open spaces provide connectivity for all non-motorized travel across neighbourhoods. An example of a grid street network is the Saddleton neighborhood in Calgary is shown below.

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## Measures to Encourage

**Provincial Agencies**

Although many of the land use planning approaches discussed are more applicable at the municipal level, provincial agencies can encourage adoption by enacting laws, policies and programs that integrate the principles common to all of the approaches discussed above (e.g. intensification targets, encouraging a range of transportation options, accessibility requirements, etc.). As municipal planning policies generally need to conform to provincial planning policies, provincial agencies can essentially ensure that multiple municipalities are working towards common goals.

**Regional and Municipal Agencies**

***Integrate principles into land use planning laws, policies and programs***

Similar to the approach discussed above for provincial agencies, regional and municipal agencies can integrate smart grown, new urbanism, TOD / TOC, Ecodistrict and/or Compact Development principles into their land use plans, policies and programs. This can range from higher-level policies (e.g. Regional Growth Strategies, Official Plans, etc.) to area plans (e.g. Master Plans, Secondary Plans, etc.) and site planning level (e.g. design guidelines, minimum and maximum floor area).

***Utilize financial incentives / programs***

Financial incentives / programs may be utilized to help facilitate a specific type of sought-after development that may not occur otherwise. For example, financial aid incentives for the construction of housing on vacant lots or areas used as parking lots or programs that provide financial mechanisms for the redevelopment of existing neighbourhoods.

***Using Development Charges to Reinforce Desired Development Patterns***

Development charges can be used to reinforce desired land use patterns. Specifically, a municipality may implement a tiered development charges system with lower rates for desired development locations and/or forms. For example, the City of Ottawa has higher development charges for development outside the greenbelt, as well as for single and semi-detached housing (City of Ottawa, 2014). Not only does this approach encourage higher-density residential development closer to the city’s downtown, but it also accounts for the higher infrastructure and servicing costs associated with lower-density suburban development.

***Locating Major Trip Generators in Urban Centres and Areas with High Quality Transit***

Application of transportation land-use planning principles both at the origins (e.g. where people reside) and the destinations of trips (e.g. where people go to work, shop, etc.) is critical to ensuring that transportation mode choices other than the vehicle are viable. Major trip generators, such as large office complexes, that are located outside of urban centres or poorly connected to public transit networks reinforce and/or create a new set of auto-dependent travel patterns and barriers to a more integrated, efficient and diverse transportation network. Planning policies that direct major trip generating land uses to urban centres and areas with high quality transit can help counter these problems. An example of this policy approach can be seen in Metro Vancouver’s Regional Growth Strategy, Metro 2040 (Metro Vancouver, 2013). Ontario`s policies regarding urban growth centres as part of the Growth Plan for the Greater Golden Horseshoe is based on similar principles.

## Pros and Cons

Benefits of transportation-efficient land use planning approaches include:

- Reduction of transportation related energy consumption and GHG emissions;
- Higher-density, mixed use development is more cost-effective, environmentally sensitive form of development than a low-density suburban development (PEW Center Global Climate Change, 2011);
- Improved health and safety of communities and individuals;

- Improved quality of environment;
- Ecodistricts in particular can help reduce the environmental footprint of development;
- Better management of urban space;
- Allows for a greater diversity in housing supply;
- Diversification of activities;
- Supports greater transportation mode choice, including increases in the usage of public and active transportation. This can contribute to reduced roadway congestion, while increasing mobility for those who cannot or prefer not to drive;
- TODs / TOCs in particular can help reduce collective and individual costs related to transportation and promote the organization of more efficient transportation networks;
- Enhanced citizen participation; and
- Increased economic competitiveness and attractiveness of urban areas.

Disadvantages include:

- Changes in land use policies are slow to yield tangible results;
- Effects of transportation-efficient land use approaches may be limited outside of planned areas; and,
- Compact development and intensification may result in increased traffic congestion locally.

**Impacts**

Intensification and mixed-use development can reduce the amount of land consumed for urban development per person, the per capita costs of infrastructure, travel distances and time, increase the viability of public and active transportation options and protect natural areas. Intensification can also lead to improved accessibility and reduce energy requirements by up to 20%, primarily by facilitating public transit (Bochet, Gay, & Pini, 2004).

Reductions in car use have positive impacts on the environment (e.g. fossil fuel consumption and GHG emissions, rainwater runoff polluted by motor oil and debris), human health (e.g. air pollution, noise, obesity) and quality of life (e.g. noise, safety hazards, urban heat islands, predominance of pavement, longer trips).

A study completed by the Canadian Mortgage and Housing Corporation (CMHC) compared the performance of neighbourhoods based on new urbanist design principles against those based on design principles of traditional suburbs (Canadian Mortgage and Housing Corporation, 2010) and found that:

- Residents living in New Urbanist neighbourhoods travelled less often by automobile (either as a driver or passenger) than residents from conventionally designed suburbs (78 % versus 85 % respectively);
- In a 24-hour period, households in traditionally designed neighbourhoods had 24 % higher VKTs than those located in new urbanist neighbourhoods (46,0 km versus 37,1 km);
- 51 % of residents from new urbanist neighbourhoods travelled several times a week by foot or bike to a shop or services in their neighborhood, compared to only 19% of residents from conventionally designed suburbs.

Ecodistricts are a relatively new concept, and no studies were found that suggested what the impacts of GHG emissions savings related to Ecodistricts may be. However, Ecodistrict charters and certifications suggest that GHG emissions reductions would be achieved through energy efficient building design, as well as promoting public and active transportation modes.

A large body of research of U.S. TODs indicates that transit is used two to five times more often by TOD residents than travelers in the larger region for both work and non-work trips. Transit mode share varies from 5 to 50% for work trips, while they are slightly lower, 2 to 20% for non-work trips (TCRP, 2008). Case studies in California show a potential for reduction of 20 to 40% of VKT for people working or living in a TOD. In terms of emissions, these studies show a decrease of 2.5 to 7.5 t CO2 eq. per household per year for a TOD, compared with a more conventional suburban area (AECOM, 2012). The table below outlines VKT and GHG reductions associated with TODs (or similar areas) in Canada and the U.S.

**Table 4-1 – Canadian and U.S. Examples of VKT and GHG Emissions Reductions for TODs or Similar Areas**

| Study area | Reduction VKT | VKT Comparison Region vs urban area/TOD | Reduction of GHG | GHG Comparison (t $CO_2$ eq./household/yr) Suburb vs urban area/TOD |
|---|---|---|---|---|
| TODs across California | 20-40 % | - | 2.5-3.7 t eq. $CO_2$/household/yr | - |
| Uptown District, San Diego, CA[6] | - | - | 20 % | - |
| The Crossings, Mountain View, CA[6] | - | - | 10-30 % | - |
| Metropolitan Portland, OR[1] | Up to 43 % | 28 VKT/capita (region) vs 16 VKT/capita | - | - |
| Metropolitan Chicago[4] | - | - | 45 % | 7.2 vs 4.1 |
| Metropolitan Toronto[5] | - | - | 73 % | 5.2 vs 1.4 |
| Metropolitan Toronto[2] | - | - | 68 % | 11 vs 3.5 |
| Atlantic Station, Atlanta, GA[3] | 70 % | 52 VKT/day (region) vs 13 -18 VKT/day | - | - |
| King regional county, WA[3] | 25 % | - | - | - |
| U.S, non-specified areas[3] | 30 % | - | - | - |

Sources:

1. California Department of Transportation. (2002). Statewide Transit-Oriented Development Study, Factors for Success in California. Caltrans.

2. Canadian Mortgage and Housing Corporation. (2000). Greenhouse Gas Emissions from Urban Travel. Ottawa : Canadian Mortgage and Housing Corporation.

3. Ewing, R., Bartholomew, K., Winkelman, S., Walters, J., & Chen, D. (2007). Growing Cooler, The Evidence on Urban Development and Climate Change. Chicago : Urban Land Institute.

4. Haas, P., Miknaitis, G., Cooper, H., Young, L., & Benedict, A. (2010). Transit Oriented Development and the Potential for VMT related Greenhouse Gas Emissions Growth Reduction. Center for Transit Oriented Development.

5. Norman, J., MacLean, H., & Kennedy, C. A. (2006). Comparing High and Low Residential Density: Life-Cycle Analysis of Energy Use and Greenhouse Gas Emissions. Journal of Urban Planning and Development , 10-21.

6. Parker, T. (1997). The Land Use - Air Quality Linkage. California EPA Air Resources Board.

### Constraints and Barriers to Implementation

- Time for implementation from "planning" stage to construction/development and full build-out is long. Full realization of GHG reductions from transportation-efficient land use initiatives requires consistent long-term political support.
- Intensification efforts can be met by opposition from existing residents due to concerns of increased traffic, loss of natural light/viewpoints and/or perceptions of higher density areas (e.g. crime, crowded environment, significant pavement and urban heat island). Early and frequent stakeholder engagement in the planning process and/or education campaigns may help alleviate some of these concerns and perceptions.
- Existing land use planning policies and zoning by-laws may be incompatible and require amendment to accommodate increased densities, mixed-uses, parking requirements, development and design standards, etc.
- Market demand for higher density housing and other uses may be insufficient. Engagement activities with the development community can help identify the most viable higher-density uses for a given area.
- Housing affordability can become jeopardized due to increases in land values and housing costs. Affordable housing requirements for new developments may counter this somewhat.
- The planning and design process, as well as multi-stakeholder coordination and engagement, can be complicated, costly and time-consuming.
- Concepts such as New Urbanism, Ecodistricts, and Grid Street Design are relatively new and generally lack empirical evidence to support the promises and predictions made regarding benefits.
- The existence of several charters, certifications and guidelines in relation to Ecodistrict design means that there are several definitions as to what constitutes an Ecodistrict, leading to challenges with implementing the concept. There is also a lack of tools and benchmarks available to decision makers to judge the quality of a project designated as an Ecodistrict.
- Minimum densities are required for public transit to be viable, yet high capacity transit is also a driver of higher density development, creating a chicken and egg type development scenario. For example, construction of park and ride facilities around major transit stations may promote car-oriented development or serve as a barrier to future densification. To overcome such circumstances, development of higher urban densities should occur in tandem with major transit infrastructure planning. With respect to park-and-ride facilities, a long term commitment to transportation-efficient land use planning should be employed as a means to ensure that such facilities are temporary or employed only on peripheral-end of transit line areas. The use of development commitments from municipalities in exchange for transit infrastructure financing and investment can be employed.
- Poor implementation of new planning concepts (e.g. the implementation of a TOD project) due to ill-conceived design or financial constraints can reflect poorly on the concept as a whole and result in a lack of enthusiasm for further implementation elsewhere. Accordingly, it is important that the implementation of new planning concepts be properly executed and held to high standards.

## 4.2 Transportation Supply-Side Alternatives

Transportation supply-side alternatives seek to promote viable transportation alternatives to single occupancy vehicle use. These include measures such as enhanced transit services and access to transit, the promotion of carsharing programs, investment in active transportation facilities for pedestrians and cyclists, and the adoption of more flexible working arrangements such as telecommuting. Providing transportation supply-side alternatives is key to reducing VKT. By getting more people to travel together in fewer vehicles, make trips by walking and bicycling, or avoid travel completely, VKT and GHG emissions can be reduced.

#### 4.2.1 Public Transit

| | | |
|---|---|---|
| **Responsibility** | | Local or regional transit agencies for transit service and facilities, local municipalities for supportive land uses and access |
| **Applicability** | S, M, L | There are a variety of transit vehicles and systems that are appropriate for all sizes of municipalities |
| **Cost** | $$ - $$$$$ | New expansion is capital intensive. Enhancements of existing transit services through operational changes may require investment in new vehicles, but overall costs are generally less than transit expansions. |
| **GHG Reduction Potential** | 3 - 4 | Targets car drivers and can have a significant impact on reducing GHG emissions, current transit vehicle fleet GHG emissions are small. |
| **Tech Feasibility** | 2 - 5 | Service expansion through capital investment more difficult, but service optimization is generally logistical and organizational in nature. |
| **Social Acceptability** | 3 – 5 | Transit projects are generally well received, but opposition may come due to implementation cost and space requirements (e.g. removing parking spaces) |
| **Timing** | Immediate, ongoing | Planning, design can occur rapidly, but construction likely in short to medium term. Transit optimization can occur immediately and on an ongoing basis. |
| **GHG reductions Timeframe** | Medium to long term | While travel by transit can eliminate emissions immediately, realization of its full emissions reduction potential may only occur in the medium to long term in coordination with supportive land use development. |

**Description**

Public transit (transit) is a mode of collective transportation allowing multiple users to travel aboard the same vehicle. Transit service provides an important alternative to travel by automobile, and is key to providing passenger mobility where different transportation measures and strategies to reduce VKT are employed by municipalities and regions (e.g. travel and parking restrictions, pricing mechanisms, land use planning, etc.). Transit can afford greater mobility for drivers who might otherwise be stuck in traffic congestion. It also provides mobility and travel flexibility for people who choose not to own a vehicle, who are unable or less able to drive (e.g. youth, elderly, persons with mobility impairments), as well as for low income earners who are less able to afford the costs of automobile use and/or ownership. Finally, transit use can reduce VKT, air pollution and GHG emissions as fewer vehicles are able to transport a given number of travellers, assuming that transit vehicle occupancy rates are higher than automobiles.

A diversity of transit vehicle types, technologies and systems are used across Canada, including buses, trolleys, tramways/streetcars, rapid transit and commuter rail systems. The various systems have advantages and trade-offs in terms of costs (e.g. construction and operation), capacity, speed, space requirements, design, intermodality, comfort, etc. A discussion about the trade-offs between the different types of systems is beyond the scope of this report. Ultimately, provinces, regions, municipalities and transit agencies must determine the appropriate vehicle, technology and system that is most suited for their context, service area, corridor, and budget. Readers wishing to find out more about the different modes of transit, advantages and trade-offs are invited to consult the large breadth of literature available on the subject, including:

- *Traveler Response to Transportation System Changes, Report 95, 2013,* by the Transit Cooperative Research Program, discussing the range of options available.
- *Transit Capacity and Quality Service Manual, 2nd Edition,2003,* by the Transit Cooperative Research Program, discussing transit quality of service and capacity concepts, and how rail and road based transit in North America perform;
- *Human Transit, How Clearer Thinking about Public Transit can Enrich our Communities and our Lives, 2011*, by Jarrett Walker, discussing the characteristics and trade-offs of different ways of organizing transit systems.

The current section focuses on how transit service can help reduce VKT and GHG emissions. However, transit vehicle operations can also contribute to GHG emissions. For example, diesel powered buses and trains generate GHG emissions through fossil-fuel combustion. There are a variety of vehicle propulsion technologies that are already available or are under development which can reduce vehicle GHG emissions (e.g. hybrid-electric propulsion, electric and fuel-cell propulsion systems). Readers are invited to consult **Chapter 6** for more details on transit vehicle propulsion technologies.

### Measures to Encourage

There are five main categories of action to encourage transit ridership. The first two categories of action deal with optimizing existing operations and increasing transit service supply. Improving transit passenger facilities and improving the experience of accessing transit are also important in facilitating the accessibility and attractiveness of transit service. The final category of actions covers awareness initiatives and financial incentives to encourage transit use. These categories of action seek to make transit service more efficient, more competitive with the automobile, and more attractive to travellers. This section does not present a discussion of the advantages and trade-offs between the various ways to organizing transit systems, which need to be evaluated according to the service area or corridor under evaluation. Such a discussion can be found in the two references cited above (TCRP, 2003; Walker, 2011).

#### *Optimize Existing Transit Services and Improve Quality of Service*

The **speed, reliability** and **on-time performance** of transit service are important characteristics for transit riders, retaining ridership and ensuring service quality. Longer travel times and less reliable trip times on transit are a major disincentive and deterrent to current and potential transit users (TCRP, 2010). These performance characteristics are affected by general traffic conditions, whether transit vehicles travel in their own right-of-way, as well as by weather conditions and vehicle operations (e.g.

passenger boarding times, express-services). Transit service speed, reliability and on-time performance can be enhanced through:

- Offering express (e.g. limited stop) services along heavily travelled corridors[16];
- Consolidating bus stops or reorganizing routes around intermodal hubs;
- Optimizing arrival times to minimize transfer wait times in lower density, low demand service areas with 'pulse' type networks;
- Providing service operation and arrival information to users in real time (e.g. next arrival, delays or breakdowns);
- Making transit routes as simple and direct as possible to enhance legibility and understanding of service by users;
- Installing infrastructure-based transit priority measures (e.g. reserved bus lanes, priority traffic signals at intersections). See **Chapter 5, section 5.7** for more information on transit priority measures.

***Increase or Expand Transit Supply***

Increasing transit supply can make transit available to more people and areas, and increase the number of people which can be carried by transit. This can be achieved by expanding a transit network's geographic coverage or increasing the frequency of services, hours of operation and/or the capacity of the transit system (e.g. higher capacity vehicles)[17].

- The geographic **coverage** of a transit network represents the portion of the population with access to transit service. Generally, walking accessibility to a transit stop or station is determined by a walking distance of approximately 400 metres (5 minute walk) to a local bus service and approximately 800 metres (a 10-minute walk) to a rapid transit station, which depends predominantly on transit frequency and speed (i.e. people would be willing to walk farther to access transit if their wait time or travel time is less). Increasing network coverage can be achieved through the creation of new travel routes and lines, the extension of existing routes or the addition of intermediate stops.
- The **frequency of service** is represented by the number of vehicle arrivals per hour. Increasing the frequency of service requires the addition of more transit vehicles to a line in order to decrease the amount of time between two arrivals. Higher service frequencies generally afford transit users greater flexibility and faster trips, as passengers wait less for the next vehicle when transferring. Where vehicle frequency is very high (i.e. less than 8 or 6 minutes), transit riders often become less concerned with vehicle arrival schedules[18].

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16 *Examples include B-lines in Metro Vancouver, Region of Waterloo's iXpress BRT, and Gatineau's Rapibus BRT services.*

17 *Note that increasing or expanding transit supply will ultimately result in trade-offs between costs and ridership. Increased geographic coverage or increased frequency in areas with lower population densities may improve transit access, but decrease vehicle load factors and increase costs. A discussion of the trade-offs of different ways of organizing transit systems can be found in Walker, 2003.*

18 *A good example of improving service frequency is the "Frequent Transit Network". The Frequent Transit Network is an interconnected set of frequent transit services that run throughout the day and into the evening, every day. The minimum level of frequency by transit agencies is typically between around 10 to 15 minutes. Minimum service frequencies throughout the day increase the dependability of the service and reduce average wait times for boarding or transfers. The interconnection of frequent services routes can form a frequent transit network, where transfers become simpler with less wait time, and the utility of the service increases substantially for multiple trip purposes and destinations. Examples of frequent transit networks include combinations of rapid transit services with frequent bus transit networks, such as in Montreal and Vancouver. For smaller size cities, frequent transit services can be employed during shorter periods during weekdays and on weekends. Frequent transit networks are also used as a tool for coordinating land use planning and transportation, such as focusing higher density growth along these networks which results in higher ridership and even further increases in frequency of service.*

- Transit **service hours of operation** represent the time during the day when transit service is offered. Increasing hours of operation can occur through offering additional arrivals before and after current service schedules, nighttime service (e.g. between midnight and morning peak period) and weekend service.
- Vehicle **capacity** corresponds to the number of travellers that can be carried by a given vehicle. Vehicle capacity is improved by increasing vehicle size (e.g. going from smaller to larger or articulated buses), adding more cars to the same vehicle (for light train, tram and trains), or implementing a higher capacity mode (e.g. bus to rapid transit).

***Improve Access to Transit Services***

In addition to enhancing existing transit services, or expanding transit supply, it is equally important that transit users be able **to access transit services conveniently**, **comfortably** and **safely**. Consideration of the characteristics and quality of access routes to transit services, whether to intermediate stops or major transit stations, is important to encouraging transit use. Municipalities have a key role to play in organizing pedestrian, cycling and vehicle access, as well as land use development patterns that facilitate access to transit services. These measures are listed below. Focus should be placed on access to transit services with higher frequencies and higher ridership.

- Develop and expand a complete network of sidewalks and pathways within walking distance of transit stops and stations (Further information about active transportation can be found in **Section 4.2.3** of this chapter);
- Improve and expand safe pedestrian crossings in proximity to transit stops and stations, especially across barriers such as major roads, highways, railways, water courses or other natural features;
- Improve cycling network and facilities around transit stops and stations;
- Provide sufficient secure bike parking at rapid transit stations and high passenger activity stops;
- Install wayfinding signage to help people better navigate to and from transit stops and stations;
- Install adequate nighttime street lighting to and from transit stops and stations;
- Include universal accessibility (i.e. accommodating persons with mobility impairments) in the design of access routes;
- Ensure adequate maintenance (e.g. leaf and snow clearing) and condition (e.g. avoid cracks, holes, unevenness) of access routes; and,
- Develop transit supportive land uses, such as transit-oriented development (TOD), around rapid transit stations or frequent transit services, and compact development forms with higher densities and diversity of uses,  diversity of housing options to accommodate different types of households, and good active transportation connectivity to transit stops and stations (Further information about the role of land-use planning can be found in **Section 4.1** of this chapter).

***Improving Transit Passenger Facilities and Vehicle Amenities***

The attractiveness of transit can also be influenced by the condition of and services offered at transit passenger facilities and aboard vehicles. As travellers spend some amount of their trip either travelling on vehicles or passing through or waiting at stops, the transit trip experience can be improved by enhancing the **accessibility, comfort** and **safety** of **transit passenger facilities and vehicles**. Transit agencies have a key role to play in improving their stop or station facilities and vehicle amenities. Measures include:

- Integrating universal accessibility in facility and vehicle design or upgrades (e.g. access ramps, low floor vehicles, elevators);

- Enhancing intermodal travel by bicycle (e.g. bicycle lock-up areas, covered parking, storage lockers, bicycle racks on buses);
- Enhancing access for certain users through passenger drop-off or park and ride facilities[19];
- Providing comfortable waiting areas and amenities protected from weather (e.g. benches, convenience store, Wi-Fi, public telephones, etc.);
- Ensuring the cleanliness of stops and vehicles;
- Providing station wayfinding signage, adequate lighting, emergency response; and,
- Providing transit stop, station and on-board travel information (e.g. stop announcements, real-time arrival information, delays or service information, etc.).

***Enhance Awareness and Offer Incentives***

Finally, **promoting** transit services and offering **incentives** can also encourage travellers to adopt transit. Measures include:

- Running advertising and awareness raising campaigns. They can, for example, showcase the advantages of using transit with respect to other modes, especially the single occupant vehicle, in terms of the economic, social and environmental benefits and impacts;
- Reducing or revising general transit fare structure;
- Offering fare free zones or periods (e.g. events);
- Offering special transit passes and discount fares. These include fares such as multiple ride tickets, off-peak travel, unlimited-ride passes. They may also include special fares targeting specific user or age groups (e.g. discount fares for youth, students or seniors)[20].
- Offering transit-benefit programs in conjunction with employers such as discounted monthly passes. Employers may themselves also offer financial incentives to commuting by alternatives to the automobile (see Section 4.3 for more information on parking and pricing mechanisms).

**Pros and Cons**

The benefits of transit service include**:**

- Reduction in automobile use and traffic congestion;
- Reduction in auto ownership rates in areas with rapid transit or frequent transit service;
- Where transit vehicle occupancy rates are higher than automobiles, it can result in reduced energy use, fuel consumption, air pollution and GHG emissions;
- Increased mobility for youth, elderly persons, and persons who do not own vehicles;
- Increased mobility and flexibility for all transit users;
- Enhanced mobility and equity for low-income earners;

[19] *While park-and-ride facilities are very commonly used across transit systems in Canada, it should be noted that they are not suitable for all transit station contexts or longer term land use planning objectives. They work well at end of line stops or in lower density environments where transit service is infrequent or unavailable, and where people access transit more easily by vehicle. However, park-and-ride facilities can diminish the quality of access for active modes of transportation around the transit stop (e.g. increased vehicle traffic, parking lot), may facilitate low density urban development or sprawl, and may be a barrier to higher density development around transit stations. See TCRP 2013, Chapter 3 on Park-and Ride facilities and Chapter 17 on TOD for a discussion of the advantages and trade-offs of park-and-ride facilities (TCRP, 2013).*

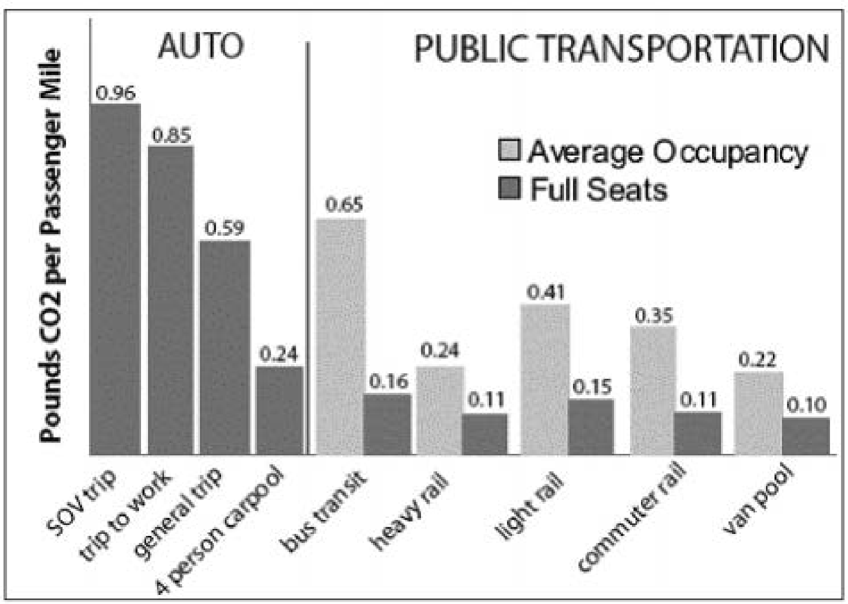
[20] *An example of a specialized fare is the U-Pass (universal passes), which are discounted passes offered to university or college students. The U-Pass differs from a regular discounted fare because all students at an institution are required to contribute to the program, which significantly reduces the cost of the transit pass per student. U-Passes typically provide unlimited transit access, and have typically seen very high usage by students.*

The disadvantages of transit service include:

- Many of the transportation and environmental advantages of transit listed above may not be realized if transit vehicle load factors are low (e.g. less than 7 persons per 40 foot diesel bus);
- Necessity on occasion to redevelop or expand existing installations (e.g. bus bays, vehicle garages) to accommodate larger capacity vehicles.
- Use of existing road space for dedicated transit travel ways is a trade-off that must be made by planners and policy makers.

## Impacts

Transit reduces GHG emissions from the transportation sector in one of three ways. First, transit vehicles can transport passengers with less fuel and energy compared to the trips made by private automobile. While the net effectiveness of transit vehicles increase with load factors (i.e. how full is the vehicle), trips made by transit have the potential to be significantly less GHG intensive than trips made by private automobile. A 2009 study of US travel found that a regular 12 metre diesel bus becomes more energy efficient than a single-occupant vehicle if it transports more than 7 persons. With hybrid buses, the number of passengers on a bus required to yield fewer emissions than a SOV would be even less. For a commuter train, this threshold is when approximately 19 % of its seats are filled (TCRP, 2010) (Figure 4-1). While a four-person carpool can sometimes be more efficient than transit vehicles loaded at average occupancy rates in the U.S., fully loaded transit vehicles are always lower than travel by automobile.




Source: Transit Cooperative Research Program, 2010

**Figure 4-1 – GHG Emissions per passenger of Transportation Options**

These results are similarly supported by Canadian examples. The Laval Transit Corporation (Société de transport de Laval) estimated that a user travelling 20 km to work (thus 40 km round trip) by diesel bus would generate around 1.28 kg GHG / day, or 0.33 tonnes GHG / year. On the contrary, the use of a compact car with an average fuel consumption of approximately 10 L/100 km would result in 10 kg GHG / day, or up to 2.5 tonnes GHG / year. Thus, the reductions in GHG emissions from a user taking the bus are seven times less as compared with using a car (Société de transport de Laval, 2015).

In an analysis of the Frequent Transit Network (FTN) for the Metro Vancouver region, TransLink found that VKT per capita was 33% less for people that lived within walking distance of frequent transit than for people living beyond it, vehicle ownership rates were much lower for people living within walking distance of frequent transit, and almost 20% of households who lived within walking distance of frequent transit did not own a car. Thus, frequent transit service contributes to reduced GHG emissions per person.

Second, transit trips help to reduce roadway congestion (e.g. stop and go traffic, idling and subsequent GHG emissions) because partially or fully loaded buses take less road space compared to the case where those travellers drove. This effect is even more pronounced for rail or subway transit, which do not occupy road space.

Finally, transit service facilitates denser, compact development patterns which can in turn facilitate travel by walking and cycling, and make trips shorter (i.e. trip origin and destinations are closer together) (TCRP, 2010).

### Constraints and Barriers to Implementation

The principal constraints to increasing transit ridership include:

- Recognizing that transit investments are longer term, city shaping investments that do not always produce quick results, but rather can serve, with proper land use planning, as the armature for more efficient, attractive and equitable urban regions (Ellis, 2002);
- Having population densities that are high enough to support transit service or transit service improvements;
- Space requirements (right-of-ways) for the installation of higher capacity dedicated bus rapid transit or fixed rail services;
- Space requirements (roadways) for the installation of reserved bus lanes, with potential impacts to general traffic and on-street parking availability; and,
- Capital and operational financing for transit expansion or improvement projects.

### 4.2.2 Taxibus Transit

| | | |
|---|---|---|
| **Responsibility** | | Taxi operators for operations, local or regional agencies for coordination, financing or subsidies. |
| **Applicability** | S | Taxibus transit service is generally limited to small, low density communities or on the peripheral areas around municipalities where regular transit service is not viable |
| **Cost** | $ - $$ | Makes use of existing taxi fleet to offer services, costs involved in administration and operation of service |
| **GHG Reduction Potential** | 1 | Generally lower ridership due to low density areas served, automobiles are still used, can induce car travel for individuals who otherwise do not have access to a vehicle |
| **Tech Feasibility** | 3 | Partnerships required with private taxi operators to offer service |
| **Social Acceptability** | 4 – 5 | Offers benefits to taxibus transit users while having little impact on other road users. |
| **Timing** | Immediate, ongoing | Service can be implemented immediately where there is demand |
| **GHG reductions Timeframe** | Short | As a taxibus service typically serves already built low density areas, GHG reductions can be achieved rapidly. |

## Description

Taxibus transit is a form of demand-response public transit suitable to areas with low population density, such as rural areas or the periphery of urban and suburban areas. It employs local taxi cars or vans to service areas where demand is generally insufficient to warrant regular bus transit service. It can also work in a complementary fashion to regular transit services by serving as feeders from outlying sectors or areas. On the range of potential public transit offerings, taxibus service can be considered as the minimum (with mini-buses, buses and rapid transit offering increasing levels of transit service).

As a demand-response service, taxibus transit requires reservations to be made anywhere from 24 to 1 hour in advance of travel. The service can accommodate both regular and non-regular clients (e.g. retired persons making non-regular trips). Taxi transit service can be organized as a door to door service (i.e. whole trip), door to stop or stop to door service (i.e. to start or complete a trip), or from stop to stop (i.e. like a transit route). Where there are no reservations for a given day, the service is generally not run.

Taxibus transit differs from regular taxi service in several ways:

- Routes and schedules for taxibus transit are generally fixed (although they require a reservation to be run);
- Like other forms of public transit, taxibus transit can pick up multiple individuals along a route;
- Taxibus transit fares are generally set at a discounted or fixed rate (e.g. like bus fare), although they may vary according to the distance of the trip;
- Taxibus operations to date have generally come about through public-private partnerships, where municipalities or transit agencies contract private taxi-operators to provide vehicles and service. In the case of the Taxibus service of the City of Rimouski, Quebec, service administration and reservations were initially handled by a non-profit corporation setup for the purpose, although this was eventually folded into the operations of the local transit agency (AECOM Tecsult Inc., 2010).

Taxibus transit also differs from fixed schedule transit service for low density areas, such as might be served by a mini-bus, because vehicle fleets are not owned by transit operators and service is not offered without prior reservations (i.e. when there is no passenger demand).

Examples of taxibus transit in Canada are primarily located in Quebec (Transport Canada, 2004), including:

- Small bedroom communities around the periphery of Montreal (pop. between 15,000 and 40,000)
- The City of Rimouski (pop. over 40,000).

## Measures to Encourage

### Provincial, Regional or Local Agencies

- Provide funding to support implementation or subsidization of operations in order to make fares affordable for travellers. For example, the City of Rimouski subsidizes the taxibus service, while in Quebec, taxibus service is recognized as a public transit service and is eligible for provincial subsides;

### Regional and Local Agencies

- Establish partnerships with local taxi companies to operate taxibus service;
- Implement a preferential or discount fare structure to attract users to the service;
- Develop a communications plan, promote awareness and advertise program.

## Pros and Cons

The benefits of taxi transit service include:

- Provides transit service for outlying or low-density areas that would not otherwise be served by regular transit;
- Provides mobility for low income persons who would not otherwise be able to afford a regular taxi or own and operate a private automobile;
- Costs of offering the service are generally lower than fixed schedule transit service, as routes can be suspended when there is no demand;
- There is no fuel consumption and or GHG emissions from the service when there is no demand, as compared to a fixed schedule transit service;
- The ability to pick up and combine multiple users to minimize the number of trips made;
- The ability to offer door to door service;
- The ability to accommodate persons with mobility impairments.

The disadvantages of taxi transit include:

- The necessity and potential inconvenience of having to reserve taxi transit service up to 24h in advance (i.e. diminished flexibility to make a trip without adequate time in advance);
- Limited capacity of vehicles used for taxi transit;
- Penalties for users in case reservations are not used.

## Impacts

Prior to 1988, the municipality of Rimouski (Quebec) was served by a bus transit system which eventually became financially unviable. Still wishing to offer public transit services, the municipality decided in 1993 to pilot a private-public partnership project with local taxi operators to fulfill the role. Since that time, the taxibus service has turned into a regular service and has grown in popularity. In 2008, a study was completed on the effectiveness of the service. It found that annual ridership was just over 114,000, with average passenger (excluding driver) loads ranging between two and three persons per trip (AECOM Tecsult Inc., 2010). The study suggests that the taxibus service provided public transportation services to areas where residents would otherwise have had to drive. An earlier study of taxibus users in Rimouski found that while 57% of them had a driver's licence, 78% of them did not own a car (Transport Canada, 2004), suggesting that the service may have reduced the pressure for car ownership.

## Constraints and Barriers to Implementation

- Due to the generally low-volume nature of the service, operating costs and revenues can be variable for the entity offering or subsidizing the service.
- Partnerships must be established with taxi companies, and reservations and logistics management must be setup to offer a service.
- Need to identify and setup appropriate legal structure to govern taxibus service (Transport Canada, 2004).
- Demand-response based transit service is more administratively intensive than fixed-schedule services as constant care is required to ensure reservations are always met by service (Transport Canada, 2004).
- The growth of taxi-bus service will be limited to low-density areas, as fixed route transit service starts to become more viable if travel demand increases beyond the taxi fleet capacity.

### 4.2.3 Active Transportation

| | | |
|---|---|---|
| **Responsibility** | | Local and Regional Municipalities |
| **Applicability** | S, M, L | Active transportation infrastructure is applicable to all sizes of municipalities |
| **Cost** | $ - $$$ | Generally very cost effective to integrate measures within new development, space requirements are lesser than for other modes |
| **GHG Reduction Potential** | 3 | Effectiveness can be high through encouraging development of zero-emission travel mode, but has little impact for medium to longer travel distances |
| **Tech Feasibility** | 3 - 5 | Depends on the scale of the project, but generally requires less space than other modes of transportation. |
| **Social Acceptability** | 4 – 5 | All travel users benefit from active transportation, although some opposition may come where lane capacity and parking spaces are affected. |
| **Timing** | Immediate, ongoing | Active transportation is a current practice in all types of urban environments and can be implemented immediately |
| **GHG reductions Timeframe** | Short | Every trip made by active transportation immediately avoids GHG emissions. More significant emissions reduction potential can be achieved in the medium to long term if supportive land use development is expanded. |

**Description**

Active transportation is defined as all forms human powered transportation. There are many modes of travel that can be classified as active transportation, including walking, jogging, running, cycling, in-line skating and skateboarding. The two predominant modes of active transportation are walking and cycling. Travel by active transportation modes can cover the whole trip, or can be combined with other modes such as transit.

Facilitating and encouraging active transportation is a key strategy for reducing transportation sector related GHG emissions. Active transportation generates no GHG emissions, and widespread adoption can have a significant impact on GHG emissions for short trips. The inclination of walkers and cyclists to undertake a trip varies according to a whole range of route specific contextual and environmental factors including distance of trip, weather conditions, urban environment, infrastructure, safety and comfort, as well as individual human factors, including personal fitness, purpose of trip and personal preferences.

This section does not cover the range of considerations and practices in planning, designing and implementing active transportation infrastructure. Readers wishing to find out more about these subjects are invited to consult the large breadth of literature available on the subject, including:

- *Planning and Design for Pedestrians and Cyclists, 2009*, by Vélo Quebec, for a full discussion on route planning and different types of segment, intersection, end of trip and facilities to facilitate active transportation (Velo Quebec, 2009);
- *Active Transportation in Canada: a Resource and Planning Guide, 2011*, by Transport Canada for a presentation of active transportation in Canada, best practices, key principles, resources and a strategic planning approach for developing active transportation projects and incorporating active transportation into municipal policy (Transport Canada, 2011a); and,
- *Bicycle End-of-Trip Facilities, 2010,* by Transport Canada for a full discussion of bicycle parking and storage options (Transport Canada, 2010a).

### Measures to Encourage

Municipalities and regional agencies can encourage active transportation practices through one of five main avenues of action:

***Develop, improve and maintain infrastructure and spaces dedicated to active transportation***

- Build, improve and widen sidewalks, including smoothing out uneven and cracked surfaces;
- Develop a network of bike lanes, traffic-separated cycling tracks and multi-user pathways suitable for people of all ages and abilities;
- Create continuous routes and reduce barriers to travel, whether physical (e.g. railways, highways, water courses, hedges, fences) or perceived (e.g. overhead road infrastructure, tunnels);
- Increase connectivity within and through zones and neighbourhoods by allowing short, direct and easy access for active transportation modes (e.g. permeable urban blocks with walkways allowing direct access to and through urban areas);
- Maintain all-season networks (i.e. keep sidewalks and cycle routes open all year round);
- Provide or support public bicycle sharing programs (e.g. public bike sharing systems in Montreal, Ottawa, Toronto, Hamilton and one to be launched soon in City of Vancouver).

***Enhance accessibility, intermodality and complementarity of active transportation and public transit***

- Install bicycle supports (e.g. racks, parking facilities) in residential areas, as well as at transit stations and near to places of work, shopping and leisure;
- Provide end-of-trip facilities such as lockers, showers, change areas for cyclists, and repair tools and services.

***Encourage supportive land use development***

- Promote a density and diversity of land uses, and compact urban form to increase the number of origins and destinations while reducing the distances between them (e.g. home to work, shops, services, see Section 4.1 on land use planning for further information).

***Enhance the safety and comfort of active transportation trips***

- Enhance intersection safety (e.g. defining edges, enhancing visibility and sightlines, signage and ground markings, signals, reserved phases, signal priority and longer phases for pedestrians and cyclists);
- Maintain and repair sidewalks and bike paths to patch up cracks, potholes and irregularities;
- Provide adequate lighting and clear signage;
- Create buffer zones for active transportation users, such as separation distances, vegetation and path delimiters (e.g. bollards or fencing);
- Implement traffic calming measures to reduce driver speeds (e.g. chicanes, special paving, speed bumps, lower speed limits);
- Raise awareness among road users to the presence of other vulnerable road users such as cyclists and rollerbladers;
- Adopt bylaws and regulations to protect active transportation travellers (e.g. passing distance, yields, speed limits, opening of doors, intersection and crosswalk priority, etc.). Enforce bylaws and regulations through increased surveillance and issuing tickets and fines;
- Implement secure travel routes to school (e.g. intersection crossing guards, employ walking school buses, accompanied by parents, volunteers or municipal workers);

***Run Information and awareness campaigns***

- Provide signage and maps to show travel routes and duration;
- Encourage employer-focused commuting campaigns such as Car-free day/week, Commuter Challenge, Vélo-boulot,
- Run awareness campaigns such as Cyclovia, June is Bike Month, International Walk to School day/week/month, critical mass rides, etc.

**Pros and Cons**

The benefits of active transportation are numerous, and include (Transport Canada, 2011a):

- The reduction of energy use for travel, GHG emissions and air pollution from motorized forms of transportation;
- Reduced noise pollution;
- Physical and mental health benefits and improved quality of life, with benefits for (avoided) health care costs;
- Individual cost savings (i.e. a cheaper way to travel);
- For public entities on a per kilometre basis, lower costs to build and maintain compared to car infrastructure or public transit. A shift to active transportation can help reduce overall costs for transportation (e.g. reduce need for new roads and reduced maintenance of existing infrastructure) (Velo Quebec, 2009);
- Positive impacts on local businesses and economic development, as more travellers passing by a local area are more likely to spend money in local businesses (Transport Canada, 2011a). Furthermore, there is some evidence that active transportation travellers also tend to frequent local businesses more often than drivers (CAP, 2009);
- Reduced space requirements for active transportation. In urban environments where car traffic and bicycles travel at similar speeds, one car driver occupies between seven to twelve times the space required by a cyclist, while taking up between 10 to 20 times the space required for a pedestrian (Transport Canada, 2011a; Velo Quebec, 2009). In urban areas where space on public right-of-ways is

limited, active transportation infrastructure represents an important means of transporting more people within existing space;

- A well-planned municipal active transportation network enhances the broader transportation network;
- As transit trips usually start or end with walking, good active transportation facilities can encourage transit use;
- Building infrastructure and environments that promote active transportation is more equitable for society, regardless of income or physical disability (Transport Canada, 2011a).

The disadvantages of active transportation include:

- Trip distances are more limited when compared to trips that can be made by car or transit;
- Viability of active transportation is subject to environmental factors (i.e. weather and seasons);
- Travellers by active transport are generally the most vulnerable group of road users.
- A significant proportion of active transportation users are former transit users or pedestrians, therefore the impact on modal shift from car to active transportation may be limited to only a fraction of those trips;
- Load or cargo carrying capacity is more limited than by vehicle without the purchase of specialized bicycles, trailers, or trolleys.

## Impacts

It is known that active forms of transportation are more efficient than fossil fuel based vehicles. For the energy equivalent of one litre of gasoline, a bicycle can travel 423 km, forty times greater than the distance achievable by an average gasoline powered car (based on 10L/100 km fuel economy) (Transport Canada, 2011a). Due to a bicycle's mechanical advantage, cyclists can cover 4 – 5 times more distance than a pedestrian using an equivalent amount of energy (Herman, Komanoff, Orcutt, & Perry, 1998). Furthermore, the average car releases about 0.85 kg of $CO_2$ eq. per kilometre travelled while active transportation releases virtually none (Transport Canada, 2011a).

A study completed in the United States, Moving Cooler, found that an approach focused only on investment in infrastructure dedicated to pedestrians and cyclists across the United States would only generate approximately 0.2 to 0.5 % savings in GHGs (approximately 3 to 10 Mt GHG/year) by the 2050s as compared to the study's business as usual baseline. However, coupled with other measures and controls to encourage other forms of sustainable transportation such as transit and more efficient land use development[21], the combined multi-modal transportation approach could achieve up to 6 – 9 % of reductions (90 – 180 Mt CO2 eq./year) by the 2050s (Cambridge Systematics Inc., 2009).

It has also been demonstrated that active transportation infrastructure is far more cost-effective than infrastructure dedicated to motorized travel. In the Netherlands, only 6% of the road infrastructure budget is allocated to cycling infrastructure, while 27% of all trips are made by bicycle (9% of all passenger kilometres travelled) (Verkeer en Waterstaat, 1993). Costs for building bicycle lanes are approximately $20,000/km if no road widening is required, or around $150,000/km if road widening is required. On the other hand, widening an urban arterial road from two to four lanes costs over 10 times more (Transport Canada, 2011a). Another study estimated that for the equivalent cost of building 1 km of an urban highway, it is possible to build approximately 150 km of bicycle paths or 100 km of traffic calmed streets (i.e. 30 km/h zone) (Velo Quebec, 2009). Similarly, high quality bicycle parking (i.e.

[21] *The study considered reinforcements of policies to strengthen more efficient land use development such as compact development, coupled with road and parking user fees.*

covered and secure) can cost around $100 – 500 per bicycle, while a parking space may cost around $8,000 - $10,000 for surface parking, and up to $50,000 for multi-level parking structures (Transport Canada, 2011a).

**Constraints and Barriers to Implementation**

- Land use characteristics and trip distance:
- Origins and destinations which are located farther apart (e.g. sprawled urban environment) will not be conducive to encouraging active transportation. In Canada, the average one-way commute takes around 30 min. This is the equivalent to around 2 – 3 km by foot and 8 – 10 km by bicycle (Transport Canada, 2011a). Encouraging land use development which helps limit trip distances and travel times to those which can comfortably be made by active transportation is important for encouraging the latter.
- Health and Safety:
- Perceived and real threats to cyclists and pedestrians safety on their journey due to poor road and intersection conditions, or designs that are not adapted to active transportation users (e.g. space, sightlines, clarity of movements, priorities, lighting, etc.);
- The perceived or actual impolite or dangerous behaviour of other road users, including other drivers, cyclists or pedestrians, may be a deterrent to active transportation;
- Despite the benefits of physically active transportation, active transportation users may be sensitive, affected, or discouraged from travelling by foot or bicycle by air pollution from vehicle fuel combustion;
- Perceived threat of theft and actual bicycle theft can be a deterrent to cycling;
- Environmental:
- Geographic conditions, inclines and route surface conditions (e.g. rough, slippery, cracked);
- Bad weather conditions such as cold temperatures, wind, rain, snowfall and freezing rain;
- Financial and Technical Resources:
- While active transportation infrastructure is less costly per capita, funding availability, especially for smaller municipalities, may be limited;
- Limited data and understanding of active transportation patterns, numbers of users and future projections. Lack of data makes it more difficult to make a business cases for investment.
- Agency staff knowledge and capacity limitations, especially in communities who do not have dedicated personnel or expertise on active transportation measures.

### 4.2.4 Carsharing

| | | |
|---|---|---|
| **Responsibility** | | Private operator, municipalities |
| **Applicability** | M, L | Carsharing services function more effectively in areas with higher population density, where more people can share the same vehicle, where walking distances to access vehicles are reasonable (e.g. 400 m), and walking conditions are good. |
| **Cost** | $ - $$ | Capital investment for private operator depends on extent of vehicle fleet being offered, costs (network growth) can be incremental. Operating costs borne by user. Municipal costs to accommodate carsharing vehicles (planning and parking space allocation) are generally minimal. |
| **GHG Reduction Potential** | 2 - 3 | Encourages more considered and moderate use for some users, but continued use of fossil fuels for vehicle travel (regular and hybrid vehicles), car travel may continue to contribute to congestion. |
| **Tech Feasibility** | 4 | May need to revise parking policies (e.g. municipal and/or private on-street, off-street parking restrictions) to allow carsharing vehicles. |
| **Social Acceptability** | 4-5 | Provides a service that is generally well received by the community. |
| **Timing** | Immediate, ongoing | Can be implemented immediately. |
| **GHG reductions Timeframe** | Short | Car-sharing services encourage individuals to moderate their vehicle usage, avoid car ownership. Effect is also immediate where trips are made by more compact vehicles, or by hybrid or electric vehicles. |

**Description**

Carsharing is an alternative method of car ownership that can have benefits for reducing vehicle travel and GHG emissions. Carsharing members sign up with an organization which makes a shared fleet of vehicles available for use by their members. Members must typically reserve a vehicle for a fixed period of time, and typically pay for the time they use the car and/or for the distance they travel. In some arrangements, the costs of gas and insurance are also included in the user fee.

There are two types of carsharing usage models that have been deployed thus far in Canada. The first model requires members to reserve the vehicle for a fixed amount of time and pick-up and return the vehicle to dedicated parking spots. The *Communauto* carsharing program in Quebec is an example of this type of usage model. The second usage model allows members to pick-up and drop-off vehicles within designated zones or parking lots in a city without having to return the vehicle to its origin (i.e. self-service vehicles, or "*auto en libre-service*"). In designated zones, vehicles can typically be left on-street in residential or commercial areas where there are no parking restrictions or fees in place. In this usage model, users are typically charged by the minute, but can retain the use of the vehicle for as long as required to complete their trip. *Communauto's Automobile* service in Quebec, and the *Car2go* network across North America are examples of this second kind of carsharing model.

Carsharing programs can reduce VKT in two ways. First, as members typically pay for time and distance of travel, travel needs are usually carefully considered. The principal of user-pay is one mechanism by which carsharing programs can reduce VKTs. Second, the vehicles that are typically made available to members are often compact in size, or may employ hybrid or electric propulsion technologies, all of which reduce fossil-fuel use per trip.

Carsharing programs can reduce the need for individual car ownership, or the need to own a second vehicle. They are part of a diversity of transportation options (e.g. bicycling, walking, public bicycle sharing, transit) available to individuals and households. Carsharing programs support other modes by providing options for transporting larger goods or reaching destinations that are not as easily accessible by other modes. Carsharing programs sometimes include special rates or discounts at private car rental companies allowing users to get a vehicle for long distance travel when needed. With this diversity of options, the need to own a private vehicle or two becomes less critical.

Carsharing programs and networks have been growing in popularity over the last two decades. According to a 2009 study, there have been 50 carsharing programs deployed in North America since 1994 (Shaheen, Cohen, & Chung, 2009). As of July 1, 2009, there were approximately 16 active programs in Canada and 26 in the USA, with an estimated 378,000 carsharing members and 9,800 vehicles (Martin & Shaheen, 2011a). Examples across Canada include:

- The Communauto network is currently available in Montreal, Quebec City, Sherbrooke, Gatineau, Ottawa (Vrtucar), Kingston and Halifax;
- Car2go network is in place in Montreal, Calgary, Toronto and Vancouver, as well as many other cities across the United States and Europe;
- The Community CarShare network is active in several dozen municipalities across Ontario, including Guelph, Kitchener-Waterloo region, Hamilton, Elmira and London;
- Discount car rental company's Student Car Share program makes vehicles available to student members across 30 college and university campuses across Canada.

There are smaller carsharing programs in place in individual municipalities. They include:

- Evo Car Share in BC (BC Automobile Association)
- Victoria Car Share Co-op (BC)
- Modo (Victoria, Metro Vancouver)
- Calgary Alternative Transportation Co-op (AB)
- Carsharing Co-operative of Edmonton (AB)
- Regina Car-Share (SK)

- The Peg City Car-Coop (Winnipeg, MB)
- Autoshare Toronto and Mississauga (ON)
- CarShareHFX (Halifax, NS)

Partnerships have been established between Vrtucar (Ottawa), Communauto, Autoshare and Community CarShare programs. These partnerships allow members to use the vehicles of other organizations without having to pay for registration fees[22]. Similarly, agreements between Communauto and Mobizen (Paris, France) allow users to reserve cars across their networks.

Partnerships have also been made between carsharing companies and transit corporations, private rental companies, taxi services, public bicycle programs and businesses. These partnerships are offered to entice individuals to sign up for car-sharing programs, but also to provide complementary and beneficial tariffs and fees for the use of complementary transportation services when needed.

## Measures to Encourage

**Regional and municipal authorities**

- Integrate carsharing services as an option within Transportation Plans and strategies;
- Revise municipal parking policy to allow for carsharing vehicle parking on and off-street;
- Revise parking policies and requirements for new developments to allow for carsharing vehicle parking;
- Discourage the purchase of a household vehicle through strict regulations on the number of parking spaces per household unit or limiting the number of parking permits per residence, etc.
- Provide carsharing spaces at municipal and government service facilities, and encourage private businesses to offer the same;
- Provide incentives or subsidies for the development of reserved parking spaces for carsharing;
- Offer tax benefits for carsharing users or incentives to sign up for carsharing services when a person returns his or her license plate or when their car is brought in for recycling (e.g. scrap yard);
- Provide a favourable tax rate on gasoline for carsharing vehicles;
- Offer incentives to employers to encourage car-sharing services for their employees;
- Facilitate or encourage agreements between agencies offering carsharing services and other sustainable transportation services.

## Pros and Cons

The benefits of carsharing include:

- Potential reduction in VKT use due to more measured use of vehicles;
- Reduction in energy and fuel consumption per trip where carsharing vehicles are more compact, hybrid or electric;
- Reduced demand for parking space. It has been estimated that private vehicles are often parked for 95 % of their lives (Équiterre, 2011). Carsharing encourages better, increased use of existing vehicles and spaces;
- Allows users to get rid of their vehicle, avoid owning a vehicle or purchasing a second vehicle, with associated cost savings;

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[22] *Operating fees still apply.*

- Can reduce development costs if parking space requirements of new multi-unit developments can be decreased where car sharing services are included.
- Convenience for users of vehicle access without having to manage maintenance or insurance;
- Provides mobility option for users without significant financial investment;

The disadvantages of carsharing include:

- The need to reserve vehicles in advance, and the lack of availability at certain times due to heavy usage;
- The use of carsharing may impact public transit and active transportation use. A recent study suggests that carsharing services may have had a net negative impact on transit use (i.e. less transit use overall), but may have had a net positive impact on the number of people using active transportation (Martin & Shaheen, 2011b).
- May contributes to road congestion;

**Impacts**

Car sharing services have resulted in reductions in GHG emissions through a more considered use of cars for travel, or from avoided trips. A recent study was conducted to evaluate household car use before and after joining a carsharing service. The study covered 11 carsharing organizations and near to 10,000 users across Canada and the U.S. The data was gathered from multiple cities, states and provinces, and was considered representative of the active carsharing population in both countries in 2008. The study found that the majority of households actually increased their emissions after joining a car sharing service, but those increases were individually small. In contrast, the remaining households decreased their emissions more significantly by driving less or getting rid of a vehicle. The net emissions balance was negative. Overall GHG reductions were equal to approximately - 0.84 tons of GHG/ year per household, considering both observed trips and avoided trips. Study authors extrapolated their data to the entire carsharing population in Canada and the USA in 2009 and estimated that between 158 – 224 kT of GHG / year were reduced or avoided by carsharing services. (Martin & Shaheen, 2011a). Another study published in 2007 estimated that the 8,320 members of Quebec's *Communauto* service in 2005 reduced approximately 10.1 kT of GHG/year (Tecsult, 2006).

Carsharing contributes to reductions in GHG emissions because of overall reduced VKT. The study cited above found that actual VKT/year decreased by 27% on average for households between the years before and after joining a carsharing service (Martin & Shaheen, 2011a). Another study by the École Polytechnique in Montreal compared car use between households with or without a car. The study found that carsharing members (specifically those who are members of Quebec's *Communauto* service) travel 3.7 times less by car than car owners, and that the former make use of active transportation and transit options far more for their travel needs than car owning households (Sioui, Morency, & Trépanier, 2012).

Finally, car sharing programs have contributed to a decreased need for car ownership by allowing households to get rid of an existing vehicle, avoid owning a car, or avoid getting a second vehicle. Martin and Shaheen's study of carsharing participants in Canada and the U.S. found that the average number of vehicles per household before and after signing up for carsharing services went from 0.47 to 0.24. The majority of this shift came from one vehicle households becoming carless. They estimated that each carshare vehicle was equivalent to 9 to 13 private vehicles, either through households getting rid of vehicles, or avoiding the acquisition of a new one (Martin, Shaheen, & Lidicker, 2010). The École Polytechnique study found that only 12% of households which subscribed to the *Communauto* service owned at least one vehicle compared to 66% of the general public (Sioui, Morency, & Trépanier, 2012).

In another study of the Metro Vancouver region, there were between five and eleven fewer private personal vehicles per car share vehicle on-average, either because households got rid of their own private vehicle, or avoided acquiring one (Metro Vancouver, 2014).

**Constraints and Barriers to Implementation**

- Carsharing programs are not viable for certain kinds of trips, such as regular home-work (commuting trips), as the cost of use may become prohibitive, and personal car ownership or other modes of transportation are better suited.
- A certain population base in close proximity to vehicle locations is often necessary to ensure sufficient use and financial viability of maintaining car fleets;
- High demand for carsharing services in central areas, and a lack of sufficient number of vehicles may frustrate potential and actual users;
- Need for supportive parking policy and parking space allocation in residential areas or busy areas of the city;
- Partnerships are sometimes required with private parking operators to make paid parking spaces available (e.g. in downtown areas) to carsharing vehicles.

### 4.2.5 Carpooling

| | | |
|---|---|---|
| **Responsibility** | | Employers, Local and Regional Agencies |
| **Applicability** | S, M, L | Appropriate for all sizes of municipalities |
| **Cost** | $ | Costs generally for promotional and awareness campaigns, organization of ride sharing coordination, creation of meeting spaces |
| **GHG Reduction Potential** | 2 - 3 | Carpoolers depend on passenger/driver matches, flexibility of riders, which have limited widespread effectiveness |
| **Tech Feasibility** | 5 | Difficulties are organizational (for carpool participants) rather than technical in nature. May also need to revise parking policies (e.g. municipal and/or private on-street, off-street parking restrictions) to allow carpooling vehicles. |
| **Social Acceptability** | 3 - 4 | While largely voluntary, some people may be wary/skeptical of trying it. |
| **Timing** | Immediate, ongoing | Can be applied immediately. |
| **GHG reductions Timeframe** | Short | Each carpool ride contributes to immediate GHG emissions reduction through an avoided trip. |

## Description

Carpooling is the sharing of a journey in a vehicle by two or more people with complementary origins and destinations. This helps reduce the number of vehicles on roads and increases vehicle occupancy rates. The greatest GHG reduction potential comes from carpoolers who would previously have driven alone, as it is less optimal when users come from other modes transportation such as transit or walking. Carpooling is a mode adapted to different types of destinations (work, studies, etc.) as well as short or long distance.

The MADITUC group at École Polytechnique defines two types of carpooling: "sustainable" and "questionable". Sustainable carpooling can limit the use of cars by combining the travel of different people with similar origins and destinations. For example, two employees of the same company with similar working hours who live in close proximity to each other may decide to use only one vehicle each day. These users optimize vehicle use sustainably.

On the other hand, questionable carpooling is based on an occupancy of two people in a car (hence the term "carpooling"), but does not limit or optimize travel by usage of one automobile as it generates additional VKT. Questionable carpooling increases vehicle use. For example, giving someone a ride from point A to point B, like a child to daycare or school, can be considered questionable carpooling. Similarly, taxi services are not a form of carpooling that reduces GHG emissions, as it generates additional VKT that would not otherwise take place without customer demand.

To facilitate carpooling, some sort of coordination between drivers and riders is required. To this end, there have been numerous public and private programs and initiatives setup for the purpose, including local and regional coordination agencies, employer based programs, and on-line social networking and ride matching services (Transport Canada, 2010b).

An example of a program to encourage carpooling is the Smart Commute program implemented by Metrolinx in the Greater Toronto and Hamilton Area. The program offers various tools to help employers encourage more sustainable forms of transportation for commuting, including carpooling. For example, the program offers surveys that help employers assess the transportation needs of their employees, tailored transportation action plans, methods to support telecommuting options, and tools to accommodate last minute changes for employees should an emergency or cancellation occur (e.g. paid taxi fare once a month) (Metrolinx, 2015). The Smart Commute program also organizes activities to promote awareness of sustainable transportation such as Carpool Week, Bike to Work Day, Bike Month, the Active Switch Challenge, the Smart Commute Week and Walktober.

## Measures to Encourage

### Regional and municipal authorities

- Include carpooling as an option within Transportation Plans for the region;
- Encourage employers to offer carpooling services to their employees;
- Make available a suitable transportation management service (e.g. coordination and reservation system) for pairing carpool drives and riders;
- Run awareness campaigns on costs associated with automobile possession, low vehicle occupancy statistics and associated emission levels;
- Revise parking policy and dedicate reserved parking spaces for carpooling (on and off street parking, park and ride facilities, shops, schools, employers, etc.);
- Provide reserved parking spaces for carpooling near municipal and governmental services;

- Designate meeting points for carpoolers, such as at intermodal transfer points, subway stations, train stations, etc.;
- Allow carpoolers to use high-occupancy vehicle (HOV), reserved bus and taxi lanes;
- Discourage the purchase of a household vehicle through strict regulations on the number of parking spaces per household unit or limit the number of parking permits per residence, etc.

## Pros and Cons

The benefits of carpooling include:

- Reductions in car use, including driving alone, fuel consumption and GHG emissions;
- Reduction in traffic congestion and parking demand;
- Cost savings for users in terms of vehicle operating, ownership, parking costs;
- Use of HOV lanes can result in time savings for carpoolers;
- Shared company while driving together in a vehicle;

The disadvantages of carpooling include:

- May decrease transit and active transportation use;
- Difficult to enforce correct use of preferential parking and/or HOV, reserved bus and taxi lanes.

## Impacts

The *Carpooling Network* estimates that a motorist can save up to $2,500 per year and reduce GHG emissions by about 1.5 tons if they carpool to work on a daily basis. However, actual GHG emission reductions will depend on factors such as type of vehicle, distance traveled, number of carpoolers, gas prices, etc. (Covoiturage.ca, 2015).

The Regional County Municipality of Maskinongé (RCM de Maskinongé) in the province of Quebec has estimated that about 2,000 workers leave the region each day to reach their workplace. The RCM Maskinongé carpool program in the area allows for reserved parking at La Porte Mauricie, a restaurant and hotel located near Highway 40 outside of the city of Trois-Rivières. Assuming all reserved spaces are being used (12 spaces), this project alone allows approximately 112,000 km of savings in terms of distance travelled by users, equivalent to about 10 tons of $CO_2$. Project costs of $ 5,000 were reimbursed under the Climate Action Funding Program (Association québécoise pour la maîtrise de l'énergie, 2014; Fonds d'Action québécois pour le développement durable, 2013).

## Constraints and Barriers to Implementation

- Lack of flexibility, or control over the trip if the driver is late or has to cancel. Having a central coordination centre can facilitate communication and alternatives in such an event;
- Travel requirements and schedules of different carpool users may make it difficult to find suitable match-ups (e.g. origins-destinations, a-typical work schedules, etc.);
- Concerns about coexistence of users and personal safety if driver and passengers are unknown to one another;
- Difficulty in accommodating trip-chaining (e.g. running an errand on the way home from work).

#### 4.2.6 Telecommuting

| | | |
|---|---|---|
| **Responsibility** | | Employers (public and private) |
| **Applicability** | S, M, L | Applicable to all sizes of municipalities |
| **Cost** | $ | Costs are nominal for the employer, related to provision of communications technology (e.g. computers with webcams, telephone, videoconferencing and file access technologies) |
| **GHG Reduction Potential** | 2 | Depends on uptake of program by employees |
| **Tech Feasibility** | 4 | Feasibility depends on type of work |
| **Social Acceptability** | 5 | Provides greater flexibility for employees |
| **Timing** | Immediate | Can be implemented immediately |
| **GHG reductions Timeframe** | Immediate | GHG emissions reduction is immediate if a trip to work by vehicle is avoided |

**Description**

Telecommuting is a working environment where employees are allowed to complete their work from their home. Telecommuting is made increasingly possible through newer and more powerful forms of information exchange and telecommunications technologies such as videoconferencing, secure file sharing and virtual collaboration tools. Telecommuting can be practiced anywhere from a partial day to several days a week, and offers employees greater flexibility in their schedules. Evidently, telecommuting can decrease the need to travel during the work week.

**Measures to Encourage**

Regional and local agencies

- Promotional campaigns to encourage telecommuting by private enterprises;
- Offering the opportunity to their own employees to telecommute.

**Pros and Cons**

The benefits of telecommuting include:

- Reduction in travel and a corresponding reduction in GHG emissions;
- Little or no additional costs for the employer;

- Provides greater schedule flexibility for employees.

The disadvantages of telecommuting include:

- Lack of oversight of employees working from home;
- Regular telecommuters may relocate in suburbs or rural areas further away from urban city centre if they no longer need to commute on a daily basis. However, overall VKT may increase even if commuting VKT decreases, as suburban or rural environment provides fewer options for non-work travel other than by vehicle.

**Impacts**

Telecommuting can lead to a reduction of VKTs by users travelling by automobile equivalent to twice the distance between their home and place of employment. Due to the variability in each employee's commute and in the application of such practices by employers, it is difficult to estimate the total actual savings associated with this type of measure. This measure has little GHG benefits for employees who usually travel by public transport or active modes.

**Constraints and Barriers to Implementation**

- Employers are not always willing to allow employees to telecommute;
- Telecommuting may not be possible with certain types of employment requiring an on-site presence.

## 4.3 Pricing Mechanisms

Pricing measures that can help reduce GHG emissions include toll roads, cordon/area pricing, distance-based pricing, distance-based insurance costs, fuel sales and carbon taxes and increased parking costs. They encourage the use of other forms of transportation such as transit, carpools, or active transportation by making these modes more attractive with respect to driving in terms of time and cost. They may also contribute to GHG reductions by encouraging travel during less expensive and less congested periods, which permit smoother vehicle flow. Finally, distanced based pricing measures may also encourage shorter trips.

### 4.3.1 Toll Roads and Cordon/Area Pricing

| | | |
|---|---|---|
| **Responsibility** | | Can be implemented by transportation infrastructure and planning agencies at all levels of government. |
| **Applicability** | M, L | Likely only applicable in medium and large municipalities where travel demand and congestion is high, and where sufficient alternative transportation options exist. Note that toll roads are difficult to implement where there are other un-tolled routes in the area (e.g. difficult to toll municipal routes if a provincial highway nearby is un-tolled). |
| **Cost** | $$$ | Requires installation of toll collection equipment. |
| **GHG Reduction Potential** | 3 | Effective in area or segment that is tolled, but some travel may shift to un-tolled routes. Will also depends on whether alternatives (e.g. transit) are attractive. |
| **Tech Feasibility** | 3 - 4 | Requires installation of toll collection equipment on existing routes |
| **Social Acceptability** | 1-2 | Tolls have generally been very unpopular in Canada, although road users who experience improved travel times (reduced congestion) may be more open to such fees. |
| **Timing** | Short | Setup of collection system. |
| **GHG reductions Timeframe** | Short | Changes to travel patterns and reductions in GHG emissions can be experienced in a short period of time. |

**Description**

Tolls roads and cordon/area pricing mechanisms are used to make drivers pay for travelling on certain road and highway segments, or within certain zones. Drivers can be charged in one of several ways:

- Bridge and highway tolls: payment is requested at the entrance of a bridge, highway or road segment. A variant of bridge and highway tolls is distance-based tolls, where the price is based on the distance traveled on a specific highway or road section.
- Area tolls: payment is requested at the entrance to a sector (cordon tolling) or to travel within a specific area (area charge).

Bridge and highway tolls are widely used around the world, and are often used for infrastructure financing (i.e. construction, operation and maintenance cost recovery). They may also serve as sources of revenue in cases where private companies were engaged to build and/or operate the tolled road or bridge. They are less frequently used to mitigate congestion or reduce vehicle-based travel demand, although this may be a side effect of the measure. In Canada, there were 18 tolled bridges and highways as of 2011, with Highway 407 in Ontario being the only Canadian example of a tolled route that is based on distance charges. In all cases, Canadian tolling systems were implemented as a mechanism for infrastructure financing and cost recovery (Lindsey, May 2007).

In the UK, highway tolls have been used as a method of congestion management, in addition to infrastructure cost recovery. In the U.S., HOV lanes have been tolled (i.e. HOT: high occupancy toll lanes) as a form of road supply capacity management. This allows drivers to pay for the use of the HOV lane which would otherwise be restricted to buses and taxis. When bus and taxi traffic is lighter, authorities allow drivers to pay for the use of the extra HOV lane capacity. This maximizes total road capacity, and also reduces some congestion on adjacent travel lanes.

Area toll pricing mechanisms are usually used in urban centres as a measure to limit congestion. Cordon tolling can target only one area, but can also be implemented as concentric zones around a sector, such as around the downtown and its periphery, in order to modulate pricing and travel demand (FHWA, 2008). Currently, there are no examples of cordon tolling or area charges in Canada. In contrast, countries like Sweden, Singapore and Great Britain have used area toll pricing mechanisms to relieve congestion, reduce GHG emissions and fund transportation projects to the benefit of all travellers (Mayer, 2011). In the U.S., the FHWA is currently studying proposals for area pricing projects as part of its Value Pricing Pilot Program Funding (FHWA, 2014).

Toll road and cordon/area pricing can be fixed or adjusted according to the time of day or day of the week. It can also vary depending on the type of vehicle. For example, different fees may be requested depending on the number of axles or vehicle type (e.g. hybrid, electric or regular vehicles).

Toll collection systems are diverse and differ in terms of the speed of payment, space and technology requirements. More manual forms of payment require toll booths which are either manned, or have drop bins for payment. A significant amount of space is required for toll booths in order to handle heavy road vehicle volumes without causing significant congestion. Automatic electronic tolling systems collect payment as vehicles pass under a toll gate, but do not require vehicles to slow down or stop. On-board electronic transponders facilitate payment, or bills can also be sent through the mail to vehicle owners. Due to their ability to maintain the flow of traffic, automatic electronic tolling systems are often used in urban areas (Siemens AG, 2011).

## Measures to Encourage

### Regional and municipal authorities

- Implement toll systems that do not require stopping for payment can be seen as better options than toll booths for drivers and traffic congestion;
- Offer and strengthen viable transportation alternatives to vehicle travel as a means of facilitating the social acceptability of implementing a toll or pricing system:
    - Increase public transportation supply and service quality;
    - Increase active transportation routes and quality;
    - Encourage carpooling.
- Demonstrate commitments and benefits in terms of reducing GHG emissions and other positive social or environmental impacts, while mitigating negative equity impacts.

## Pros and Cons

The benefits of toll roads and cordon area pricing include:

- Financial incentive to reduce vehicle use, as well as single-occupant vehicle (SOV) use, and shift travel modes to public transit, carpooling and active transportation where suitable alternatives exist;
- Reduces congestion on routes or in areas where tolls apply. GHG reductions may also result from modal shift.
- Revenues from tolls provide financing for new infrastructure as well as cover maintenance costs of existing infrastructure. Revenues can also be applied to new transportation programs;
- Effectiveness of congestion and GHG reduction can be adjusted with toll rates.

The disadvantages of toll roads and cordon/area pricing include:

- Increase in traffic on non-tolled corridors which may shift congestion to other routes or other times of the day. However area/cordon tolling helps prevent this from occurring;
- GHG emissions reductions may be lessened if drivers simply shift to other non-tolled travel routes;
- Increased costs to road users;
- Toll measures can be seen as regressive or inequitable if there are no exemptions or rebates for low-income users;
- Reduction in the number of "non-essential" trips made by users through tolls, such as family visits, shopping in certain areas, etc. Businesses along toll roads could see less traffic after the implementation of tolls.

## Impacts

Impacts related to pricing vary and depend on many factors including choice of technology, toll fee, region, traffic patterns and alternative networks (e.g. public transportation). In the United States, it was estimated that tolls can reduce VKT from 2 to 10% and reduce GHG emissions by 2 to 6% (Federal Highway Administration, 2012)

The following paragraphs present three different examples of toll systems in London, Stockholm and Singapore.

In 2003, Transport for London, England, set up a toll area (area pricing) in downtown London that resulted in a significant decrease in vehicle traffic. A rate of £5 (about $11 CAD) was charged to all vehicles traveling in the area on weekdays between 7 AM and 6:30 PM. The toll system included 650 cameras with license plate identification technology installed at borders as well as within the area. Immediately after implementation, the number of private vehicles entering the zone fell by 30%, while the number of buses increased by 23%. The net vehicle reduction in the zone was 14% (Transport for London, 2006). In the first year, $CO_2$ emissions declined by approximately 19%. In 2005, a toll rate increase to £8 (about $18 CAD) contributed to a further 5% reduction in emissions. Travel of people to the area did not decline significantly but the method of transportation did change drastically. While 60,000 fewer vehicles entered the toll area, only 4,000 fewer people entered the area, suggesting that mobility remained high. Taxi, public transportation and bicycles saw an increase in usage during that period. The cost of the license plate toll system was approximately $439 million CAD ($378 million USD) and operating costs were approximately $283 million CAD ($244 million USD) per year, or 48% of gross revenue (Federal Highway Administration, 2012).

In another example, in 2006, a cordon tolling system was introduced in Stockholm as a seven month pilot project. Toll rates changed with time of day travel and ranged from 10 to 20 SEK (equivalent to approximately $1.50 to $3.00 CAD). Alternative fuel vehicles were exempt from toll charges. The toll system used license plate identification technology. Implementation costs were approximately $256 million, while operating costs were $33 million per year (25% of gross revenue). Vehicular traffic in the area decreased by 22-28% (compared to traffic data drawn from the same period of the previous year). $CO_2$ emissions in Stockholm declined by about 2.7% per year afterwards (equivalent to approximately 41,000 Mt). The system was reinstated at the beginning of 2007 and similar impacts (reduction of about 2.7% in $CO_2$ emissions) were observed.

In both London and Stockholm, travel on peripheral roads did not increase significantly following the installation of the toll systems due to an increase of the public transportation supply. (Federal Highway Administration, 2012). Furthermore, in the Stockholm case, 2% of trips were made by alternative-fuel vehicles. In December 2008 the share of alternative fuel vehicles had increased to 14%. It is important to note that exemption from toll charges is not the only factor explaining the rise in sales of alternative-fuel vehicles. Owners of alternative-fuel vehicles have also been exempt from residential parking fees in the city since 1997 (Börjesson, Eliasson, Hugosson, & Brundell-Freij, 2012).

A network of toll roads has been in place in Singapore since 1975. Fees charged range from 0 to $2.5 SGD, depending on the route and time of use. In the morning peak periods, a reduction of 45% of traffic flows was observed on toll lanes (Federal Highway Administration, 2012).

## Constraints and Barriers to Implementation

- The effectiveness of toll road pricing on GHG emissions is highly dependent on the availability of viable alternative modes of transportation;
- Coordination and agreement on tolling systems between different jurisdictions may be required. It would not be effective to implement road user-fees at a regional or municipal level if there are non-tolled federal, provincial or regional roadways which offer alternative transportation routes nearby;
- Social acceptance related to the addition of a toll fee for the use of a corridor or road can be difficult to obtain, especially as it can affect people with lower incomes. However, these social acceptability issues can be overcome if drivers see a reduction in congestion and commute times; if authorities show transparently how revenues are being spent or reinvested into transportation projects (Mayer, 2011); and if exemptions, rebates or refunds for low-income users are provided to help address equity concerns;
- It is perceived that long term toll or area pricing systems may make tolled areas less attractive and shift economic activity to peripheral regions. Land use planning and economic development strategies to manage the perception and potential displacement effects could be applied.

### 4.3.2 Distance-Based Pricing

| | | |
|---|---|---|
| **Responsibility** | | Regional or provincial agencies |
| **Applicability** | S, M, L | Applicable to all sizes of municipalities, although it may disproportionately affect users in rural and remote communities |
| **Cost** | $$$ | Requires implementation of equipment or mechanisms to track VKT in individual vehicles |
| **GHG Reduction Potential** | 5 | Impact directly proportional to VKT, provides strong incentive to changing travel behaviour |
| **Tech Feasibility** | 3 | Requires implementation of equipment or mechanisms to track VKT in individual vehicles |
| **Social Acceptability** | 1 | Direct financial impact on users, concerns about privacy and economic equity |
| **Timing** | Short to Medium | May require changes in provincial regulatory frameworks and setup of administrative system, more sophisticated devices and systems charging based on time of day or route travelled are not yet available for wide-scale deployment. |
| **GHG reductions Timeframe** | Short | Assuming immediate implementation, changes to travel patterns and reductions in GHG emissions can be experienced in a short period of time. Pricing mechanisms can play a significant role in the longer term in influencing changes travel patterns and behaviours. |

**Description**

Pricing based on distance traveled consists of charging a rate to drivers directly proportional to the use of private vehicles. Unlike toll and cordon/area pricing, distance-based pricing is based on vehicle mileage. Pricing could be set at a fixed rate irrespective of where the vehicle is driven, or adjusted according to time of day or which routes or areas are travelled. Pricing can also be varied depending on the type of vehicle; smaller vehicles, hybrid vehicles or vehicles emitting less GHG can be charged a preferential rate. Second and third vehicles of the same household may also be subject to higher rates.

Monitoring of distances travelled (via odometer on vehicles) can be performed yearly or a more frequent basis. It can also be included in a vehicle maintenance program or be combined with its registration process. Geographical positioning devices (GPS) can also be installed in vehicles to calculate distances automatically. More sophisticated pricing systems based on time of day or area of travel would require the use of in-vehicle devices and tracking systems. The technology for more sophisticated systems is still under development and has not yet been deployed on a wide-scale.

There are very few examples of distance-based pricing projects around the world. However, in 2005, the State of Oregon studied a mileage fee as an alternative to motor vehicle fuel taxes. The objective of the pilot program was not to alleviate congestion or reduce GHG emissions, but rather to prepare for a future when vehicle fleet fuel efficiency gains would make gas tax revenues insufficient to fund the road system. (FHWA, 2015). In the Metro Vancouver region, the Mayors' Council on Regional Transportation identified distance- and time-based mobility pricing as a mechanism to consider for introduction in the early 2020s to improve the efficiency and fairness of the transportation system, while also raising revenue from users across the road and transit networks. In 2014, the Mayors' Council passed a motion to establish an independent commission on mobility pricing to oversee all the required policy, technical, communications, and engagement work in order to implement mobility pricing on the road network by that timeframe.

Note that distance-based insurance costs, which are similar to distance-based pricing, are covered in the next section.

### Measure to Encourage

Encourage wide scale implementation to avoid disproportionately affecting one region over another.

### Pros and Cons

The benefits of distance-based fees include:

- Reduction in the use of private vehicles;
- Reduction of GHG emissions;
- Direct impact on drivers, leading to short-term behavioural changes;
- Can serve as an incentive to buy fuel-efficient vehicles if they are granted preferential rates;
- For authorities, potential sources of income to reinvest in transportation;
- Region-wide application can avoid disadvantages of toll or cordon/area pricing based systems in potentially displacing travel patterns and economic activity.

The disadvantages of distance-based fees include:

- Increase in travel costs for drivers;
- Negative economic impacts on low-income households without a rebate or subsidy system, as well as on individuals living in remote and rural areas;
- Negative financial impacts on businesses that require large amounts of driving without viable alternatives;
- A reduction in "non-essential" travel, such as visits to close friends and family, shopping, etc.

### Impacts

The impacts associated with the implementation of pricing based on distance travelled will depend on rates charged. A study in Leeds (UK) was used to estimate a 20% increase in $CO_2$ emissions between 2005 and 2015 if no road pricing mechanisms were put in place. The study also evaluated several different pricing scenarios. Among the scenarios studied, $CO_2$ emission reductions vary with the rate charged to users. Study authors estimated that no reductions in GHG emissions would result for an area priced at only £3 (approximately $7 CAD) while a 60% reduction could occur for a fee of £0.20 per kilometer ($0.45 CAD per km) (Mitchell, Namdeo, & Milne, 2005).

In the U.S., it was estimated that a cost of $0.05 per mile (about $0.03 CAD per kilometer) would result in average yearly cost of $566, considering that a vehicle travelled an average of 11,329 miles (approximately 18,120 km) in 1995 (FHWA, 1995). The average distance traveled by vehicles in Canada in 2008 varied by province or territory between 13,100 and 18,100 km (Office of Energy Efficiency of Canada, 2008). If a similar fee applied to Canadian drivers, the approximate cost for a distance usage fee would vary between approximately $390 and $540 per year (1995 CAD value).

Finally, pricing regarding lane usage for high-occupancy vehicles driving on expressways can also reduce GHG emissions. A study conducted in the Bay region of San Francisco on the use (with associated fees) of reserved lanes for high-occupancy vehicles estimated a 7% reduction in $CO_2$ emissions during the morning rush period. The study concentrated on a 800 mile stretch (on a total of 1,200 miles) of transformed highway lanes into reserved toll lanes, where a rate of $0.20 to $0.60 per mile would be requested per vehicle in 2015 (approximately $0.12 to $0.40 per kilometer) and $0.50 to $1.00 per mile in 2030 (approximately $0.30 to $0.65 per kilometer) (Metropolitan Transportation Commission, 2008).

**Constraints and Barriers to Implementation**

- The effectiveness of distance-based pricing on a regional or national scale depends on local strategies, particularly with respect to additional public transportation offered in the area;
- Social acceptability of charging drivers a distance based fee is a challenge;
- Implementation of a vehicle distance tracking system on a large scale is required, possibly through technological solutions or vehicle registration procedures;
- A perceived breach of privacy can be felt by users, especially in the case of mileage tracking by GPS;
- System implementation requires setting up an administrative structure.

### 4.3.3 Distance-Based Insurance Costs

| | | |
|---|---|---|
| **Responsibility** | | Insurance Companies, Provincial agencies in cases where basic vehicle insurance is provincially administered. |
| **Applicability** | S, M, L | Applicable to all sizes of municipalities, although it may disproportionately affect users in rural and remote communities. |
| **Cost** | $$ | Requires mechanism to track VKT, although use of personal smartphones to track distance is becoming increasingly common. |
| **GHG Reduction Potential** | 3 – 5 | Impact directly proportional to VKT, but non-mandatory implementation may see only some drivers adhere to the program. |
| **Tech Feasibility** | 4 – 5 | Implementation on a programmatic level |
| **Social Acceptability** | 3-4 | Some drivers who benefit from reduced rates will find the program more acceptable, mandatory implementation will be less socially acceptable |
| **Timing** | Short to Medium | May require changes in provincial regulatory frameworks and setup of administrative system, more sophisticated devices and systems charging based on time of day or route travelled may require continued technology development |
| **GHG reductions Timeframe** | Short | Changes to travel patterns and reductions in GHG emissions can be experienced in a short period of time. Pricing mechanisms can play a significant role in the longer term in influencing changes travel patterns and behaviours. |

**Description**

Insurance costs tied proportionally to distance travelled is another way of pricing aspects of vehicle usage. Distance-based vehicle insurance costs can involve charging insurance premiums based on the annual VKT. It can be implemented on a voluntary or mandatory basis. These systems are already used in other jurisdictions such as Australia and the U.S.

Monitoring of distances travelled and usage of vehicles can be performed yearly or on a more frequent basis. Recording of such data can also be included in a vehicle maintenance program or be combined with its registration. Odometer readings can be carried out by the specialist responsible for the maintenance of the vehicle. Geographical positioning devices (GPS) can also be installed in vehicles to calculate distances instantaneously. More recently, insurance companies are beginning to offer their customers the possibility of tracking their driving habits through the use of their smartphone.

Distance-based insurance costs could also be administered through charging a premium on fuel prices and paid directly at the pump (pay-as-you-drive insurance). Discounts can also be made available for less frequent users or can also be based on the average usage of over a certain time period.

Further refinements of the program can include charging premiums based on (good or bad) driving habits. Devices can be installed in vehicles, or applications can be loaded onto smartphones to measure acceleration and deceleration rates. This driving data can then be communicated to the insurance company, who can then reward drivers who limit their carbon footprint by having good driving habits (eco-driving). Details of the eco-driving programs can be found in **Section 5.8**.

However, it should be noted that vehicle insurance premiums to date have not been based on distance travelled. Rather, they take into account factors that influence the risk of accidents, which generally depend on the address of the vehicle owner, the profile of the driver, the history of the driver, the type of vehicle covered, usage of vehicle (e.g. work, pleasure, etc.) and on board equipment (e.g. anti-theft system). Adding a distance travelled factor to determining insurance premiums adds an additional decision criterion to the list of factors, but its correlation with accident risk may not actually be beneficial for insurance companies (e.g. people who drive less may actually be at higher risk of accidents due to less driver experience).

## Measures to Encourage:

**Provincial authorities**

- Review insurance regulatory systems in place to allow for proportional insurance cost systems;
- Form partnerships with insurance companies to support them in implementing the system;
- Facilitate data collection procedures for annual VKT, such as through vehicle registration system;
- Provide incentives to reduce the costs related to data collection technologies on board vehicles;
- Provide incentives and promotional campaigns focused on discounts rather than cost increases;
- Demonstrate commitment to reduce GHG emissions, including short, medium or long term emissions.
- Encourage or adopt region or province wide programs, as they are more effective than local operations to avoid drivers going to other jurisdictions without such a system (FHWA, February 2012).

## Pros and Cons

The benefits of proportional insurance costs include:

- Reduction of vehicle usage and GHG emissions;
- Increased equity between users as variation of premiums depend on usage;
- Allowing users to reduce their insurance costs by making costs directly related to their travel choice;
- Savings achieved by the majority of users: an estimate reveals that two thirds of drivers would save on their insurance costs with this type of insurance (Federal Highway Administration, 2012)
- Possible reduction in accidents due to encouraging safer driving habits, which may compensate for decline in revenues for insurance companies due to reduction of insurance premiums.

The disadvantages of proportional insurance costs include:

- Adding complexity to calculating the insurance premium due to an extra decisional factor;
- Difficulties related to the pre-determination of premiums to be paid;

## Impacts

Studies show that proportional insurance costs reduced mileage from 5 to 10% per vehicle (FHWA, February 2012). A pilot project in Minnesota has tested the responsiveness of 130 volunteer drivers to a proportional insurance cost program. The distance traveled by volunteers decreased by 4.4%. Largest reductions were observed during rush hours (6.6%) and weekends (8.1%) (Cambridge Systematics, GeoStats, & MarketLine Research, 2006). A second study of 3,000 households in Texas evaluated 5% reduction in mileage following the implementation of the same type of insurance. The study determined a 3.2% reduction in travel during peak hours (Progressive County Mutual Assurance Company & North Central Texas Council of Governments, 2007).

Another study predicted that the impact of a proportional insurance cost program applied nationally in the U.S. would result in an 8% reduction in annual mileage, a 4% reduction in fuel consumption and a 2% reduction in $CO_2$ emissions[23]. In addition, nearly two-thirds of all households would reduce their insurance costs by an annual average of $270, about 28% of the average costs of insurance premiums in the United States (Bordoff & Noel, 2008).

These values are consistent with those from a study performed by Parry (2005), revealing that the establishment of insurance proportional to vehicle usage in the United States could reduce fuel consumption up to 9.1% annually. This corresponds to a savings of approximately 11.4 billion gallons of fuel (equivalent to approximately 43 billion litres).

While these studies and pilot projects demonstrate that proportional insurance costs can have some effect on encouraging drivers to moderate their vehicle usage, the effectiveness of proportional insurance costs will be highly dependent upon whether adherence to the program is voluntary or mandatory in nature. Voluntary adherence programs would tend to attract drivers with low annual VKT to sign up as they stand to benefit from such a cost rate structure. Others with higher annual VKT may likely look to other more financially advantageous insurance products for their needs.

## Constraints and Barriers to Implementation

- Implementation depends not only on government, but also on private insurance companies;
- Both insurance companies and vehicle owners must buy-in to the program;
- Users may perceive tracking methods as an intrusion on privacy;
- Costs of implementation may outweigh revenues generated through such a scheme (i.e. decreasing due to lower distance travelled), serving as a financial disincentive to insurance companies. For example, a proportional insurance cost program was abolished by Norwich Union in England as costs related to equipment installation were higher than the revenue generated by the program (Federal Highway Administration, 2012).
- Established laws in current insurance plans can make the implementation of such programs difficult or impossible. For example, the introduction of proportional insurance could not be implemented in some American states since regulations require that the amount of the premium be known when the insurance service contract is signed. This would not be the case with a variable cost of insurance.

[23] *These estimations are based on data from 2006.*

#### 4.3.4 Fuel Sales and Carbon Tax

| | | |
|---|---|---|
| **Responsibility** | | Fuel sales taxes can be applied by all levels of government. Carbon taxes can be applied only by provincial or federal governments. |
| **Applicability** | S, M, L | Applicable to all sizes of municipalities, although it may disproportionately affect users in rural and remote communities. |
| **Cost** | $ | Costs tied to program implementation and administration. |
| **GHG Reduction Potential** | 5 | The effectiveness of fuel sales or carbon taxes depends on whether price of carbon is set sufficiently high. From the perspective of urban transportation, both fuel sales and carbon taxes are equally effective. However, from a societal perspective, carbon taxes can have a broader, multi-sectoral impacts (e.g transportation, energy production, heating, industrial processes), while fuel sales taxes are generally limited to the transportation sector. The impact of both types of taxes for transportation are directly proportional to VKT, with the exception of hybrid or electric powered vehicles. |
| **Tech Feasibility** | 5 | Implementation constraints only programmatic and administrative in nature. |
| **Social Acceptability** | 1 – 2 | Direct financial impact on petroleum based industries and end users, economic equity concerns. |
| **Timing** | Short | May require changes in regulatory frameworks and setup of administrative system. |
| **GHG reductions Timeframe** | Short | Changes to travel patterns and reductions in GHG emissions can be experienced in a short period of time. Pricing mechanisms can play a significant role in the longer term in influencing changes to travel behaviour. |

**Description**

Fuel sales and carbon taxes are another pricing mechanism to increase the cost of vehicle travel and encourage users to adopt alternative travel modes or travel shorter distances. A fuel sales tax (also referred to as a fuel excise tax or gas tax) differs from a carbon tax because it is usually only applied to the sale of fossil-fuels to power vehicles (e.g. in cars, trucks, diesel trains), while a carbon tax can be applied to a broad range of sectors (e.g. transportation, heating, energy production, industrial processes) that produce GHG emissions. While these taxes generally apply to fuel producers and distributors, increased costs are likely to be passed down to the end user through the price of fuel or energy. Fuel sales taxes can be applied by local, regional, provincial and federal governments, while carbon taxes are generally only applied by provincial and federal governments due to the need to ensure broader geographic and multi-sector application.

The majority of fuel sales taxes in place in Canada are for the purposes of raising revenue for government as general revenues or for funding road transportation or transit. In Canada as of December 2014, the federal government collects an excise tax of 10¢/L for gasoline and 4¢/L for diesel. Provincial governments across the country impose some kind of fuel consumption tax ranging from 9¢ (AB) to 20¢ (QC, PEI) per litre. Metro Vancouver, Greater Victoria specifically charge an additional fuel tax of 17¢ and 3.5¢ respectively, while Montreal charges an additional 3¢/L for gasoline only (NRCan, 2015). The latter three regional taxes are used to fund public transit projects, as well as major roads and regional bridges in the case of Metro Vancouver.

British Columbia is currently the only province to have a broad-based carbon tax in place[24]. The tax, established in 2008, started at $10 per ton of $CO_2$ emitted, and increased to $30 per ton in 2012 (Ministry of Finance, British Columbia, 2015). This works out to a tax of approximately 7¢/L of gasoline in 2013. An important distinction between fuel excise taxes and the BC carbon tax is the fact that the former is designed to raise revenue while the latter is designed to be revenue neutral. The BC carbon tax revenues are returned through reductions in personal and business taxes.

Another example of a purchase tax is the French feebate program *Bonus-Malus* introduced in 2007, which provides a rebate or charges a fee based on vehicle $CO_2$ emissions. The program encourages the purchase of low-emissions vehicles by offering rebates of up to € 1,000 (approximately $1,400 CAD in 2015) to people purchasing vehicles which emit less than 130 grams of $CO_2$ per kilometre. On the other hand, fees up to € 2600 (approximately $3,700 CAD in 2015) are added to vehicle sale prices for vehicles which emit more than 160 grams of $CO_2$.

## Measures to Encourage

**Provincial or regional agencies**

- Reinvestment of revenues in transportation alternatives or as a return to low-income households;
- Gradual increases of the tax can be used to minimize the perceived impacts on consumers.

## Pros and Cons

The benefits of fuel sales and carbon taxes include:

- Direct impact on users, leading to the short-term reduction of fuel consumption, GHG emissions and vehicle use;
- Carbon taxes may encourage a multi-sector shift to low carbon fuels, since taxes apply to all petroleum-based industries as well as transportation and energy generation sectors;
- Carbon taxes have the advantage over fuel taxes because of its multi-sector application (e.g. transportation, energy production, heating, industrial processes). As an economy wide instrument,

[24] *In 2007, Quebec was the first province to impose a carbon tax. However, the tax only covers fuel producers, and is set at a low rate compared to BC's Carbon tax ($4 / tonne of carbon emissions in QC versus $30 / tonne in BC) (Holmes, 2012). It should be noted that Quebec has taken a slightly different approach to pricing carbon. In 2013, it joined the Western Climate Initiative's (WCI) carbon market employing a Cap-and-Trade system. The program targets the industrial and electricity sectors, as well as fossil fuel distributors starting in 2015. The government of Ontario announced in 2015 that it would join Quebec and California in the WCI. A Cap-and-trade approach represents another viable method to pricing carbon, and a comparison can be found at www.davidsuzuki.org/issues/climate-change/science/climate-solutions/carbon-tax-or-cap-and-trade/.*

carbon taxes can be more cost-effective (i.e. greater GHG emissions reductions per dollar spent) because GHG emissions reductions could be realized where they are cheaper to implement, such as in the power generation sector (Karplus, Kishimoto, & Paltsev, 2015);
- Encourages modal shift, particularly in areas where other modes of transportation are available;
- Provides incentive for manufacturers to design more fuel efficient vehicles, and for consumers to adopt them;
- Use of revenue to finance maintenance of roads, public transportation, etc. However, taxes may also be designed to be revenue neutral;
- Ability to modulate fuel or carbon tax rate to achieving a desired emissions reduction goal.

The disadvantages of fuel and carbon taxes include:

- Increased costs of fuel may have inequitable impacts for low-income individuals unless mitigation measures, such as reductions in other taxes for low-income individuals or investments to improve transportation options such as transit and active transportation are made;
- Effectiveness of change in travel behaviour may be diminished due to the variation in the price of fuel (i.e. prices affected by global market supplies, transportation costs, profit margins).

## Impacts

Significant price increases in fuel costs are required to bring about a reduction in fuel consumption. First, user perception associated with the increase in the price of gasoline varies according to many factors, including age, available alternative transportation methods, urban development, employment rates, and wages, as well as the total price of gasoline. Economists suggest that an increase of 5 to 10% of the price of fuel has little effect on users given the variability of the price of fuel (German, 1997). A more significant increase, such as more than $1 per gallon (about $0.26 per liter) is necessary before national effects can be observed (FHWA, 1995). This suggests that an increase in fuel prices from gas or carbon taxes must offset the perceived fluctuation in gasoline prices from other market factors before a change in habit can be observed. Similarly, a study by Barla et al., based on 1990 to 2004 provincial level data for Canadian light-duty vehicles, found that the short and long term price-elasticity of gasoline demand in Canada is -0.1 and -0.3 respectively, or that a 10 % increase in fuel costs would lead to a 1 % and 3 % decrease in gasoline demand respectively (Barla, Lamonde, Miranda-Moreno, & Boucher, 2009; Barla & Miranda-Moreno, 2014). Gasoline demand is inelastic, and large price increases would be needed in order to reduce demand and GHG emissions significantly (Barla, Lamonde, Miranda-Moreno, & Boucher, 2009).

The gradual implementation of a carbon tax in British Columbia between 2008 and 2012 resulted in an estimated reduction of between 2% and 7% per year per capita in fuel consumption, or a decrease of 17% over the four years, while fuel consumption per capita increased by 1.5 % over the same period in the rest of Canada. GHG emissions per capita fell by 10% between 2008 and 2011 in British Columbia, compared to a decrease of only 1.1% per capita in the rest of Canada. The BC Carbon tax was cited as a contributing factor to the greater relative reductions seen in British Columbia (Elgie & McClay, 2013), and has been hailed as successful in reducing GHG emissions while not compromising economic growth and prosperity (Elgie & Lipsey, 2015).

Gas or carbon taxes tend to reduce the sales of fuel-inefficient vehicles and encourage the purchase of "greener" vehicles. The years following the introduction of the French feebate program *Bonus-Malus* saw a 5% reduction in less fuel efficient vehicle sales, resulting in a decrease of GHG emissions equivalent to about 7 grams of $CO_2$ per kilometer travelled (Greene, Baker, & Plotkin, 2011). In the

United States, a study conducted by the University of California in Davis for the California Air Resources Board estimated that new cars sold would emit less GHG (equivalent to 10 grams of $CO_2$ per mile or about 6 grams per kilometer) should a tax program of $20 per gram of $CO_2$ per mile (approximately $12.50 per gram of $CO_2$ per kilometer) be put in place (Greene, Baker, & Plotkin, 2011).

**Constraints and Barriers to Implementation**

- Effects of a fuel sales tax will be limited if it is imposed on a small territory (may encourage users to purchase fuel outside of affected areas). This is less of an issue with an economy wide carbon tax. Effects may also be limited near borders as drivers may want to purchase fuel in non-affected areas;
- Social acceptance of increases in gas prices may be a challenge.

### 4.3.5 Increase Parking Costs

| | | |
|---|---|---|
| **Responsibility** | | Public (local municipality) and private parking lot operators |
| **Applicability** | M, L | Applicable most in medium and larger municipalities where congestion and demand for parking is high and parking supply and free parking is limited. |
| **Cost** | $ - $$ | Costs are only programmatic or operational in nature. |
| **GHG Reduction Potential** | 2 - 3 | Provides strong incentive to changing travel behaviour. Preferential parking favouring carpoolers will have limited impact, change in zoning requirements apply only to new developments and not to existing zones. |
| **Tech Feasibility** | 5 | Generally a policy or programmatic change, pay stations may be required in current free parking lots. |
| **Social Acceptability** | 2 | Direct financial impact on drivers, zones where parking cost increases may be opposed. |
| **Timing** | Immediate, ongoing | Can be implemented immediately. |
| **GHG reductions Timeframe** | Immediate | Where pricing mechanisms encourage travellers to switch to a different mode for travel, the GHG emissions reductions are immediate. Pricing mechanisms can play a role in the longer term changes travel patterns and behaviours. |

## Description

The variation of parking costs is an incentive to reduce car use, especially single-occupancy vehicle (SOV) trips. Two mechanisms can be used in this case, including:

- Increase in parking costs (where they are free or low);
- Institute preferential parking fees for specific users.

Increasing parking costs can be used to reduce car use in certain congested areas. Municipalities can charge for parking where it was previously free, or increase the rates it already charges for public parking. For private parking operators, increases in parking costs can be achieved by increasing taxes (property or other) imposed on private parking operators. While this adjustment is indirect, cost increases will likely translate into increased parking fees for users. The increase in parking fees can also be implemented by the establishment of pricing zones across a district or a city. Pricing could then be adjusted according to the distance from a central point (e.g. downtown). Preferential parking fee structures can also be applied to encourage carpooling or carsharing, such as by providing free spaces for these modes.

Generally, parking fees may also depend on the time of day. Imposing higher parking costs during the morning peak period when parking demand for commuters is highest can encourage a modal shift or an increase in vehicle occupancy rates during these travel times.

For residential parking spaces, the costs for a space can be separated from the price of rent or sale of the residential property. Tenants and owners would then have the choice to rent or purchase the parking space. Such a policy would encourage households with fewer or no vehicles.

## Measures to Encourage

**Regional and municipal authorities**

- Develop parking policies at the city or region-level to ensure consistency between transportation objectives and parking controls;
- As parking is generally managed at the municipal level, collaboration and agreements between municipalities are required for a regional application of increased parking costs;
- Adopting land use policies which supports public transit and active transportation alternatives;
- Programs to encourage telecommuting (no parking fees) or carpooling (division of parking fees);
- Reduce free parking supply;
- Reinvestment of revenues in transportation alternatives (e.g. transit);
- Adjustments in the regulation and implementation of special permits, in particular to offer free parking for residents in residential areas;
- Improvement in the supply of alternative transportation (public transportation networks, active transportation networks, carsharing networks, ridesharing platforms, etc.).

## Pros and Cons

The benefits of parking cost measures include:

- Strong financial disincentive to use private vehicles for travel to areas with higher parking costs;
- Encourages modal shift and carpooling to areas where other modes of transportation are available;
- Reductions in GHG emissions;

- Generates revenue to finance new infrastructure, maintain existing infrastructure or support transportation programs;
- Control of travel demand easily exercised through differential pricing based on time of day;

The disadvantages of parking cost measures include:

- Potential increases in the time to find a free parking place (GHG increase);
- Decreases in the number of trips to a specific area (economic impact), and the potential impact on businesses located within the pricing zone;
- Increase in costs for drivers;
- Social impacts related to the addition of a parking fee for the use of cars can be difficult to accept;
- Potential negative impacts on economic equity (low income earners).

## Impacts

An increase in parking fees is aimed at reducing SOV trips and the overall number of trips made by car. Studies in the United States have shown that the sensitivity (elasticity) of average parking demand is -0.3 in relation to increased parking rates; a 10% increase in the cost of parking would reduce demand by 3% (Vaca & Kuzmyak, 2005).

The impact of parking pricing varies depending on individual habits and place of residence. In general, individuals from urban areas are accustomed to pay for parking compared to individuals from suburbs. For example, it was estimated that an increase of between $1.00 and $3.00 per day in parking lots of suburban areas would impact the same number of users in terms of their travel habits as an increase between $3.00 and $8.00 per day in parking lots of urban centres (Kuppam, Pendyala, & Gollakoti, 1998).

A Federal Highway Administration study on employee travel habits found that parking rates influence commuter travel behaviour. The study looked at targeted programs that increased parking fees for employees and found a decrease of 26 to 81% for SOV trips. Study results also showed that employees traveling alone made modal shifts to transit or carpooling. The decrease in the number of cars parked was greater if other modes of transportation were available. The study concludes that increased parking rates will have a direct influence on the daily commute of the employees (FHWA, 1995).

Another study by the Washington State Department of Transportation estimated the sensitivity of users and their travel patterns to a range of factors, including the density of signalized intersections, mixed developments, development of public transit networks and sidewalks, number of jobs, travel time, cost of parking and cost of public transit. Study analysts set up two scenarios comprising combinations of these factors in an attempt to reduce VKT and $CO_2$ emissions. In both scenarios, analysts found that users were most sensitive to variations in parking fees. The study found an increase in the parking fee from $0.28 to $1.19 per trip per household (moving from 50th to 75th percentile of data) would reduce VKT, through either avoided trips or modal shift, by 11.5% and $CO_2$ emissions by 9.9%. (Frank, Greenwalg, Kavage, & Devlin, 2011).

Parking tariff zones were established in 1999 in Perth, Australia. Rates charged varied according to parking time (short or long term) and the type of space (i.e. residential parking lots and parking lots with less than five spaces were free). The modal share of trips made by car for work purposes decreased from 66 to 58% between 1999 and 2001. Conversely, the modal share of trips made by train for work purposes increased from 5 to 18% over the same period. In addition, the number of jobs in the area increased by 4% between 1999 and 2001, implying a real change of individual travel habits. The annual reduction in $CO_2$ emissions related to this modal shift was estimated at approximately 17,000 Mt, based on an estimated average distance traveled by car of approximately 20 km (Sinclair Knight Merz, 2007).

**Constraints and Barriers to Implementation**

- Social acceptability and resistance to implementing parking fees in areas which are currently free. Resistance can also be encountered when raising parking fees. For example, in Vancouver the imposition of a regional tax on parking faced significant opposition from residents and business owners. In 2006 this tax was fixed at $0.78 per square metre. The economic impact was estimated at $20 million per year, which was then reinvested into transportation infrastructure (Transport Canada, 2006). However, despite this revenue gain, the tax was removed after 2 years (Federal Highway Administration, 2012);
- Increased parking fees are more challenging to implement in private parking lots, as municipalities would have to employ indirect measures such as property taxes for private lot owners;
- Effectiveness of parking fee increases also depends on the supply free parking nearby (e.g. residential, shopping malls, businesses, and offices). Furthermore, in smaller towns and municipalities where free parking is abundant, parking pricing is not likely to be feasible.

### 4.3.6 Fees in Lieu of Travel and Cash in Lieu of Parking

| | | |
|---|---|---|
| **Responsibility** | | Employers (public and private) |
| **Applicability** | M, L | Generally applicable in municipalities where abundant free parking is not available, and where alternative forms of transportation are readily available. |
| **Cost** | $ - $$ | Depends on the amount paid out by employers. |
| **GHG Reduction Potential** | 2 – 3 | Depends on uptake of program by employees. |
| **Tech Feasibility** | 4 | Only requires employers to implement program. |
| **Social Acceptability** | 5 | Provides financial incentives on a voluntary basis. |
| **Timing** | Immediate | Can be implemented immediately. |
| **GHG reductions Timeframe** | Immediate | Where employees chose an alternative mode to travel than by automobile, GHG emissions reductions are immediate. |

**Description**

Fees in lieu of travel represent financial compensation offered by employers to employees for relinquishing a parking space, known as parking cash-out, or for choosing alternative modes of travel such as transit or carpooling. These fees constitute monetary incentives to reduce car usage for daily travel to and from work. The implementation of a fee in lieu of travel program paid for by the employer can take several forms:

- Choice between a free parking space or financial compensation in lieu of this space;
- Financial compensation offered to public transit users or carpoolers.
- Financial compensation for work related travel by more sustainable travel modes such as transit or bicycle, rather than just by car.

The amount of financial compensation offered can also vary as a function of the balance between the use of the car versus other alternative modes, especially where an employee does not use the same mode every day. Financial compensation can be inversely proportional to the use of the car as a further means of discouraging its use (i.e. it increases as car use decreases).

## Measures to Encourage

**Regional and municipal agencies**

- Implement awareness and support programs to encourage employers to deploy such financial compensation measures;
- Regional and municipal public agencies can deploy such programs for their own workforce;
- Develop a parking strategy for the city or region covering both public and private spaces;
- Improve alternative modes of transportation (e.g. transit, active transport networks, car-pooling measures).

## Pros and Cons

The benefits of fees in lieu of travel measures include:

- Can reduce parking demand and reduce employer parking requirements;
- Can be easily implemented by large employers;
- Unused parking spaces vacated by employees can be converted into paid parking for visitors and serve as a revenue stream;
- Measure is more easily accepted, being a financial compensation measure rather than penalty.

## Impacts

According to a study of eight different employers[25] covering a total of the 1,694 employees around Los Angeles (varying from 120 – 300 employees each), a parking cash-out compensation offered to SOV commuters reduced their modal share by 13% (from 76 to 63%). At the same time, the number of car carpoolers rose by 9% (from 14 to 23%), transit share rose by 3% (from 6 to 9%), and walking and bicycling modal share increased by 1% (from 3 to 4%). Study authors found that parking cash-out reduced 12% of total $CO_2$ emissions caused by automobile commuting, the equivalent of removing approximately 1 in 8 vehicles from the road. Authors concluded that it was beneficial from

[25] *The eight employers were comprised of an accounting firm, a bank, a government agency, a medical care provider, a video post-production company and three law firms.*

environmental and economic perspectives for employers to subside how people travel, rather than the parking spaces they use (i.e. rental of parking spaces) (Shoup, 1997).

The Climate Change Action Plan: Technical Supplement put out by the US Department of Energy estimated that if a mandatory parking cash-out program was implemented across the United States, national VMT could be reduced by 1.1 % in the year 2000 compared to study baseline without the measure, which was equivalent to approximately 25 billion VMT (40 billion VKT). A mandatory program would require employers who provided subsidized parking to also offer their employees the option of receiving taxable income instead of parking. Study estimates were based on the assumption that travel price elasticity for home to work commutes ranged between 0.1 to 0.2, based on previous parking pricing studies done in California. Furthermore, the national effect on GHG emissions would depend on the extent to which employers actually offered the parking cash out to employees, and whether suitable alternative modes of transportation were available (FHWA, 1995; US Department of Energy, 1994).

**Constraints and Barriers to Implementation**

- The application by employers of a fee in lieu of travel or cash in lieu of parking program is not guaranteed, and mandatory application could be met by employer resistance, all while creating the need for enforcement (FHWA, 1995);
- The need for employers to have funds to compensate employees;
- Difficulty in implementation by small employers due to costs;
- The appropriate value of a parking space to incite a change in behaviour may be difficult to estimate.

## 4.4 Parking Management

Parking is an essential component to vehicle travel. Drivers must be able to find a parking space in order to use their vehicle. Proactively managing or even constraining parking supply can encourage travellers to choose other modes of transportation to certain destinations. Furthermore, decreased parking supply can support more transportation-efficient land use development (see **Section 4.1)**. Parking management strategies include dynamic parking guidance systems and modifying municipal bylaws to reduce minimum parking requirements for developments.

| Optimize or reduce parking supply, and implement a dynamic parking guidance system | | |
|---|---|---|
| **Responsibility** | | Municipality responsible for parking policies and regulations, agency (local municipality) responsible for public lots and private parking lot operators. |
| **Applicability** | M, L | Applicable to medium and larger municipalities and areas where congestion and demand for parking is high, and parking supply is limited. |
| **Cost** | $,<br>$$$ | Optimizing or reducing parking supply requires only policy, regulatory and parking lot management changes.<br>Implementation of a dynamic parking guidance system necessitates installation of signaling equipment, communication systems and parking space tracking mechanisms across an area's parking lots. |
| **GHG Reduction Potential** | 2<br>1 | Reducing parking availability is a strong mechanism for encouraging a change in travel behaviour. Furthermore, it supports densification of urban environment, which may in the long term contribute to more active transportation and transit use.<br>Dynamic parking guidance systems help drivers find parking spaces more quickly, but do not discourage vehicle use. |
| **Tech Feasibility** | 5,<br>3 | Generally a policy, regulatory or programmatic change; signage and pay stations may be required in current free parking areas.<br>Dynamic parking guidance systems necessitate installation of signaling equipment, communication systems and parking space tracking mechanisms across an area's parking lots. |
| **Social Acceptability** | 4 – 5,<br>1 – 2 | Optimization of existing supply, and dynamic parking guidance systems are usually welcomed by parking lot operators and travellers.<br>However, travellers and businesses may be extremely opposed to reduction in parking supply. |
| **Timing** | Immediate, ongoing | Can be implemented immediately. |
| **GHG reductions Timeframe** | Immediate | Where parking constraints encourage travellers to switch to a different mode for travel, the GHG emissions reductions are immediate. Parking management can play a role in the longer term changes to travel patterns and behaviours. |

| Modify parking bylaws to reduce minimum parking requirements | | |
|---|---|---|
| **Responsibility** | | Municipality responsible for zoning |
| **Applicability** | M, L | Generally applicable to medium and larger municipalities where higher densities and alternative forms of transportation are readily available, and where free parking is limited. |
| **Cost** | $ | Change in zoning by-law, may save developers construction costs |
| **GHG Reduction Potential** | 1 - 2 | Short term effectiveness limited to new developments, but supports denser urban development by reducing parking needs, contributes to active transportation and transit use in the long term. |
| **Tech Feasibility** | 5 | Changes at a policy level only. |
| **Social Acceptability** | 1 – 3 | Dependent upon developers, real estate market conditions and demand for housing and parking. |
| **Timing** | Immediate, ongoing | Can be implemented immediately. |
| **GHG reductions Timeframe** | Medium to long term | Reduced parking requirements supports longer term changes land use, travel patterns and rates of vehicle ownership. |

## Description

Parking management seeks to optimize the use of parking supply in order to encourage a better and more appropriate use of existing parking spaces. It also seeks to reduce parking availability as a means of limiting the number of trips made by car. In this way, parking management is complementary to parking fees, as they seek to make it more difficult or costly to park as disincentives to making trips by car. Parking management actions can be divided into two subcategories of action, based on whether actions can be implemented on an ongoing basis, or whether they are one-time actions.

***Optimize or Reduce Parking Supply, Implement Dynamic Parking Guidance System***

Ongoing parking management activities include optimizing the use of existing parking spaces; installing dynamic guidance parking systems to direct drivers to parking lots with available spaces; and reducing parking availability in key sectors (e.g. those served by transit) and during key peak periods (e.g. morning peak). Another mechanism, cash-in lieu of travel or parking, is discussed separately in Section 4.3.6 above.

- **Optimizing the use of existing parking spaces** is achieved through making spaces available to different types of users so that spaces are utilized to their maximum. This optimization also seeks to reduce the need to build new parking spaces by accommodating demand growth within existing spaces. For example, modifying existing parking rules and restrictions to allow different types of users at different times of day could encourage a more optimal use of existing capacity. Optimizing the use of existing parking spaces would also limit the number of physical parking spaces that need to be created or made available in a sector, constraining to some degree the number of vehicles that can drive to that sector.

- A **dynamic guidance parking system** shows drivers real time information on the location of available parking spaces in an area, especially for indoor parking garages. These systems use variable message panels to indicate whether lots are open or not, as well as the number of remaining parking spaces. Dynamic guidance parking systems are complementary to optimizing the use of existing parking space, as they help guide drivers to lots with available spaces. At the same time, this helps reduce the time that drivers spend looking for parking (i.e. decreased VKT and GHG emissions).
- Finally, the **reduction in the number of parking places** in certain sectors or during certain periods can lead to a reduction in the number of car trips. First, by constraining parking supply in areas generally well served by transit (e.g. downtown), users will be encouraged to choose alternative modes of travel since finding parking becomes a greater hassle. Existing spaces usually available to all drivers could also be converted to spaces reserved for only certain types of users such as car-poolers. Constraining parking supply can also be exercised temporarily, such as during the morning rush hour, to encourage other travel modes during these peak periods.

***Modify Parking Space Requirements***

One-time actions with respect to controlling parking can be exercised when new developments are built. Specifically, municipalities can look to modifying their parking by-laws in order to reduce parking space requirements for new developments. For example, parking by-laws could be designed to reduce the number of parking spaces offered per residential unit or commercial floor space by setting maximums, rather than minimums, on the number of allowable spaces. The reduction of parking space requirements in sectors well served by transit can contribute to decreased car ownership rates, thereby reducing pressures in terms of the number of parking spaces required. In general, it should be noted that this sub-category of measures fall under the zoning responsibilities of local municipalities.

## Measures to Encourage

**Regional and local agencies**

- Modify land use planning policy in favour of parking management and reduction;
- Develop a parking strategy for the city or region covering both public and private spaces;
- Use of parking planning tools such as “Right sized parking” can help municipalities plan for an sufficient amount of parking spaces[26];
- Improve alternative modes of transportation (e.g. transit, active transport networks, car-pooling measures);
- Support or encourage telecommuting or car-pooling programs and practices;
- Reduce the amount of free parking

## Pros and Cons

The benefits of on-going parking management measures include:

- Discourages the use of the car, especially SOVs;

[26] *Reference: http://www.rightsizeparking.org/*

- Ability to modulate demand as a function of the time of day;
- Has a direct impact on users and leads to a change in behaviour in the short term;
- Can be implemented easily through modification of parking by-laws;
- Parking management and control policies support broader policy goals such as encouraging transit, active transportation and more sustainable land use development patterns;
- Encourages modal transfer, especially to areas where other modes of transportation are available;
- Dynamic guidance parking systems reduce the time needed to find a parking space, and therefore vehicle travel emissions. They also help city planners, residents and businesses understand whether parking supply meets demand by showing how many vacant spaces are still available.

The benefits of modifying parking bylaws to reduce parking requirements include:

- Can be implemented easily through modification of zoning by-laws;
- Reduces the cost of construction of new developments if the number of parking spaces required is reduced;
- Parking management and control policies support broader policy goals such as encouraging transit, active transportation and more sustainable land use development patterns;
- Discourages car-ownership, which in turn can lead to reduced VKT.

The disadvantages of parking management measures include:

- Reduced parking requirements in the zoning code affects only new developments, while having little to no impact on pre-existing buildings;
- Effectiveness of municipal parking controls on trip mode choice will be dependent on the availability of free (or cheaper) parking in proximity (e.g. in residential zones or offered by businesses and enterprises);
- Where parking supply is reduced, the amount of time need to find an available space may increase if not accompanied by some sort of driver guidance system, thereby increasing GHG emissions;
- Decreases in parking supply may affect the economic activity in a sector, or the competitiveness of businesses located in that sector.

## Impacts

Parking management is one of the mechanisms available to reduce the number of trips made by car. Moreover, the introduction of parking spaces reserved for high-occupancy vehicles in the United States has led to an average increase in carpooling of nearly 100% in many areas (KT Analytics, Inc., 1995).

In Oakland, California, a study of the impacts of implementing a smart parking system around commuter rail stations, including the use of variable message displays to inform users in real time of the number of available places in nearby parking lots, was carried out. The system allowed individuals approaching the station from the highway to see where and how many parking spaces were available. The project also involved a booking system to reserve parking spaces in advance. The system resulted in an average reduction of approximately 9.7 miles per month for drivers (15.6 km) looking for parking. However, the study found that the variable message displays were not as successful as initially anticipated; they were noticed by only 37% of the parking lots users. Of these, about a third said that these displays had influenced their decision. (Rodier, Shaheen, & Kemmerer, 2008).

It was estimated that the benefits from the modification of zoning regulations in terms of the number of required parking spaces resulted in a decrease of buildings construction costs in King County

(Washington). Savings were estimated at $4,200 per parking space during construction and $200 per year per parking space for maintenance costs (KT Analytics, Inc. and TDA, Inc., 1990).

A study carried out in the territory of New York, in the areas of Jackson Heights (Queens) and Park Slope (Brooklyn), found that residents of neighborhoods with a guaranteed off-street parking (sufficient supply) are more likely to use their vehicle. It has also been argued that the New York zoning laws, which involve a minimum number of off-street parking for a large part of the residents, greatly encourages automobile travel, particularly for work trips. Factors such as income, car ownership, population density, types of jobs and the differences between the travel time by car and by public transit to downtown Manhattan (Manhattan CBD) also influence automobile travel for residents. Thus, it is estimated that 45% of the residents of Jackson Heights are more likely to use their car to go to work in Manhattan and 28% of them are more likely to use their vehicles in general (Weinberger, Seaman, Johnson, & Kaehny, 2008).

## Constraints and Barriers to Implementation

- As parking control is generally a local municipal responsibility, specific agreements between municipalities would be required for the regional application of parking management strategies;
- The costs of planning, coordinating, installing, operating and maintaining a dynamic guidance parking system may discourage its implementation;
- Difficult to force parking management measures on privately owned lots. Notably, the ability to affect travel mode choice through parking management is dependent on whether employers and businesses offer large quantities of free parking on their lots.

## 4.5 Trucking

The following sections present measures that seek to reduce VKT for goods movement. First, freight logistic management practices are discussed. Enhancing freight logistic management practices can decrease the number and length of truck trips and truck-based VKT by maximizing the efficiency of deliveries, decreasing route length and reducing journey times. Measures that encourage a modal shift from road to rail or water-based movements are also presented. Finally, strengthening inspection and maintenance programs for trucks can help ensure optimal vehicle driving efficiencies in order to reduce GHG emissions

### 4.5.1 Enhancing Logistics Management

| | | |
|---|---|---|
| **Responsibility** | | Private transportation companies, storage and handling facility operators |
| **Applicability** | M, L | Most usefully applicable to medium and large municipalities where congestion is an issue. |
| **Cost** | $$ - $$$ | Investments largely in operational procedures and changes. |
| **GHG Reduction Potential** | 2 - 3 | Depends on the extent to which truck loads can be maximized while minimizing VKT. |
| **Tech Feasibility** | 3 | Requires collaboration of transporters and facility operators. |
| **Social Acceptability** | 4 - 5 | Companies tend to adopt better logistics management practices in order to decrease operating costs and achieve transportation efficiencies, and no negative consequences for communities. |
| **Timing** | Immediate, ongoing | Can be implemented immediately. Organizational and operational adjustments likely to happen on an ongoing basis. |
| **GHG reductions Timeframe** | Short – medium | Logistics management changes can take several years for companies to adapt and to implement procedures and technologies. |

**Description**

Logistics is the organization and management of the flow of physical goods and information within and between companies. It involves the coordination of production and distribution activities, of which transportation plays an essential component. Both production (goods generators, shippers) and delivery companies seek to optimize logistical operations because it can reduce transportation costs, improve service quality, accelerate delivery, enhance competitiveness and improve environmental performance.

Trucking plays a major role in goods delivery in North America. Due to the extensive road networks in North America, trucking has been more flexible than either freight by boat or rail. However, trucking produces more GHG emissions per tonne of goods moved per km travelled than the other two modes

(Industry Canada, 2009; World Economic Forum, 2009). As such, minimizing distances travelled by trucks through enhancing logistics management is an avenue to reducing GHG emissions. Enhancing logistics management for the truck transportation can be accomplished through a variety of ways, including (Industry Canada, 2009; PEW Center Global Climate Change, 2011)[27]:

- improving truck routing for deliveries;
- maximizing truck loads;
- optimizing or decreasing the size of product packaging;
- minimizing distance of empty return trips;
- consolidating shipments;
- using higher capacity trucks;
- decreasing wait times for loading and at borders;
- using information technology systems for organizing and enhancing delivery logistics (including load tracking, route optimization, product identification, monitoring of delays and incidents, etc.).

Urban deliveries can also be supported by the development of specialized logistics and delivery centres near to central urban areas. This is especially important, because in this last leg of the delivery chain, delivery trucks are often circulating in urban centres where traffic congestion is an ongoing issue. These logistics and delivery centres can help shippers and transportation companies consolidate shipments, optimize the load factors on vehicles, ensure "right-size" vehicle capacity and make use of fuel efficient vehicles. Furthermore, their familiarity with local contexts can help local delivery centres optimize delivery routes in consideration of local traffic conditions. Similarly, competitors may partner and share facilities and distribution networks in order to promote delivery efficiencies for companies in a similar manner.

Reducing emissions from freight transportation, especially on long distance and inter-urban deliveries, can also be performed by replacing several small delivery trucks by a larger truck. The use of larger capacity trucks can increase delivery loads as well as the amount of goods transported and can limit the number of trucks making (empty) return trips to warehouses for reloading. It is important to note that larger trucks must be filled to capacity in order to have an advantage over smaller trucks.

The truck waiting time, especially in case of loading or waiting times can also be minimized. Methods for packaging items and different technologies to reduce the weighing time, waiting time at borders, etc. are factors that contribute to the optimization of time spent out for delivery. Optimization of the shape and design of products and their packaging can reduce transportation and storage requirements.

A survey of logistics and transportation service providers conducted by the Supply Chain and Logistics Association Canada suggests that businesses are already adopting and continually refining logistics management practices. Load maximization and route optimization have proven to be low-risk, minimal capital intensive investments that see a return-on-investment within short periods of time (Industry Canada, 2009).

### Measures to Encourage

It should be noted that direct operational changes, vehicle types and goods packing are largely the purview of logistics and transportation service providers and their clients (e.g. shippers). While

[27] *Note that use of vehicle technologies and less carbon intensive fuels are treated in Chapter 6.*

government agencies and municipalities typically have little direct influence on these kinds of activities, there are several types of actions which can be adopted.

**Federal or Provincial Authorities**

- Tightening air pollution regulations or mandating increased fuel efficiency standards, thereby encouraging businesses to make their operations more environmentally friendly;
- Facilitate information and knowledge sharing among university research groups, manufacturers, exporters, transporters and sectoral associations about studies, guides and best practices on logistics management;
- Funding the development of information technology systems which support improved logistics management;
- Provide training programs for shippers and transporters on the management of goods transport, and methods to reduce the environmental impact of these operations.

**Regional and Municipal Authorities**

- Ban on larger trucks in urban centres as well as encouraging the use of electric or fuel efficient vehicles;
- Implementing zoning that facilitates the installation of distribution or delivery centres near to urban areas;
- Incentives for pilot projects related to the creation of distribution centres;
- Re-evaluation of truck routes to accommodate larger vehicles.

## Pros and Cons

The benefits of enhancing logistics management include:

- Potential reduction in the number of vehicles circulating in cities;
- Cost savings for transport companies and operators;
- Reduction in energy consumption and air pollution emissions from trucks;
- Energy and waste reduction in distribution activities;
- Companies may achieve competitive advantages in trucking, better compliance with regulatory and supply chain partner mandates, and improved customer satisfaction.

The disadvantages of enhancing logistics management include:

- Required collaboration between transportation companies and operators;
- Required change in work habits;
- Investment costs required for new logistics areas.

The disadvantages of higher capacity trucks include:

- Limited effectiveness if truck load factors are not high;
- Degradation of road surfaces due to heavier truck loads.
- The introduction of the double-length transport trucks, for example, necessitates wider turning radii at intersections and driveways, which has the negative impact of increasing impervious surfaces and making intersections less pedestrian-friendly. Wider roads and intersections can lead to higher operating speeds, which in turn has negative comfort and safety impacts for pedestrian and cyclists.

## Impacts

According to a study published by the World Economic Forum on strategies to decarbonize the supply chain, encouraging the switch to clean vehicle technologies and reducing the speed of travel was rated as most effective in reducing global transportation and logistics sector GHG emissions (up to 12% of current total sector related GHG emissions). However, optimizing the delivery network to promote higher vehicle load factors and less distanced travelled when vehicles are empty, as well as encouraging a redesign of packaging to reduce weight and volume, also scored highly in terms of effectiveness in GHG reduction and feasibility of implementation (i.e. considering barriers to implementation, extent of deployment, number of stakeholders involved). Both of these measures were estimated to be able to reduce approximately 8% of emissions from the global logistics and transportation sector emissions (World Economic Forum, 2009).

Alimentation Couche-Tard in Quebec, a convenience store retail chain (also known as Mac's in Canada) undertook a study on logistics optimization in partnership with the Université du Quebec à Montreal and Oméga Optimisation. The study estimated delivery times for trucks and developed scenarios for optimizing delivery routes. The reference scenario was based on Couche-Tard's existing delivery routes. On a weekly basis, it was estimated that truck deliveries took more than 1,010 hours, travelling over almost 21,800 kilometers on Quebec's road network. Several optimization scenarios were evaluated that resulted in a reduction in distance travelled of 17.3% (3,770 km less) and a reduction of time spent on delivery of 5.7% (57 h less) (Trudeau, 2008). Couche-Tard subsequently adopted the optimized delivery scenarios for its operations.

An example of an urban distribution centre was established in City of La Rochelle, France in 2001 to handle goods distribution in its historic city centre. The distribution centre serves as a logistics management centre, and has helped to reduce the environmental and transportation impacts of goods distribution through optimizing truck load factors, time of delivery and combining trips. Due to a ban on driving trucks over 3.5 tons in the city's historic centre, the logistics centre makes use of lighter, more energy efficient vehicles for delivery. The use of electric vehicles for delivery has also helped diminish the environmental impacts of goods distribution. All of this has been achieved while maintaining existing delivery service levels. It is estimated that the distribution centre in La Rochelle has reduced truck related GHG emissions in the area by 61%, a yearly reduction of 1.5 tons of $CO_2$. The distribution centre handles 350 parcels and 10 pallets each day. (Agence de l'Environnement et de la Maîtrise de l'Énergie, 2006).

In another example of an urban delivery centre, the Simplycité distribution centre was setup in the city of Saint-Étienne, France, to provide delivery services in the city center. Seven transportation companies currently use the Simplycité's delivery services, while eight are on its waiting list. The distribution centre allows the final leg of the deliveries that need to be made by each of the seven companies to be consolidated. Furthermore, the service simplifies deliveries for customers, as all goods are delivered once per day, without compromising the existing business practices of transportation companies or the quality of the delivery (e.g. timeliness, frequency). The use of electric vehicles owned by the distribution centre and the consolidation of deliveries has reduced GHG emissions and traffic congestion within the city centre (Cerema, 2015).

In terms of larger capacity trucks, Rocky Mountain trucks with 2 or 3 trailers cans emit 17 to 21% less greenhouse gases than the standard 53-foot trucks. These trucks are generally used in less populated U.S. states, including Colorado, Idaho, Montana, Utah and Wyoming (NESCCAF, ICCT, Southwest Research Institute, TIAX LLC, 2009).

It was estimated in 1999 that among the approximately 159,000 goods delivery trips made in Quebec, fully loaded trucks (by volume and weight) accounted for only 26% of total trips. Optimization of product packing and weight can contribute to truck delivery efficiencies.

**Constraints and Barriers to Implementation**

- Logistics management is generally the responsibility of private transporters and shippers. Municipal authorities have little influence on this process;
- Collaboration between transportation companies and shippers may be difficult to obtain;
- The use of centralized logistics and delivery centres requires companies to give up some control over the distribution of their goods, especially on the last segment of delivery;
- Requires changes in processes and work habits;
- Investment cost for the creation of a logistics area.

For higher capacity trucks,

- Street sizes and geometric constraints can restrict the ability of larger trucks to circulate within some parts of the city.

### 4.5.2 Modal Shift

| | | |
|---|---|---|
| **Responsibility** | | Private transportation companies |
| **Applicability** | Limited | Limited applicability to urban areas because intermodal transportation is only feasible for longer distance inter-urban deliveries. |
| **Cost** | $$$ - $$$$ | Depends on whether facilities for modal transfer are available. |
| **GHG Reduction Potential** | 1 | Freight by train and boat have significantly lower GHG emissions per tonne/km than trucks, although opportunities for intermodal deliveries in urban areas will be limited. |
| **Tech Feasibility** | 1 – 2 | Requires alternative modes of transport to be available, as well as facilities to handle modal transfers. |
| **Social Acceptability** | 4 - 5 | Companies tend to adopt modal shift if it can be as profitable as existing practices, and communities see lesser truck traffic on roads. |
| **Timing** | Immediate, ongoing | Can be implemented immediately. Organizational and operational adjustments likely to happen on an ongoing basis. |
| **GHG reductions Timeframe** | Short - medium | Changes to mode of transport can occur in the short - medium term as companies explore and adopt alternative modes, and as supply adjusts to meet demand. |

## Description

Reductions in GHGs from shipping can come from the delivery of goods by other modes other than trucks. The most fuel efficient means of shipping in terms of GHGs per weight transported is by ship and rail. A UK Defra study found that both of these modes emit approximately one sixth of carbon emissions per ton/km travelled as compared to road based transport (World Economic Forum, 2009). Another study found that ships emit 12 grams of $CO_2$ per ton-kilometre, while trucks emit between 720 and 1440 grams of $CO_2$ per ton-kilometre (Lemoine D. , 2008).

However, rail and marine shipping options are viable only for inter-urban transportation. For distances of more than 800 km, goods transportation via rail becomes more advantageous than truck. For shorter distances, handling costs and waiting times at intermodal terminals disadvantage this modal choice (Conseil de la science et de la technologie, 2010). Furthermore, rail or marine networks are not comprehensive enough to allow for deliveries within a city or region. In urban areas, certain types of deliveries can be made by hybrid and electric vehicles or even by bicycle.

## Measures to Encourage

Provincial or regional authorities:

- Government assistance for work associated with the maintenance of the railway network, since the rail industry itself assumes the costs of expansion. A tax credit has also been established in the U.S. for the rehabilitation of railways;
- Assistance program to encourage the reduction of GHG emissions through development and adoption of intermodal transportation, such as the PAREGES (*Programme d'aide visant la réduction ou l'évitement des émissions de GES*) program developed by the Government du Quebec. The program provided subsidies of up to $750 per ton of avoided GHG emissions to encourage shippers and transporters to use intermodal transportation options. Funding was provided to 40 companies between 2008 and 2013 and led to the reduction of an estimated 300,000 tons of GHG per year. The total cost of the funding from the government was approximately $52 million (Government du Québec, 2015), or $173 / ton GHG avoided.

## Pros and Cons

The benefits of modal shift for the transportation of goods include:

- Removal of vehicles from roads, contributing to a reduction in traffic volume and congestion;
- Fastest border crossing of trains transporting goods, since convoys can be preregistered to avoid stopping for inspection purposes (as is the case for trucks);
- Reduction of road degradation;
- Reduction of GHG emissions through the use of less polluting transportation modes.

The disadvantages of modal shifting for the transportation of goods include:

- Transhipment sites and access routes may become more heavily travelled, leading to negative localized impacts on surrounding neighbourhoods.
- Shipment logistics becomes more complex for transporters who need to track and organize mode transfers.

### Impacts

SCM, a logistics provider for Walmart Canada, achieved a modal shift from trucks to trains to supply 10 stores in Nova Scotia and Prince Edward Island. This shift reduced $CO_2$ emissions by approximately 2,600 tons (Conseil de la science et de la technologie, 2010).

The Alouette Spirit, a multi-functional barge, commissioned in 2006 by the aluminium smelter Alouette, McKeil Marine and Logistec Arrimage, transported almost half of the smelter's production output between Sept-Îles and Trois-Rivières in Quebec (almost 800 km apart by road). Transported loads were estimated to be equivalent to approximately 20,000 truck trips, which in reduced approximately 26,000 tons of GHG emissions and $500,000 in roadway infrastructure maintenance costs for provincial Route 138 annually (Conseil de la science et de la technologie, 2010).

### Constraints and Barriers to Implementation

- Possibility of intermodal service is dependent on rail and marine transportation supply and networks, apply only to inter-urban travel and have limited opportunities within urban centres. Truck and air transportation tend to be the most flexible forms of transportation. Conversely, the flexibility (in terms of schedule, total delivery time and routing) of rail and marine modes can be a constraint to adoption;
- Road transportation is in part subsidized through public investment in road and highway networks and infrastructure. On the other hand, infrastructure capital and maintenance costs for railways are largely born by private industry. This has provided a competitive advantage for truck transportation, and has been a factor in the greater growth of truck transport as compared to rail in the United States in the last half of the 20th century (Spychalski & Thomchick, 2009);
- The mismatch between certain modes of transport and "just in time" delivery method, since handling of freight can create delays, increase costs and risks of damage, theft and lost goods.

### 4.5.3 Inspection and Maintenance

| | | |
|---|---|---|
| **Responsibility** | | Local and Regional Municipalities, Truck Operators. |
| **Applicability** | S, M, L | Applicable to all sizes of municipalities. |
| **Cost** | $$$ | Municipalities must implement inspection programs and set up inspection locations. |
| **GHG Reduction Potential** | 1 - 2 | Inspection programs tend to have a greater impact on air pollution emissions from inefficient or older combustion engines, but GHG emission reductions are small. |
| **Tech Feasibility** | 2 - 3 | Municipalities must set up inspection locations and make inspections mandatory. |
| **Social** | 3 | Resistance may come from truck operators due delays in |

| | | |
|---|---|---|
| **Acceptability** | | transportation and costs, but positive benefits for the community. |
| **Timing** | Immediate, ongoing | Can be implemented immediately. |
| **GHG reductions Timeframe** | Short | Inspection programs can help identify problems, repairs and optimization of truck efficiency can result in the short term. |

## Description

The regular inspection and maintenance of trucks is essential to successfully detect mechanical problems and limit unpredictable pollutant emissions related to these problems. Vehicle inspections can be carried out at a fixed frequency, as is the case of the AirCare ON-ROAD (ACOR) program implemented in British Columbia.

ACOR is a mobile excessive smoke emissions detection service. It aims to protect public health by reducing emissions. ACOR experts monitor the colour and opacity of truck exhaust smoke. The choice of vehicles inspected is performed based on traffic observations. Once intercepted, a truck is verified and the opacity of the smoke emitted from the vehicle is accurately measured and compared to standards (40% or 55% depending on the year of the vehicle). Trucks failing the opacity test are required to repair and retest. Fines can also be given to drivers. Total costs related to the implementation of the program in 2000 were $730,000.

In Quebec, since June 2006, the inspection and maintenance program for heavy-duty vehicles (*"PIEVAL"*) aims to reduce particulate emissions by heavy-duty vehicles. Inspections are carried out on route as well as at accredited institutions. Vehicles that have shown signs of excessive emissions or abundant smoke or odour are subjected to analysis by the *Société de l'assurance automobile du Québec* (SAAQ). The standards of the PIEVAL program are stricter than those of the ACOR program due to maximum opacity percentages allowed of 30 to 40% depending on the year of the vehicle.

## Measures to Encourage

- Inspection and maintenance programs can be offered or subsidized by the government, such as is the case for the AirCare ON-ROAD program;
- Fines can be given to companies and drivers who do not comply with the inspection test results and repair requirements.

## Pros and Cons

The benefits of inspection and maintenance programs include:

- Inspection and maintenance performed once can reduce emissions for multiples trips;
- Reduction of emissions, including particulate matter and GHG emissions;
- Service life of vehicles is extended, and lower overall maintenance costs may result (with regular scheduled maintenance);
- Image and reputation improvement of the trucking industry.

The disadvantages of inspection and maintenance programs include:

- The random verification of vehicles is not the most efficient method of verification;
- Relying on visual inspection only, particularly in the case of AirCare ON-ROAD program for deciding whether the vehicles will be subject to the tests may be less accurate;
- Possibility of replacing faulty pieces of the engine with older, cheaper components when maintenance is performed. This can lead to more or worse emissions.

## Impacts

It was estimated that the introduction of the AirCare ON-ROAD program in British Columbia in 2000 has reduced fine particulate emissions ($PM_{10}$ et $PM_{2.5}$) by 24%, nitrogen oxide (NOx) emission by 2% and hydrocarbon (HC) emissions by 12%, which correspond to 160, 113 and 99 tons respectively of each of these particles (G. W. Taylor Consulting, 2002)

In the case of Quebec's *PIEVAL* program, it is estimated that the yearly reduction in terms of particulates emitted by trucks was 500 tons, while $CO_2$ emissions were reduced by 107,000 tons (1% GHG emissions) (Government of Quebec, 2015b).

## Constraints and Barriers to Implementation

- Applicability of inspection and enforcement programs difficult for vehicles registered outside of the province or the country;
- Refusal of intercepted transportation companies during a time sensitive delivery, given the additional time spent on the road (increased operating costs).

# 5 – Improve Transportation System and Driver Efficiency

The following chapter presents a range of measures that are generally designed to increase the fuel efficiency of moving vehicles. They are designed to get travellers and goods to their destination using the least amount of fossil fuel possible, while generally avoiding increasing infrastructure capacity such as widening highways or bridges. However, in contrast to measures aimed at getting travellers to adopt more fuel efficient (hybrid or electric) vehicles or less carbon intensive fuels (discussed in Chapter 6), measures included in this chapter are infrastructure based. Their implementation generally falls under the responsibility of government agencies who are responsible for the construction and operation of infrastructure. The measures discussed in this chapter relate to:

- Increasing or optimizing infrastructure capacity
- Speed change policies
- Traffic signal optimization
- Ramp metering
- Incident management
- Transit priority measures and transit operation optimization
- Eco-driving training

These measures contribute to GHG emission reductions by decreasing vehicle congestion (when demand for road space by vehicles exceeds supply), idling times and frequent starts and stops. These activities increase vehicle fuel consumption because vehicles travel at less than optimal speeds for the distance covered (Mott MacDonald Ltd, June 2008).

However, it should be noted that this category of intervention, with the exception of transit priority measures, does not encourage modal shift. In fact, congestion reduction measures remove one of the main drivers which encourage people to change travel behaviour. By making driving more fluid and faster, people may be more willing to drive, and induced vehicle travel may offset the benefits of greater fuel efficiency. Furthermore, alternative modes of transportation such as transit and active transportation may become less competitive in terms of travel time compared to vehicles. However, given the essential role of road infrastructure in cities, many of the measures included under this category of intervention are targeted at optimizing the capacity and use of existing systems, thereby maximizing the benefits and use of existing transportation infrastructure and investments which have already been made.

Finally, as measures in this category of intervention generally deal with infrastructure improvements, they are generally more effective in medium and large cities where congestion is an ongoing problem.

## 5.1 Intelligent Transportation Systems

Many of the measures described in this chapter make use of Intelligent Transportation Systems (ITS). The Intelligent Transportation Systems Society of Canada defines ITS as *"the application of advanced and emerging technologies (computers, sensors, control, communications, and electronic devices) in transportation to save lives, time, money, energy and the environment"*. ITS provide tools with which to implement many of measures described in this chapter. Examples of ITS tools are:

- Vehicles detection systems which use video, radar, magnetometers and detector loops (for actuation at intersections, data collection or advance detection of vehicles);
- Intersection traffic control with advance traffic management tools (new ATC controllers with additional coordination features and flexibility than older NEMA TS1 and TS2 equipment);
- Video surveillance cameras on highways, intersections and high congestion areas, where a real-time video feed is routed to a centralized location to allow viewing and monitoring of traffic conditions;
- Variable message signs located above highways or next to roads to inform drivers of traffic conditions, travel times, detours, etc.;
- Computer aided dispatch/automatic vehicle location systems (CAD/AVL) that allow transit agencies to follow their vehicles in real-time as well as provide information on schedule adherence and on-board communication methods between drivers and transit agency dispatch centres;
- Transit signal priority (TSP) systems with equipment on buses and at intersections to allow approaching vehicles to be detected and, with minimal or no effect on coordination, allow for transit signal strategies to be put in place;
- Emergency vehicle priority (EVP) systems, similar to TSP but for emergency vehicles;
- Advanced Traffic Management Systems (ATMS) where information is collected from various sources and integrated within a centralized system to be viewed or analyzed at a Traffic Management Centre (TMC);
- Incident Management tools such as centralized, real-time logging of information related to an unplanned event affecting the mobility of vehicles on roadways or affecting the service levels of public transportation.

Thus, many system components working together allow for real-time management of information to be able to better adapt to traffic and/or mobility conditions and increase roadway capacity and smooth traffic flow. ITS are not treated as separate measures, as they do not by themselves contribute to reducing transportation related GHG emissions. Rather, the application of ITS as an integral part of many of the measures described in this chapter can help to reduce GHG emissions.

## 5.2 Optimize Infrastructure Capacity

| Increase Infrastructure Capacity | | |
|---|---|---|
| **Responsibility** | | Local, Regional and Provincial Agencies |
| **Applicability** | S, M, L | Applicable to all sizes of municipalities |
| **Cost** | $$$$ - $$$$$ | Construction of new lane or road capacity is very costly |
| **GHG Reduction Potential** | 1 | Benefit of added capacity reduces congestion in the short term, but does not encourage modal shift. In the medium to longer term induced vehicle traffic will lead to congestion in the future, erasing early GHG reductions. |
| **Tech Feasibility** | 2 | Depends on space availability, significant planning and construction |

| | | |
|---|---|---|
| | | activities. |
| **Social Acceptability** | 3 | Existing road users are generally in favour of increased capacity, while neighbourhoods surrounding expanded roadways are less supportive. |
| **Timing** | Short - medium | Planning, design can occur rapidly, but construction likely only to begin in short to medium term. |
| **GHG reductions Timeframe** | Short term | GHG emissions reduction can be experienced in the short term, but diminish over the medium to long term with induced vehicle traffic. |

| **Manage Roadway Capacity Dynamically** | | |
|---|---|---|
| **Responsibility** | | Local and regional municipalities, Provincial Transportation Agencies |
| **Applicability** | S, M, L | Applicable to all sizes of municipalities |
| **Cost** | $$$ | Requires traffic sensors (cameras, roadway detectors), signalling equipment, and operations staff. |
| **GHG Reduction Potential** | 1 – 2 | Benefits of added capacity reduce congestion in the short term, but vehicles are still being used. In the medium to longer term induced vehicle traffic will lead to congestion in the future, erasing gains. |
| **Tech Feasibility** | 3 | Depends on space availability (e.g. shoulder lanes). |
| **Social Acceptability** | 4 | Makes use of existing roadway capacity. |
| **Timing** | Immediate, ongoing | Can be implemented immediately. Management is an ongoing activity. |
| **GHG reductions Timeframe** | Short term | GHG emissions reduction can be experienced in the short term, but diminish over the medium to long term with induced vehicle traffic. |

### Description

Expanding road capacity on congested roads and highways can potentially reduce traffic delays and improve mobility by allowing vehicles to move more freely across the expanded roadway. Thus, capacity increases through road or highway construction and expansion are often used to relieve urban congestion. However, it should be noted that increased or induced vehicle travel may offset short term gains in traffic fluidity and vehicle fuel efficiency.

In relation to infrastructure arrangements, modifications of existing infrastructure can also potentially help in reducing roadway congestion. Infrastructure modifications such as roundabouts in lieu of signalized intersections can also help reduce vehicle stops and increase traffic fluidity. Traffic enters a continuous one-way stream around a central island and drivers can enter and exit the intersection more fluidly than would be the case for a signalized intersection. Roundabouts also help traffic flow in lieu of intersections that require dedicated lanes and queues for left-turning vehicles. Yield signs instead of stops can also be employed at intersections to reduce the number of stops and starts where clear sightlines permit.

Furthermore, pavement surfaces can also play a role in traffic fluidity. Not only do rougher roads reduce driver comfort and satisfaction, they also reduce driver safety and can increase vehicle wear and tear (AASHTO, 2009b). Resurfacing rough roads can reduce friction, which can improve fuel efficiency and reduce GHG emissions (FHWA, February 2012).

Optimized infrastructure capacity can also include initiatives to use existing infrastructure in other ways than initially planned. For example, real time roadway management measures can create additional lane capacity on existing roads, such as by permitting the temporary use of shoulder or underutilized high occupancy vehicle lanes. For example, in Quebec, designated shoulder sections of Highway 40, a major east-west corridor crossing Montreal, can be used by public transit buses when the speed of traffic is less than 50km/h in normal travel lanes.

## Measures to Encourage

Infrastructure optimization includes the implementation of a traffic management centre (TMC) as well as cameras in high traffic areas to allow visibility at all times of traffic flow, detection of recurring events with time and observation of impacts of optimized infrastructure on vehicle on road traffic.

## Pros and Cons

The benefits of optimized infrastructure capacity measures include:

- The reduction of GHG emissions in the short term due to less traffic congestion on problematic areas
- Roundabouts can increase intersection capacity and traffic fluidity;
- Increased road capacity and increased accessibility to an area can be a stimulator for local residential and economic development.

The disadvantages of optimized infrastructure measures include:

- Increased urban heat Island effects;
- New roadway infrastructure could be less conducive to active modes of transportation;
- Roundabouts, especially larger capacity ones, can increase the distance that must be travelled to cross the intersection by pedestrians;
- Land/space requirements for roundabouts is considerably more than for a typical signalized intersection;
- Generally, the addition of more roads/highways makes traffic smoother in the short term, but could induce more automobile usage, therefore negating early reductions in GHG emissions.

## Impacts

One of the impacts experienced with infrastructure optimization is a reduction in travel time in congested areas. As an example, the Legacy Parkway Project, completed by the Utah Department of Transportation in 2008, allowed for less congestion in the area, reducing GHG emissions significantly. This new 22 km four-lane highway provides an alternate route to the most congested freeway corridor in the area, cutting the afternoon commute time from 42 to 16 minutes from Salt Lake City to Farmington (AASHTO, 2009a). In Canada, the 407 East extension project currently underway will add east/west capacity through the Durham Region, increasing capacity up to 6,000 vehicles/hour per direction.

Bottleneck relief can also be seen in other types of infrastructure capacity projects. The West Dodge Expressway, an elevated expressway bridge project completed in 2006 in Nebraska, reduced congestion at an intersection that saw more than 105,000 vehicles a day. The project entailed a total of two 1.6 km elevated expressway bridges and was part of a $100 million project aimed at transferring 70% of local traffic onto the new expressways (AASHTO, 2009a).

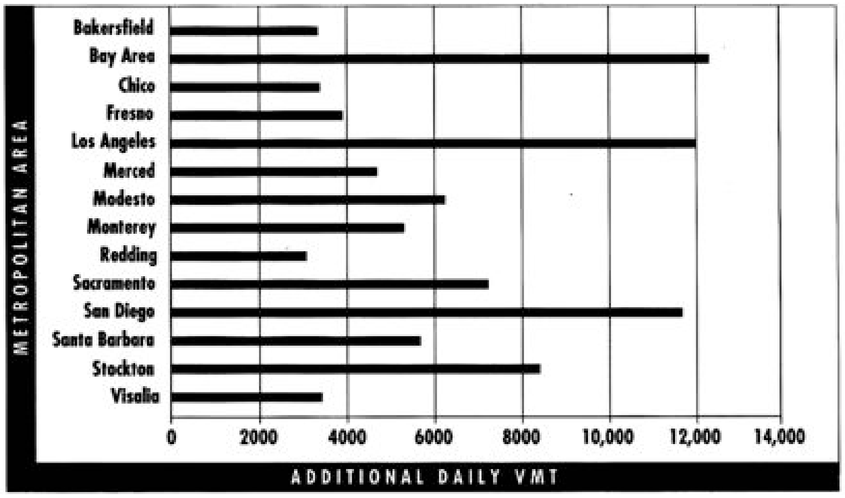
Substituting a roundabout for a conventional signalized or signed intersection may reduce fuel consumption and $CO_2$ emissions: estimates suggest reductions of 16% to 30% in fuel consumption at roundabouts than conventional intersections (FHWA, February 2012).

Resurfacing roads also has an effect on the overall fuel efficiency of vehicles. In a Missouri study of vehicle performance on roads before and after paving, diesel dump trucks averaged 5.97 miles per gallon before repaving; after paving they averaged 6.11 miles per gallon. This difference accounts for approximately a 2.4% improvement (FHWA, February 2012). Generally, the overall reduction in fuel consumption depends on the length of resurfaced roads. However, it is important to note that fuel consumption reduction may be counter-balanced by the $CO_2$ emissions generated by the road construction itself and the energy consumptions required to carry out the work.

Despite the evidence that infrastructure capacity expansion can relieve congestion in the short term, overall GHG savings in the long term may in fact be minimal or even negative. Expanded road capacity and more fluid traffic flow in the short term tends to induce further travel by vehicles. Studies confirm that the average long-term elasticity of vehicle miles travelled (VMT) with respect to lane miles is approximately 0.73. For every 1% increase in area-wide highway capacity, VMTs increases by 0.73. As it is easier to drive, more people will choose to drive over the long term, eventually contributing to congestion in the future (Ewing, Bartholomew, Winkelman, Walters, & Chen, 2007).

The amount of induced VKT on the expanded roadway also depends on the level of congestion that was previously present on that road. Adding capacity in an area with no congestion has little to no effect on VKT because everyone who wanted to drive could already have done so with little restriction. Adding capacity in an area with severe congestion will increase VMT in that area (Ewing, Bartholomew, Winkelman, Walters, & Chen, 2007). People who were formerly discouraged from driving due to congestion may decide to begin driving once congestion is reduced. As an example, Figure 5-1 shows the relation between VMT increases per lane-mile of capacity added in California metropolitan areas. It shows that the Bay Area, Los Angeles and San Diego all show the greatest increase in VMT, due to heavy congestion and pent up demand vehicle travel in these areas.

**Figure 5-1 – VMT Increases per Lane-Mile of Additional Capacity in California**




**Constraints and Barriers to Implementation**

- Most of the measures related to infrastructure capacity increase are under provincial jurisdiction in Canada
- Space around an intersection is required to build a roundabout, as compared to four way stops or traffic signalized intersections.
- Adding highway lanes requires available space on adjacent lands

## 5.3 Speed Change Policies

| | | |
|---|---|---|
| **Responsibility** | | Local and regional municipalities, Provincial Transportation Agencies. |
| **Applicability** | S, M, L | Applicable to all sizes of municipalities. |
| **Cost** | $$ - $$$ | Depends on whether speed control signage is static, variable, or dynamically adjusted (in increasing order of costs). |
| **GHG Reduction Potential** | 3 - 4 | May reduce traffic congestion, but does not encourage modal shift. |
| **Tech Feasibility** | 2 – 3 | Depends on whether speed control measures are static, variable, or dynamically adjusted, which require increasing complex control systems |
| **Social** | 2 - 3 | Drivers may see benefits where travel times and congestion are reduced, but enforcement measures (e.g. tickets) are generally |

| | | |
|---|---|---|
| **Acceptability** | | disliked. |
| **Timing** | Immediate | Can be implemented immediately. |
| **GHG reductions Timeframe** | Short term | GHG emissions reduction can be experienced in the short term. |

## Description

Controlling vehicle travel speeds can reduce GHG emissions by decreasing fuel consumption in two ways. First, research demonstrates that vehicles travelling at a constant speed consume less energy than vehicles that are constantly accelerating and decelerating (i.e. stop and go traffic). Vehicles that are stopped or driving slowly in congested traffic consume energy for no to very little distance travelled. On the other hand, vehicles travelling at high speed consume more energy per distance travelled due to aerodynamic drag forces (see next paragraph). Efficiency losses also result from vehicle acceleration and braking. Research has shown that the optimal traveling speed for automobiles in terms of vehicles emissions is around 72km/h to 80 km/h (AASHTO, 2009a; Barth & Boriboonsomsin, 2008).

Aerodynamic drag forces increases with the square of speed (e.g. drag forces increase fourfold for a doubling of travel speed from 50km/h to 100 km/h). At highway driving speeds (e.g. 90 km/h+), aerodynamic drag forces can become a significant factor in vehicle energy and fuel consumption (Barth & Boriboonsomsin, 2008).

From a public agency standpoint, control over vehicle travel speeds and maximums, or speed control policies, can be implemented through regulation and enforcement. Such measures include:

- Decreasing maximum speed limits for all vehicles;
- Implementing variable speed limit measures in congested areas to dynamically change speed limits. By dynamically adjusting speed limits downward close to congested areas, vehicles are essentially spread out over the roadway and delayed from entering the congested zone, thereby allowing more time for the congestion to clear. ITS equipment such as inductive loop detectors or other vehicle detection systems capture vehicle speed fluctuations along roads and highways and, combined with real time detection of traffic, can dynamically reduce speed limits on highways. Drivers are then informed of current speed limits or speed limit changes by variable message signs and other ITS equipment strategically placed along a corridor;
- Enforcing speed limits through control by means of police radar surveillance or automatic photo radars at intersections and on highways;

- Requiring built-in electronic heavy truck speed limiter systems to be activated[28]. As of 2013, only Ontario and Quebec have legislation in place requiring heavy trucks travelling through those provinces to activate their speed limiter systems (allowing a maximum speed of 105 km/h).

Variable Speed limit sign installation in Pennsylvania

Variable speed System on the New Jersey Turnpike

Note that the optimization of vehicle aerodynamics (i.e. cross-sectional area, shape, underbody air-flow, etc.) can reduce aerodynamic drag (see Chapter 6 on vehicle and fuel technology for more details).

## Measures to Encourage

- Speed control measures applied to infrastructure can be implemented by local, regional and provincial agencies responsible for road transportation;
- Variable speed limits can also be used when road surface conditions deteriorate due to weather in order to require drivers to slow down and reduce the potential for accidents;
- Consider speed limiter regulation for trucks limiting maximum speeds to 105 km/h.

## Pros and Cons

The benefits of speed change policy measures include:

- Increased vehicle fuel efficiency, and decreased GHG emissions due to reduction in frequency of accelerations and decelerations along roadways;
- Improvement in road safety and the potential decrease in the number and severity of road accidents. Inappropriate and excessive speeds are significant factors in the causes and severity of road accidents in OECD countries (OECD, 2003).

The disadvantages of speed change policy measures include:

- May increase travel time.

*[28] Electronic speed limiters have been standard equipment on the majority of heavy trucks built since the mid-1990s. However, activation of this equipment is left to the truck purchaser (Transport Canada, 2013).*

### Impacts

Regulating speeds to avoid traffic congestion, accelerations, or decelerations improves overall traffic fluidity. Research shows that an automobile in traffic emits more GHG per kilometer than one traveling at a constant speed. Research has shown that the optimal traveling speed for automobiles in terms of vehicles emissions is around 72km/h to 80 km/h (AASHTO, 2009a; Barth & Boriboonsomsin, 2008).

Similarly, reducing maximum speed limits of public transportation buses from 120km/h to 105km/h would translate into a 20.9% reduction of their fuel consumption. Reducing maximum speed limits of public transportation buses from 105 km/h to 90km/h would decrease fuel consumption by another 15% (Research and Traffic Group, 2000).

Studies carried out for Transport Canada estimated that a national mandatory speed limiter requirement for heavy trucks (limiting heavy truck speeds to 105 km/h) could result in a decrease of 1.4 % in diesel fuel consumption, based on 2006 heavy truck travel patterns across all provinces. Annual GHG savings from such a measure were estimated to be 0.64 MT. Trucking in Ontario, Quebec and Alberta would account for some 83% of the fuel savings based on truck travel patterns in those provinces (Transport Canada, 2013).

Research carried out by the University of California (in Riverside, CA) demonstrated that the following 3 measures could reduce $CO_2$ emissions on the highways of Los Angeles from 7 to 12% (up to 30% if combined) (Greene, Baker, & Plotkin, 2011):

- **Congestion mitigation**: ramp metering, incident management / real-time information, congestion pricing
- **Speed management**: enforcement of speed limits, speed limits of adaptation in real time
- **Homogenization of congestion (or traffic smoothing)**: variable speed limits, dynamically manage and limit speeds, congestion pricing

### Constraints and Barriers to Implementation

- Compliance by travellers to new speed regulations, necessitating both education and enforcement;
- Resistance from trucking industry to adoption of speed limiter systems;
- Need for investment and integration of speed monitoring and control systems into existing infrastructure.

## 5.4 Traffic Signal Optimization

| | | |
|---|---|---|
| **Responsibility** | | **Local and Regional municipalities** |
| **Applicability** | S, M, L | Applicable to all sizes of municipalities |
| **Cost** | $ - $$$ | Costs are related to studies, modelling and programming, but some intersections may require modernization of traffic signal controllers. |
| **GHG Reduction** | 2 - 3 | Can improve traffic flow, but does not stimulate modal shift. |

| | | |
|---|---|---|
| **Potential** | | |
| **Tech Feasibility** | 4 – 5 | Planning and programming. |
| **Social Acceptability** | 5 | Impacts to end user are generally positive. |
| **Timing** | Immediate, ongoing | Can be implemented immediately, and is an on-going activity. |
| **GHG reductions Timeframe** | Short term | GHG emissions reduction can be experienced in the short term, but diminish over the medium to long term with induced vehicle traffic. |

## Description

Traffic signal optimization seeks to reduce vehicle stops and starts at signalized intersections and allow vehicles to travel at a more constant speed (smoother traffic flow) across a road corridor. For the same reasons raised in the section under speed change policies, smoother traffic flow can decrease vehicle GHG emissions.

Reducing stop and go traffic along a corridor requires analysis of current vehicular movement along the corridor. Traffic studies are normally performed to evaluate vehicle counts, current travel times along a corridor and specific requirements of an intersection (needs for left-turn signals and dedicated lane, right turn counts, etc.).

Traffic signal optimization entails the following measures:

- Optimization of traffic phasing at intersections (performed by tested simulations using actual traffic data);
- Coordination and synchronization of traffic signals along major travel corridors to allow for less stops (and more distanced travelled within a given timeframe);
- Traffic signal controls adjusted according to a schedule or time period (AM peak, PM peak, off-peak) as well as directionally;
- Use of Intelligent Transportation Systems (ITS) for real-time intersection management (Emergency Vehicle Priority or Transit Signal Priority measures). These measures allow for better integration of transit or emergency vehicle travel within a corridor, while allowing other vehicles to maintain smoother travelling speeds than would be the case without these measures.

Traffic corridors may span multiple jurisdictions and be managed by different traffic departments. Coordination between traffic departments on traffic signals is essential to ensure smooth traffic flows across the area.

## Pros and Cons

The benefits of traffic signal optimization measures include:

- Phase / timings optimization ensures an adapted response to traffic demand at intersections;
- Reduction in number of accidents as traffic is flowing at a natural pace (rather than frequent starts and stops);

- Reduction in the number of effective traffic signalled intersections when intersections are spaced closed together;
- May reduce or even eliminate the need to expand roadway capacity;

The disadvantages of traffic signal optimization measures include:

- Coordination of traffic lights along an axis ensures a better flow in the direction of the pre-planned rush hour program, but can degrade fluidity of other movements;
- Optimization for vehicles may make other modes such as cycling less efficient due to different average travel speeds.

## Impacts

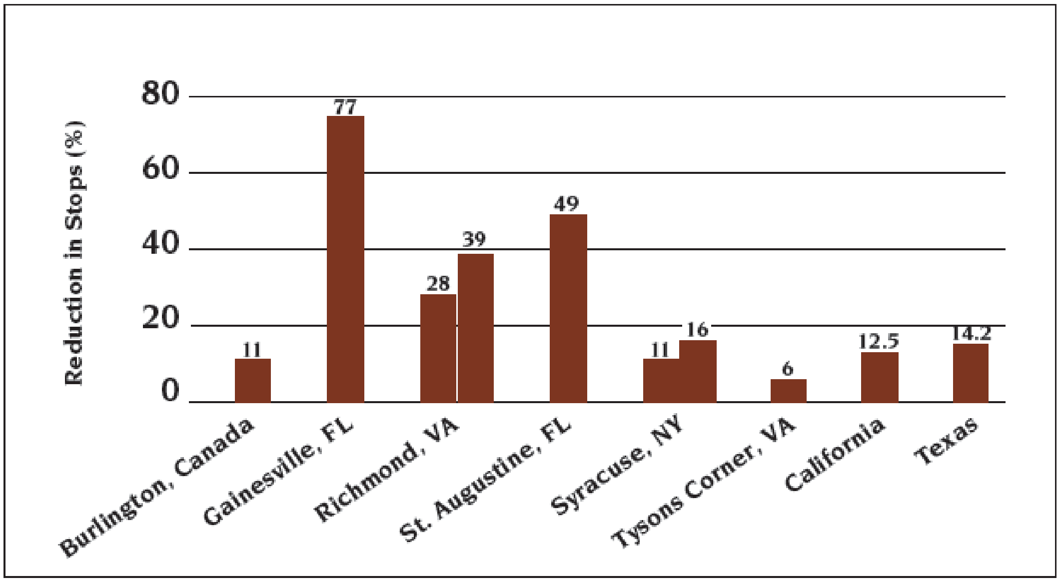
Traffic signal coordination optimization provides tools to better manage vehicular flow, reduce the number of stops at red lights encountered by drivers and, consequently, reduces idling and accelerations.

Studies done by the USDOT/RITA in six North American cities and two American states with signal coordination have shown a reduction in the number of overall stops in a given route as shown in Figure 5-2 (USDOT / RITA, 2008):

Modeling studies in five of the U.S. cities have shown vehicle emission reductions ranging from no significant impact up to 22 percent when traffic signal optimization is performed (USDOT / RITA, 2008).

Research performed by the Quebec Ministry of Transportation (MTQ) indicated that the coordination of traffic signals can reduce fuel consumption up to 17% (MTQ, 2013). The City of Toronto, with its congestion management plan for 2014-2018, recently reviewed its timing plans on six corridors with 250 traffic signal intersections in 2014.Total delay at intersections was successfully reduced between 4 and 18%, resulting in a reduction of fuel consumption and GHG emission between 1 to 7% for each corridor (City of Toronto, 2014).

**Figure 5-2 – Reductions in Stops Due to Signal Coordination**




Traffic signal optimization may make driving safer. Studies suggest that the coordination of traffic signals can reduce the number of rear-end collisions (OECD, 2003). However, overall vehicle speed increases may increase the risk of serious accidents in the same corridor (OECD, 2003).

## Constraints and Barriers to Implementation

The implementation of measures listed above could require additional or new traffic controllers, traffic controller cabinets or new equipment to be installed in existing traffic equipment. Compatibility constraints between existing and new equipment can require additional study and analysis.

## 5.5 Ramp Metering

| | | |
|---|---|---|
| **Responsibility** | | Local and regional municipalities, Provincial Transportation Agencies |
| **Applicability** | M, L | Likely only applicable to medium to large municipalities where highway congestion is an issue. |
| **Cost** | $$ - $$$$ | Signalling infrastructure and ramp space required. |
| **GHG Reduction Potential** | 3 – 4 | Has little impact on mode shift, reduced congestion gains on highways are offset by vehicle idling and acceleration from ramps. |
| **Tech Feasibility** | 3 – 4 | Signalling infrastructure and ramp space required. |
| **Social Acceptability** | 2 – 3 | Waiting on ramps may cause traffic spillover into adjacent neighbourhoods, benefits accrue only to drivers already on the highway. |
| **Timing** | Immediate | Can be implemented immediately. |
| **GHG reductions Timeframe** | Short term | GHG emissions reduction can be experienced in the short term, but diminish over the medium to long term with induced vehicle traffic. |

### Description

Ramp metering includes various methods to manage and control the number and frequency of vehicles entering a highway via ramp or other type of access. Ramp metering is designed to maintain the fluidity of traffic flow on the highway itself where the majority of traffic is travelling.

Ramp metering can include the provision and installation of:

- Red/Green Traffic signals along with indicative signage installed on or before the ramp access, allowing one (or a pre-determined number) of vehicles through each green light cycle. This creates a fixed delay (from 4 to 15 seconds) between vehicles and reduces the number of vehicles entering the highway at the same time (Washington State Department of Transportation);
- Dynamically managed rate of entry depending on congestion levels on the highway.


**Figure 5-3 – Ramp meter installed in Milwaukee, Wisconsin**

Image source: Wikipedia

## Pros and Cons

The benefits of ramp metering measures include:

- Reduction of congestion and delays on highway segments;
- Can reduce number of accidents due to vehicle entry onto the highway (FHWA, February 2012).

The disadvantages of ramp metering measures include:

- Possible queuing and idling of vehicles on the waiting ramp, with potential spillover effects into adjoining streets and neighbourhoods;
- Road users already on the highway are advantaged over drivers waiting to get onto the highway, especially those closer to inner cities or downtowns. This may promote the use of highways for road users living in less central locations (i.e. encourages urban sprawl) (FHWA, February 2012);
- While vehicle fuel efficiency may improve on highway, fuel consumption and emission increase for vehicles waiting on the ramp and then accelerating from stop.

## Impacts

In a study of 27 freeway bottlenecks sites in the area of the Twin Cities (Minneapolis-Saint Paul, Minnesota), the implementation of ramp management increased vehicle capacity by delaying the occurrence of the bottleneck or eliminating it altogether, increasing vehicle throughput on the freeway, and increased speed and fluidity of travel (Levinson, 2010).

As described above, the reduced congestion on the highway allows for greater fuel efficiency and reduced emissions for vehicles travelling on the highway. However, the decrease in congestion may increase overall vehicle speeds, induce vehicle demand and offset GHG emission reductions. Furthermore, vehicles idling at on ramps and then accelerating rapidly onto the highway can also increase rates of fuel consumption and GHG emissions (FHWA, February 2012). The net balance in fuel consumption and GHG emissions is likely to be case specific and requires further study.

### Constraints and Barriers to Implementation

- Space availability for ramp metering to ensure that the formation of the queue on the ramp does not block upstream intersections.

## 5.6 Incident Management

| | | |
|---|---|---|
| **Responsibility** | | Municipalities, Emergency Response Organizations, Tow Truck Operators |
| **Applicability** | S, M, L | Applicable to all sizes of municipalities. |
| **Cost** | $$ - $$$ | Requires organizational collaboration and development of incident management procedures, as well as traffic condition monitoring (e.g. cameras). |
| **GHG Reduction Potential** | 3 - 4 | Removes bottlenecks and congestion more rapidly. |
| **Tech Feasibility** | 3 - 4 | Many agencies already conduct incident management, improvements require organizational efforts to coordinate responses more efficiently. |
| **Social Acceptability** | 5 | Making existing practices in responding to incidents and accidents more rapid, safe and efficient. |
| **Timing** | Immediate | Can be implemented immediately. |
| **GHG reductions Timeframe** | Short term | GHG emissions reduction can be experienced in the short term. |

### Description

Incident management is a systematic, multi-agency effort to improve and facilitate the clearance of highway incidents such as (Tennessee Department of Transportation, 2003):

- Vehicle collisions and crashes;
- Disabled or abandoned vehicles;

- Debris blocking lanes;
- Any other type of planned or unplanned event causing a disruption to traffic flow on roads and highways.

These types of events can have a significant impact on the fluidity of traffic. Incidents can reduce road capacity when they occur in the travel lane and also increase the risks of additional accidents when drivers decelerate quickly due to the sudden blockage, curiosity or concern about the roadside event. Rapid incident management is designed to remove roadway obstacles more quickly to free up travel lanes and remove these driver distractions.

Improved incident management can be achieved through:

- Real-time tracking of incidents with respect to location, description and any adjustments required locally to limit the impact on other users;
- Diffusion of information to users (variable message signs, radio messages, etc.) allowing them to choose their alternative route based on the situation;
- Implementation of monitoring mechanisms such as detection algorithm, free cellphone call systems, surveillance cameras, patrol services.

Furthermore, incident management typically requires the close coordination of a various agencies who can be involved in the response to incidents and restoration thereafter, including:

- First responders (police, fire and emergency communication services)
- Towing and recovery operators
- Hazardous materials responders
- Traffic monitors and reporters
- Utility companies
- Public work agencies

## Measures to Encourage

**Local and regional agencies**

- Establish an interagency action plan with clear road safety objectives;
- Promote interagency cooperation and coordination;
- Establish a centralized incident and transportation management centre.

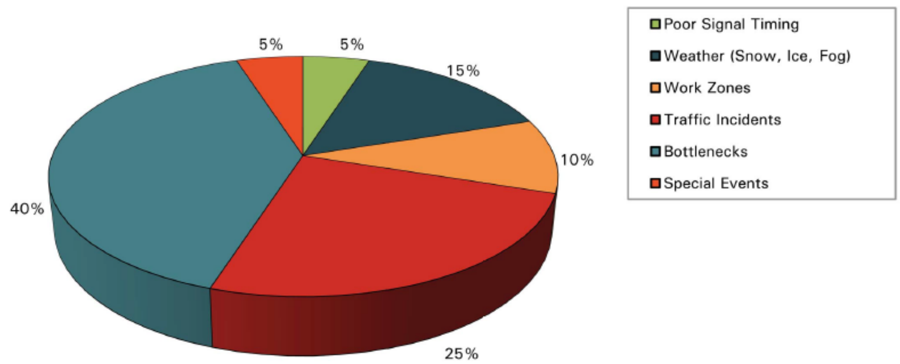
## Pros and Cons

The benefits of incident management measures include:

- Faster interventions due to real-time detection and management of incidents;
- Limits the impact and duration of congestion in proximity to the incident;
- Improves overall security of travelers as well as responders;
- Generally requires little capital investment, as coordination, rather than equipment, is required to enhance incident management;
- Maximizes capacity of existing road infrastructure and emergency response services without need for significant new investment.

## Impacts

In 1986, a study conducted by the FHWA concluded that 61% of all congestion delays on urban freeways were caused by incidents (Lindley, 1986). However, more recent studies suggest that incidents were responsible for between 25% to 50% of all traffic congestion on urban freeways (Texas Transportation Institute, 2002; Chin, 2004). Figure 5-4 shows relative sources of congestion (Chin, 2004).




(Source: Chin et al., *Temporary Losses of Highway Capacity and Impacts on Performance*, prepared for FHWA, 2004, http://www-cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2004_209.pdf.)

**Figure 5-4 – Relative Sources of Congestion**

On a smaller scale, a URS study demonstrated the impact of the incident management portion of the NaviGAtor Intelligent Transportation System implemented in Atlanta, Georgia. The study, conducted between May 2003 and April 2004, confirms that the system reduced incidents to an average time of 45,9 minutes (translated into approximately 7.2 million vehicle-hours of incident-delay savings), therefore saving approximately 6.8 million gallons of gasoline related to delays due to incidents (URS, 2006).

## Constraints and Barriers to Implementation

- Interagency cooperation and coordination: incident response planning, coordination and procedures must be established and agreed upon by the various agencies who need to respond to incidents. Notably, knowing which agency to call, and a clear allocation of responsibilities and tasks depending on the type of incident, need to be clearly defined as part of improving incident management systems.

## 5.7 Transit Priority Measures

| | | |
|---|---|---|
| **Responsibility** | | Transit Agencies, Municipalities |
| **Applicability** | S, M, L | Applicable to all sizes of municipalities |
| **Cost** | $ - $$$ | May require additional bus lanes to be installed, requires ITS equipment |
| **GHG Reduction Potential** | 2 | Decreases fuel consumption by transit vehicle fleet, plays a role in improving overall performance of transit system and encourages modal switch |
| **Tech Feasibility** | 2 – 3 | Studies required, space requirements, implementation of ITS equipment |
| **Social Acceptability** | 3 - 4 | Positive impacts for transit users, other road users may experience increased delays |
| **Timing** | Immediate | Can be implemented immediately |
| **GHG reductions Timeframe** | Short term | GHG emissions reduction can be experienced in the short term |

### Description

Transit priority measures comprise a whole series of infrastructure-based measures that are aimed primarily at improving trip travel times and service reliability of public transit (TCRP, 2008) (Non-infrastructure based optimizations to improve travel times and reliability are discussed in the Transit section, **Chapter 4**, **Section 4.2.1**). Transit use is heavily influenced by trip travel time vis-à-vis the automobile. Therefore, improving transit travel times and transit reliability is a key factor in encouraging modal shift.

Examples of transit priority measures are:

- Implementation of reserved lanes (for bus and/or high-occupancy vehicles);
- Implementation of Transit Signal Priority (TSP) measures at traffic intersections (e.g. bus priority phase);
- Queue jumping lanes along arteries or highways.

### Measures to Encourage

- Provincial agencies can provide grants and subsidies for the implementation of transit priority measures, such as through funding investments in traffic analyses, tracking transit vehicle usage, signaling equipment and other infrastructure work. For example, in Quebec, the provincial government assistance program for the collective transportation of people (*Programme d'aide gouvernementale au transport collectif de personnes)* offers grants of up to 100% to cover the costs associated with all infrastructure work related to transit optimization measures for buses.

- Provincial and local agencies can provide reserved bus lanes, bus queue jumping lanes and intersection signal priority measures on their own highway or arterial road networks respectively.

## Pros and Cons

The benefits of transit operational optimization measures include:

- Shorter commute times for transit vehicles using reserved lanes (buses, taxis, high occupancy vehicles);
- Increased transit reliability;
- Shorter travel times for transit vehicles which can result in increased frequencies or reduced number of transit vehicles;
- Better customer satisfaction should the use of transit require less time for their day-to-day travels;

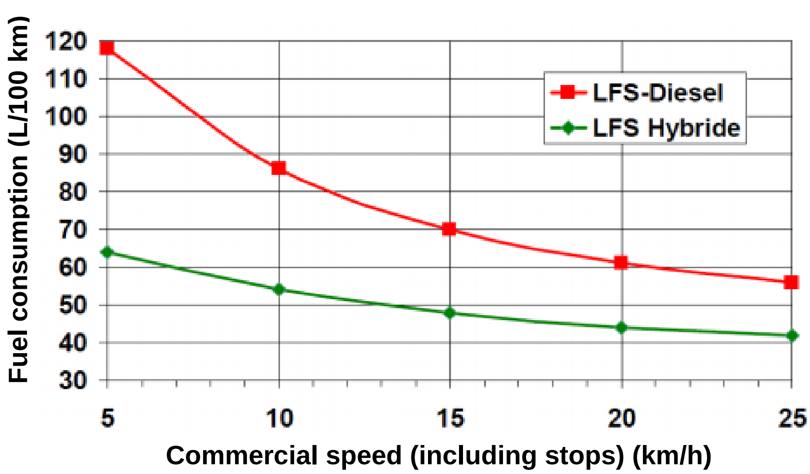
The disadvantages of transit operational optimization measures include:

- TSP measures, if implemented within the normal traffic light cycle duration, reduce times on other phases, which could potentially create delays elsewhere and for cross-traffic.

## Impacts

Reducing the number of stops that transit vehicles make increases their commercial speed and reduces fuel consumption. Figure 5-5 illustrates the effects of travel speed for both hybrid and diesel transit buses (STM, 2003).

**Figure 5-5 Effects of Travel Speeds for Hybrid and Diesel Transit Buses**




The City of Montreal together with its transit agency (the *STM*) evaluated that time savings associated with bus priority measures along a major artery in the city. They estimated that total travel time savings of 10% and 5% were achievable with reserved lanes and the use of traffic signals for bus priority at intersections respectively (STM, 2003). Furthermore, these measures increased the rate of vehicle punctuality at stops to 95%, and reduced the number of buses required to service the route by 2 buses per day;

By 2020, the STM plans to integrate bus priority measures such as reserved lanes and traffic signal priority into 56 routes across the city. The STM estimates the benefits of these measures to include (STM, 2003):

- Total travel time savings of between 10 and 20%
- Savings of 4000 tons of GHG emissions
- 40 buses per day need reduction (savings of $ 15 million per year)

Transit agencies can employ onboard GPS vehicle locators coupled with central computer aided dispatching to coordinate and optimize transit vehicle movements across the network. Such a system was employed by the public transit agency in Nancy (France). Onboard vehicle communication systems tied to traffic light signals were studied by the transit agency in Nancy, France. Detection of transit vehicles at intersections triggered transit priority lights or an extended green light phase. The study found that such systems led to a reduction in transit vehicle travel times, which allowed for a reduction in number of vehicles (and operating costs) required to provide similar levels of transit service (STIF, June 2001).

However, the use of traffic signals for bus priority does come at a cost for other travelers. As time is distributed from other phases to the traffic signals for the bus priority phase in a cycle, other phases can see a 2 to 7 second decrease of their part of the cycle, which can attribute to longer waiting times for non-transit modes (Ville de Montréal, Direction des transports, May 2004).

For trains, a study conducted by GO Transit in Greater Toronto on stopping vehicles only when "requested" by passengers outside of peak periods was able to reduce stops by 11.5%. Each skipped stop would save 15 liters of fuel, potentially saving 538 liters per day and 140 000 litres annually (or 0.42KT GHG) if implemented (Research and Traffic Group, 2000).

**Constraints and Barriers to Implementation**

- The implementation of reserved lanes may impact other travelers and create delays and congestions elsewhere.
- Compatibility issues may arise when different technologies are added to existing fleets and intersections.

## 5.8 Encourage Eco-driving

| | | |
|---|---|---|
| **Responsibility** | | Local, regional or provincial agencies, Drivers |
| **Applicability** | S, M, L | Applicable to all sizes of municipalities |
| **Cost** | $ - $$$ | Costs associated with awareness campaigns, training and monitoring programs, also depends on extent of campaign |

| | | |
|---|---|---|
| **GHG Reduction Potential** | 3 - 4 | Individual fuel savings are small, but large scale training can lead to significant reductions. Long term effectiveness depends on continued practice by drivers. |
| **Tech Feasibility** | 4 - 5 | Training programs can be implemented relatively easily. |
| **Social Acceptability** | 3 | Resistance may come from drivers, but no negative consequences for communities. |
| **Timing** | Immediate, ongoing | Can be implemented immediately. |
| **GHG reductions Timeframe** | Short - medium | Eco-driving will have an immediate impact on GHG emissions, but uptake and continued practice by larger portion of population may result in more significant reductions in the short to medium terms. |

## Description

Eco-driving is a set of driving behaviours that reduces vehicle fuel consumption. It is applicable to all drivers of motorized vehicles (trucks or cars). Eco-driving involves changing one's habits related to acceleration, breaking and idling to reduce fuel consumption. Through training programs, drivers can be taught techniques such as anticipating decelerations and stops to reduce sudden braking, reducing driving speeds, limiting idling, using downhills for acceleration purposes, and shift change techniques for uphill driving. Furthermore, eco-driving also includes routine maintenance checks on vehicles such as checking tire pressures and basic engine maintenance to keep the vehicle running optimally.

Vehicles can also be modified to limit their maximum travelling speed, for example to 100 or 105 km /h. Although such modifications cannot control braking or acceleration, limiting travelling speed still allows a reduction of overall GHG emissions. See Section 5.3 for a discussion on speed limiting policies. Vehicle technologies, rather than driver behaviour, can also be employed to limit idling. See Chapter 6 for a discussion on vehicle technologies to reduce GHG emissions.

## Measures to Encourage

- Eco-driving programs for truck and car drivers may be offered or subsidized by the government. For example, in 2009, the Quebec government set up an eco-driving pilot training program for companies operating school and public buses, intercity trucking and urban trucking.
- Government funding for the installation of driving monitoring systems in trucks or larger vehicles can encourage companies to use such devices as well as encourage drivers to monitor their habits.

## Pros and Cons

The benefits of eco-driving include:

- Reduction of fuel consumption and GHG emissions.

## Impacts

Impacts related to eco-driving are limited and depend on how each driver integrates new habits in his or her driving routine. Good practices have to be learned, practiced and constantly maintained. Data on impacts of eco-driving programs is limited.

The trucking company Transport JE Fortin and the Office of Energy Efficiency set up a pilot project to promote eco-driving among its drivers. Initially, training was provided to drivers to raise awareness about the impacts of speed, idling, and sudden accelerations and decelerations on fuel consumption. Follow-up evaluations showed that fuel savings for the company could be significant, prompting it to introduce a bonus system to encourage all of its drivers to adopt more eco-driving habits. According to Transport JE Fortin, these practices helped in reducing the company’s fuel consumption by up to 5% (Agence de l'efficacité énergétique, 2007).

## Constraints and Barriers to Implementation

- Drivers need to constantly practice eco-driving;
- Given the voluntary nature of the measure, effects can diminish over time;
- Continuous monitoring of drivers' driving habits can be negatively perceived by employees.

# 6 – Encourage Alternative Vehicle and Fuel Technologies

The following chapter presents vehicle engine technologies and alternative fuels that are being developed for light-duty vehicles, transit vehicles and heavy-duty trucks to decrease the reliance on, or consumption of fossil fuels as a transportation energy source. The alternative vehicle and fuel technologies discussed include:

- Encouraging the adoption of more efficient light-duty vehicle propulsion technologies;
- Implementing new transit vehicle technologies;
- Encouraging new heavy-duty vehicle technologies; and,
- The use of low carbon fuels.

The alternative technologies discussed in this chapter are generally designed to facilitate increased fuel efficiency of vehicles themselves through vehicle based technologies rather than transportation system optimizations (Chapter 5). Net reductions in GHG emissions will also depend on external factors such as whether electricity used to power electric vehicles are produced in jurisdictions with low or no fossil fuel-based electricity generation. Furthermore, the adoption of certain vehicle technologies will also depend upon consumer demand and vehicle industry support. Local and regional agencies can help encourage the adoption of these alternative technologies through regulations, policies and information sharing.

## 6.1 Encourage Adoption of More Efficient Light-duty Vehicle Propulsion Technologies

| | | |
|---|---|---|
| **Responsibility** | | Auto industry, all levels of government, local electrical distribution companies. |
| **Applicability** | S, M, L | All municipalities can provide support for more efficient vehicle propulsion technologies. |
| **Cost** | $$$ - $$$$$ | Auto industry for technology development and deployment; all levels of government for incentives and financial support, infrastructure, and vehicle fleets. |
| **GHG Reduction Potential** | 4 - 5 | Vehicle technologies have the potential to significantly reduce GHG emissions. Plug-in hybrid electric vehicles (PHEV) and All-Electric Vehicles (EV) in particular have significant potential in jurisdictions where grid electricity is less reliant on fossil fuels. |
| **Tech Feasibility** | 1 - 3 | Technology development, and charging/refueling infrastructure deployment required. |

| | | |
|---|---|---|
| **Social Acceptability** | 4 - 5 | Consumers may choose to adopt more efficient vehicle propulsion technologies as technology matures, support infrastructure becomes more widespread, and overall financial benefits are clear. |
| **Application Timeframe** | Immediate, ongoing | Regulations, financial incentives, building support infrastructure can be implemented immediately to support ongoing development and uptake of new light-duty vehicle technologies. |
| **GHG reductions Timeframe** | Medium to long term | Significant emissions reductions would likely only be realized in the medium to long term due to current barriers to widespread consumer adoption and slow turnover of vehicle fleet. However, many different technologies have reached the market and are available commercially today. |

## Description

Hybrid and electric vehicle technologies, downsized and more fuel efficient internal combustion engines (ICE), and advanced transmission systems are among the technologies that can reduce the reliance on fossil-fuels for vehicle propulsion. The following section focuses largely on hybrid and electric vehicle technologies, as local and regional agencies can support their deployment through policy, regulations or infrastructure deployment and financing. Downsized ICE and advanced transmission systems[29], which contribute to lighter, more fuel efficient vehicles, are not the focus of this section, since local and regional agencies have little-to-no influence on the development of this technology[30].

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[29] The engine is the most inefficient component of a vehicle and is responsible for approximately 60% of its energy loss (National Research Council of Canada, 2015). Due to this inefficiency, automakers have begun focusing on engine downsizing (e.g. reduce engine capacity and number of cylinders) in order to increase fuel efficiency. A downsized engine is lighter than a conventional engine, which results in a lighter vehicle, improves fuel consumption and increases engine efficiency. While a downsized ICE may result in a loss of power, manufacturers can compensate or increase engine efficiencies by adding a boosting device (e.g. turbocharger), direct injection technologies, new materials and coatings. Furthermore, efficiencies can be gained through the utilization of advanced transmission technologies. Manufacturers can increase the number of forward gears in a vehicle or add continuously variable transmissions (CVTs) to allow an engine to operate more optimally over a wider range of vehicle speeds. Similarly, automated manual transmissions (AMTs) and dual clutch transmissions (DCTs) result in increased engine efficiency and reduce fuel consumption. Other advanced transmission concepts include low-friction and wear-resistant coatings, as well as high strength and density powder metallurgy manufacturing technologies for gears and other components of the powertrain.

Further information about the development of more efficient ICE and advanced transmissions can be obtained from:

- National Research Council Canada - http://www.nrc-cnrc.gc.ca/eng/solutions/collaborative/vpt.html
- Car and Driver - http://www.caranddriver.com/features/the-future-of-the-internal-combustion-engine
- Natural Resources Canada - http://www.nrcan.gc.ca/energy/efficiency/transportation/cars-light-trucks/buying/16769

[30] Local and regional governments may play a role in the deployment of these technologies by integrating them into their own light and heavy duty fleets or include requirements within procurement processes for services. However, the choice preference between these vehicle technologies over HEV, PHEV and BEV technologies would need to be evaluated;

Hybrid-electric vehicles (HEV) combine an ICE and an electric motor. The electric motor can assist the ICE when the vehicle accelerates, passes or climbs hills. This allows for a smaller, more efficient ICE to be used. The electric motor can also be used exclusively for low-speed driving conditions when ICEs are least efficient. In some HEVs like the Chevrolet Volt, the electric motor is the primary power plant for propulsion, and a gasoline motor is used only to generate electricity to recharge the vehicle's battery. Plug-in hybrid electric vehicles (PHEVs) are similar to conventional HEVs, except that PHEVs can recharge their batteries by plugging the vehicle into an electrical outlet.

Battery electric vehicles (BEVs) run exclusively on electricity via batteries that are charged by plugging into an outlet or charging station. BEVs have no ICE engine, do not produce tailpipe emissions, and have longer electric driving ranges compared to PHEVs. However, with current battery technology, most BEVs have less than half of autonomous driving range of hybrid or conventional vehicles. While they may be suitable for urban commuting, they offer less flexibility for households which only want to own one vehicle.

Canadian electric vehicle (EV) registration data for PHEV and BEV indicate that there were just over 14,000 EVs registered in Canada as of June 2015 (Stevens, 2015). The electrification of the light-duty vehicle fleet is proceeding more quickly in three provinces, Quebec, Ontario and British Columbia, where incentive programs for the purchase of these vehicles are in place. Estimates of total EV registrations by province are shown in the Table 6-1.

Fuel Cell Electric Vehicles (FCEVs) also use an electric-only motor powered by hydrogen fuel cells instead of batteries. The fuel cell in FCEVs combines hydrogen with oxygen from the air to produce electricity. Additionally, there is no need to plug-in FCEVs, as their fuel cells are recharged by refilling with hydrogen. Refueling time and driving range are comparable to ICE vehicles.

These types of vehicles also typically include regenerative braking technology, an energy recovery mechanism that converts the vehicle's kinetic energy into chemical energy (i.e. recharge the battery), energy that would otherwise be lost when braking. They may also include automatic start/shutoff, whereby the engine is automatically shut off when the vehicle comes to a stop and restarts when the accelerator is pressed. This avoids wasting energy through vehicle idling.

Further information about hybrid and electric vehicles can be found at:

- Canadian Automobile Association - http://electricvehicles.caa.ca/types-of-electric-vehicles/
- U.S. Department of Energy - https://www.fueleconomy.gov/feg/hybridtech.shtml and https://www.fueleconomy.gov/feg/fuelcell.shtml
- Union of Concerned Scientists - http://blog.ucsusa.org/comparing-electric-vehicles-hybrid-vs-bev-vs-phev-vs-fcev-411
- Transportation Canada - https://www.tc.gc.ca/eng/programs/environment-etv-evprimer-eng-1994.htm

**Table 6-1 – Total Electric Vehicle Registrations by Province, June 2015**

| Province | BEV | PHEV | Total | % Total |
|---|---|---|---|---|
| Quebec | 2731 | 3697 | 6428 | 45 % |
| Ontario | 2749 | 2092 | 4841 | 34 % |
| British Columbia | 1701 | 669 | 2370 | 17 % |
| Alberta | 180 | 182 | 362 | 3 % |
| Manitoba | 48 | 49 | 97 | 1 % |
| Nova Scotia | 46 | 38 | 84 | 1 % |
| New Brunswick | 13 | 29 | 42 | < 1 % |
| Saskatchewan | 23 | 25 | 48 | < 1 % |
| Newfoundland & Labrador* | 2 | 9 | 11 | < 1 % |
| Prince Edward Island* | 7 | 2 | 9 | < 1 % |
| Northwest Territories* | 2 | 1 | 3 | < 1 % |
| Yukon* | 1 | 0 | 1 | < 1 % |
| **Total** | **7503** | **6794** | **14297** | **100 %** |

*Low values may be less accurate

Source: Stevens, 2015: www.fleetcarma.com/electric-vehicle-sales-canada-june-2015

## Measures to Encourage

### Federal Level

#### *Establish regulations requiring vehicle fuel efficiency*

Many of the measures intended to encourage the utilization of more efficient vehicle propulsion technologies have been established at the federal level. In Canada, the *Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations* established mandatory GHG emission standards for new vehicles of the 2011 and later model years that are aligned with U.S. standards (Environment Canada, 2015). The regulations require cars to achieve, on average, 5% annual reductions in GHG emissions between 2017 and 2025. In order to allow manufacturers to find technological solutions that reduce emissions without affecting the utility of the vehicle, light trucks are required to achieve, on average, 3.5% annual GHG emissions between 2017 to 2021 and 5% reductions from 2022 to 2025. With these regulations, it is projected that 2025 model vehicles will consume up to 50% less fuel and emit close to 50% less GHG emissions than 2008 model vehicles (Environment Canada, 2013).

***Enhance awareness of environmental and economic advantages***

The Government of Canada has developed the EnerGuide Label for Vehicles, which is affixed to all new light-duty vehicles available for retail sale in Canada. Beginning with 2016 model year vehicles, the label will be upgraded to provide model-specific fuel consumption information, as well as $CO_2$ emissions and smog-ratings.

One of the challenges associated with the adoption of more fuel efficient vehicle technology is consumer willingness to pay for fuel efficiency enhancements. While costs have become less significant for vehicle technologies like direct fuel injection and advanced transmissions, upfront purchase costs for hybrid-electric and electric vehicles are still a barrier to adoption. Consumer desire for short term payback leads to discounting of future fuel savings, while some vehicle ownership periods (e.g. 3 to 5 year leasing periods) may also not encourage a long term financial view (McKinsey and Company, 2007). In some cases, vehicle price premiums may not be off-set by savings. According to the automotive research company Vincentric, out of 33 hybrid vehicles evaluated in 2013, 13 had a total cost of ownership that was lower than their all-gasoline powered counterparts, indicating that the overall benefit to the consumer depends on the specific vehicle model (Vincentric, 2013). In addition to offering financial incentives, enhancing information and awareness about overall vehicle ownership costs can help to alleviate challenges associated with costs. Furthermore, it is also important to note that such cost-benefit evaluations are also dependent on fuel prices and annual VKT. Increases in fuel prices and/or large annual VKT may provide greater value and incentives to consumers for the adoption of advanced ICE, plugin hybrid or electric vehicles.

**Provincial and Municipal Level**

***Establish a zero emission vehicle regulation***

The British Columbia Greenhouse Gas Reduction (Vehicle Emissions) Act 2008 has established a zero emission vehicle requirement for vehicle fleets, although regulations with respect to the zero emission vehicle requirements have yet to be made.

***Offer financial incentives***

To encourage the adoption of hybrid or electric vehicles and offset the initial purchase cost barriers, some provinces offer financial incentives to consumers. Data on electric vehicle purchases to date show that provinces offering incentives are seeing far higher numbers of vehicles being added to their vehicle fleets (Stevens, 2015). The following list provides some examples of available provincial subsidies as of this report's publication:

- The Government of Ontario offers rebates of up to $8,500 on the purchase or lease an eligible electric vehicle and up to $1,000 on the purchase and installation of an eligible charging station. The Electric Vehicle Incentive Program was launched on July 1, 2010 (Ontario Ministry of Transportation, 2015);
- The Government of British Columbia, with assistance from the New Car Dealers Association of BC (NDCA), offers rebates of up to $5,000 on the purchase of qualifying electric vehicles and up to

$6,000 for hydrogen fuel cell vehicles. The program began on April 1, 2015 and is available until March 31, 2018 or until funds are exhausted (New Car Dealers Association of BC, 2015);
- The Government of Quebec offers rebates of up to $8,000 on the purchase or lease of an eligible electric vehicle and up to $1,000 on the installation of an eligible charging station. The Drive Electric Program was launched on January 1, 2012 and is active until December 31, 2016 (Government of Quebec, 2015a).

***Encourage or install charging stations and hydrogen fueling stations***

Electrical distribution programs can help encourage the installation of charging stations. Examples of this in Canada include:

- The Electric Circuit network, established by Hydro Quebec, which is the first public charging network in Canada and a major initiative in providing the charging infrastructure required to support of the adoption of electric vehicles in Quebec. Since its launch in 2012, the Electric Circuit has rapidly expanded into several Quebec regions and urban areas and has helped install more than 446 Level II and 19 DC Fast Charge charging stations across Quebec (Hydro Quebec, 2015; MTQ, 2015);
- In British Columbia Phase 2 of the Clean Energy Vehicle (CEV) Program which started on April 1, 2015 will distribute $10.6 million from the Province's Innovative Clean Energy Fund over the next three years which includes $1.59 million for investments in charging infrastructure and hydrogen fuelling infrastructure. BC Hydro, with support from the Province of BC and the federal government, is also managing the DC Fast Charger (DCFC) network pilot, which will result in 30 DCFC stations throughout the province (Fraser Basin Council, 2015);
- The City of Vancouver, BC, partnered with Telus Corporation in a demonstration project to deploy two combined telecommunications receiver – EV charging stations. The project demonstrated the benefits of infrastructure co-location, including reducing space requirements and leveraging private investment to finance construction costs (FCM, 2013).

***Encourage adoption through leadership, demonstration, awareness and education***

Provincial and municipal fleets are also incorporating hybrid and electric vehicles. Not only do these vehicles help government agencies to reduce their GHG footprint, but they also demonstrate leadership in technology adoption and serve as a public awareness and education tool. For example:

- Municipality of Delta, BC, adopted a Green Fleet Management Plan that includes the purchase of hybrid-electric vehicles, an off-road vehicle pollution prevention program and a strategy to purchase energy efficient vehicles and components (FCM, 2013);
- City of Surrey, BC, has deployed an array of initiatives for its fleet of vehicles, including the purchase of fuel-efficient alternative vehicle technologies, application of route optimization strategies, and training of staff on eco-driving and idle-reduction practices. As a result of these measures, it estimates that the efficiency of its vehicle fleet is improving by an average of 1.3 % every year (FCM, 2013).

***Adopt policies and by-laws to facilitate the integration and use of hybrid and electric vehicles***

Municipalities can adopt bylaws, design guidelines or policies to encourage integration of hybrid and electric vehicles within new and existing developments. They can require minimum parking spaces that are electric vehicle-ready, or promote renewable energy production (e.g. solar panels, building orientation to maximize solar gain) and storage (e.g. batteries) to support EVs. Some examples include:

- The City of Vancouver has partnered with Project Get Ready to develop a list of actions to support and increase electric vehicle use and has bylaws requiring that 10% of parking stalls in mixed-use/commercial buildings, 20% of parking stalls in apartments/condos and all stalls in houses to be electric vehicle ready (City of Vancouver, 2014);

- The Toronto Green Standard requires that additional parking spaces, above and beyond what is allotted for a particular building, be able to accommodate the future installation of charging stations. The City of Toronto has also run a one-year pilot project to implement on-street electric vehicle charging stations (City of Toronto, 2015);
- The Ministry of Transportation of Quebec is conducting a pilot-project allowing electric vehicles to use the Transit and HOV lane on the highway Robert-Bourassa in Québec City (AVEQ, 2014);
- In Quebec, points for eco-building certifications (e.g. LEED, Novoclimat 2.0) can be earned through developments that are electric vehicle ready (Ecohabilitation, 2015);
- Deployment of a green certification program for more fuel efficient vehicles that provides certificate holders privileged access to special parking spaces or even roads and areas that may be more congested[31].

## Pros and Cons

Benefits of adopting more efficient light-duty vehicle propulsion technologies include:

- More efficient vehicle propulsion technologies can help achieve substantial reductions in fuel consumption and GHG emissions;
- Substituting fossil fuel combustion engines with zero-tailpipe-emission technologies such as EVs and FCEVs can also significantly reduce GHG emissions, especially in jurisdictions with low or no fossil fuel-based electricity generation;
- Economic benefits include fuel savings and reduced operating costs for vehicle operators. There are also potential impacts that are not quantified and monetized, including the health and environmental impacts associated with changes in ambient exposures to toxic air pollutants and ozone, and the benefits associated with avoided non-$CO_2$ GHGs (methane, nitrous oxide, HFCs).

Disadvantages of adopting more efficient light-duty vehicle propulsion technologies include:

- Improved fuel economy and decreased operational costs may encourage the purchase of larger vehicles, induce additional vehicle travel and contribute to congestion and urban sprawl;
- The production of hybrid cars, specifically the use of rare earth minerals, lighter aluminum frames and nickel and/or lithium-ion batteries, requires a substantially larger amount of energy to produce, which in turn has negative environmental ramifications (Roos, 2010);
- Some combustion technologies such as direct injection may lead to higher tailpipe emissions of other pollutants such as NOx (Csere, 2010);
- Projects funding and revenues from gasoline taxes may decline due to decreased fuel consumption.

## Impacts

The burning of petroleum fuels in internal combustion engines has resulted in road transportation becoming the largest source of transportation $CO_2$ emissions in many jurisdictions. According to the U.S. Department of Transportation, potential GHG emissions reduction benefits of improved fuel economy

[31] *For further information about the roll-out of a green certification program for vehicles in France, see: http://www.developpement-durable.gouv.fr/IMG/pdf/DP-02-06-2015-Qualite_de_l_air.pdf (in French only).*

per vehicle (compared with the baseline projection for conventional gasoline vehicles) in 2030 and beyond range from 8% to 30% (U.S. Department of Transportation, 2010).

A 2013 report published by the U.S. Department of Energy states that improvements in engine efficiency have the potential to increase passenger vehicle fuel economy by 35% to 50%, while advanced transmission technologies are estimated to reduce fuel consumption by 1% to 9% over traditional transmission technologies depending on the technology and vehicle (NRCan, 2014). These improvements are expected to be even greater when coupled with advanced hybrid-electric powertrains.

WWF-Canada's transportation simulation model estimates that the potential emissions reduction of newly proposed fuel economy regulations on light-duty vehicles would be 17 Mt of $CO_2$-equivalent per year by 2020. WWF-Canada also estimates that electric vehicles will be able to save 7 Mt of $CO_2$-equivalent GHG emissions per year by 2025. As stated previously, the potential for electric vehicles to contribute to GHG emissions reduction goals increases as electricity generation moves to renewable energy, so this number would improve as fossil fuels are phased out of provincial grids. On a per vehicle basis, PHEV's that employed petroleum fuels result in 40-60% less petroleum energy use and a 30-60% reduction in GHG emissions compared to a conventional internal combustion engine vehicle that uses gasoline only (Argonne National Laboratory, 2010).

### Constraints and Barriers to Implementation

- Higher upfront purchase costs for consumers, and perceptions of financial benefits that are realisable in the longer term. Financial subsidies and increased information awareness can help overcome these challenges;
- Research and development costs and technical challenges for automobile manufacturers to bring vehicle fuel efficiency technologies to market (Csere, 2010). Regulation, partnerships, research and development incentives could help to offset some of the challenges for industry;
- Limited consumer vehicle choice for electric vehicles as compared to fossil-fuel based counterparts. As of June 2015, there were 22 different BEV and PHEV models from 12 different manufacturers available in Canada. However, 70% of EVs in Canada are made up of only three models: the Chevrolet Volt, Nissan LEAF and Tesla Model S, which is indicative of the limited attractiveness of the range of available vehicles (Stevens, 2015). Ongoing development by the automobile industry will alleviate this challenge over time;
- Limited range of EV needs to be addressed to help move EVs from a niche market (e.g., for daily commutes) to all-purpose vehicle (e.g., for long distance trips). Industry advancement in developing higher capacity batteries could help to increase vehicle autonomy;
- Improvements to fuel economy of gasoline vehicles means diminished EV benefits – have to drive significant amount for EV purchase to pay back relative to new fuel efficient gas vehicle;
- Lower gas prices (and lack of carbon pricing) resulting in less incentive to switch to EVs;
- Limited number of charging stations, especially outside of urban areas, and incompatible car/charger technology. Charging stations may become more ubiquitous as agencies work to increase deployment (see measures to encourage above). Furthermore, vehicle manufacturers are working towards adopting a common charging standard;
- Very few hydrogen fueling stations;
- Reduced battery performance under cold temperatures in northern climates such as Canada. Industry advancement in battery technology could help reduce cold weather operating constraints over time.

## 6.2 Implement New Transit Vehicle Technologies

| | | |
|---|---|---|
| **Responsibility** | | Vehicle industry, all levels of government, transit agencies, local electrical distribution companies |
| **Applicability** | S, M, L | Technologies are applicable to all fleets irrespective of size of municipality |
| **Cost** | \$\$\$ - \$\$\$\$\$ | Vehicle, transit agencies, all levels of government |
| **GHG Reduction Potential** | 1 | Transit vehicle GHG emissions are a very small % of overall transportation GHG emissions in Canada. Reductions in transit vehicle GHG emissions will therefore make a small contribution to overall GHG emission reductions. |
| **Tech Feasibility** | 2 - 3 | Technology development, and charging/refueling infrastructure deployment required. |
| **Social Acceptability** | 1, 5 | New transit vehicles can decrease nuisances associated with diesel buses such as noise and air pollution, and also integrate measures to enhance passenger comfort. Installation of overhead catenary lines for trolley buses may solicit opposition in areas where no overhead lines are in use. |
| **Application Timeframe** | Immediate, ongoing | Financial incentives, building support infrastructure, vehicle acquisitions can be implemented immediately. |
| **GHG reductions Timeframe** | Medium to long term | While various technologies are now available commercially, emissions reductions would likely only be realized in the medium to long term due to slow turnover of existing transit vehicle fleets. |

### Description

Transit vehicle technologies may be categorized by the two primary forms of transit, bus and rail, and largely include alternative propulsion technologies and methods for storing and transferring energy.

***Bus***

Bus propulsion technologies used to enhance the fuel efficiency of transit buses can be divided into hybrid-electric buses, and zero-emission buses. Hybrid-electric buses, like their light-duty vehicle counterparts, supplement the ICE (e.g. diesel or gas turbine) with an electric motor, which in turn is powered by an energy storage device (e.g. batteries, ultracapacitors or flywheels) as well as energy from regenerative braking systems. The energy required to drive the vehicle may be provided by the ICE, the electric motor or both.

Zero-emission systems include battery electric buses and fuel cell buses. Battery electric buses use an electric motor and store energy in a battery charged by an external source. A variety of charging technologies are available, including fast-charge stations, inductive charging stations and overhead catenary wires. Fast-charge and inductive charging stations may be located along the route, or at the start/end of a route. Fast-charge stations recharge vehicle batteries through a physical connection with the vehicle, while inductive charging stations recharge batteries via an electromagnetic field generated by coils typically buried under the street. Overhead catenary wires can provide continuous power to buses (usually referred to as trolley buses) through catenary poles located on the roof of the trolley bus. The catenary poles may be retracted to allow the bus to operate off the grid for short distances. Fuel cell electric buses use compressed hydrogen to generate electricity to power the bus.

Other alternative propulsion technologies which may be used in buses to reduce emissions compared to conventional diesel fuel buses include compressed natural gas (CNG), liquefied natural gas (LNG), liquefied petroleum gas (LPG), and biodiesels mixed with conventional fuels.

Diesel buses may be retrofitted with emission reduction measures such as the replacement of traditional mechanically-driven hydraulic cooling systems with electronically-driven systems. In these systems, electric fans are used to cool the charged air and engine coolant, which helps to increase fuel efficiency for stop-start conditions. Intelligent transmission systems may be used to optimize gear shifting to account for driving conditions and reduce fuel consumption. Lighter materials may also be used to reduce the weight of the vehicle and improve fuel efficiency, including ultra-high strength stainless steel and composites (e.g. carbon fiber) in vehicle bodies and chassis.

***Rail***

In jurisdictions where the electrical supply is less fossil-fuel intensive, the electrification of rail system represents a means to reducing diesel emissions. Regenerative braking is another key technology that may be used to reduce energy consumption and emissions. On-board energy storage systems store braking energy within the vehicle, which can then be reused for acceleration. In electrified rail systems, brake energy can also be distributed back into the grid, or be captured in wayside energy storage systems. Wayside energy storage systems may also be used to capture energy from multiple trains decelerating into a station, and transferring it back to outgoing trains. To maximize the efficiency of wayside energy storage systems, smart grid technologies and specialized software are also employed to control the capture and release of electricity.

Existing locomotives may be retrofitted to reduce fuel consumption and emissions. Retrofits include more efficient fuel injectors and after-cooler equipment, anti-idling devices, and automatic engine stop-start units that operate when the locomotive is stationary.

Measures can also be taken to reduce thermal losses and power consumption. These include features such as electrically heated windshields, triple-pane side windows with low solar transmittance, and improved vehicle insulation, lighter weight materials and energy efficient LED lighting.

Further information about transit vehicle technologies can be found in:

- US Federal Transit Administration (2012)
- Transportation Research Board (2010)

## Measures to Encourage

### Federal and Provincial Levels

***Provide financial support for vehicle demonstration, testing or acquisition***

Diesel retrofits and zero-emission bus technologies are likely to incur a total cost of ownership premium over conventional diesel buses due a range of factors including alternative fuel production and distribution, technology development, and operational adjustments (e.g. space for infrastructure, training staff) (McKinsey and Company, 2012). Providing financial support to transit agencies, especially to early adopters, can help to defray the costs of technology demonstration, testing and acquisition and accelerate adoption. In Canada, several federal initiatives exist for encouraging investment in more sustainable infrastructure, including transit, such as the Building Canada Fund[32], Annual Gas Tax Fund[33], and Canada Strategic Infrastructure Fund[34]. Although these programs are not explicitly targeted at encouraging alternative transit vehicle technologies, they have been used by municipalities for such projects. For example, Halifax Metro Transit purchased a fleet of 22 environmentally friendly buses with support from the Gas Tax Fund.

### Municipal Level

***Adopt vehicle procurement policies, test and evaluate feasibility of new vehicle technologies***

Municipal transit agencies can adopt new procurement or fleet conversion policies in order to facilitate the uptake of low- or zero-emission vehicles. In many cases, municipal transit agencies have fully or in part relied on federal or provincial funding sources in order to implement these programs. For example:

- The Montreal Transit Corporation's (STM) Strategic Plan 2020[35] commits to procuring only hybrid or electric vehicles. Their ultimate goal is to procure only fully-electric vehicles as of 2025, while from 2013 all new standard buses are diesel-electric hybrids;
- Calgary Transit plans to build a new garage facility for up to 400 CNG-powered buses by 2019[36]. The City of Calgary entered into a funding agreement with the federal government through PPP Canada for the proposed garage;
- Other municipal transit agencies have implemented programs to procure hybrid-electric buses across Canada, ranging from the largest cities (e.g. Toronto, Edmonton, Vancouver) to medium-sized cities (e.g. Halifax, London, Saskatoon) and smaller cities (e.g. Windsor, St. Catharines).

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[32] *www.infrastructure.gc.ca/plan/nbcf-nfcc-eng.html*

[33] *www.infrastructure.gc.ca/plan/gtf-fte-eng.html*

[34] *www.infrastructure.gc.ca/prog/csif-fcis-eng.html*

[35] *www.stm.info/en/about/financial_and_corporate_information/strategic-plan-2020*

[36] *www.calgary.ca/Transportation/TI/Pages/Transit-projects/Stoney-CNG-Transit-Bus-Garage.aspx?redirect=/stoneybusgarage*

***Adopt policies and programs to retrofit existing vehicles***

Retrofitting existing vehicles may be a means to achieve some reductions in fuel, pollutant and GHG emissions in the short term while maximizing the useful life of existing fleets and investments. Further evaluation of the costs and benefits of retrofits versus vehicle replacement would be required.

## Pros and Cons

Benefits include:

- Alternative propulsion systems including electric drive technologies may result in significant improvements in fuel consumption and GHG emission reductions, especially in jurisdictions with low fossil-fuel dependent electricity production;
- Retrofit technologies can be installed on existing buses and as such have a high applicability to a wide range of transit operations; they are relatively inexpensive in comparison to alternative propulsion technologies;
- Hybrid and zero-emissions systems can lead to improved air quality and lower noise pollution (e.g. from electric motors).

Disadvantages include:

- The use of some alternative fuel technologies in buses may require changes to existing vehicle maintenance and handling procedures;
- The supply of alternative fuels may be uncertain for transit operators and their affordability may change on a frequent basis (e.g. monthly);
- The efficiency of hybrid-electric and electric systems will depend on route conditions (e.g. number of start-stops, elevation changes, weather conditions).

## Impacts

The contribution of transit vehicles to overall transportation GHG emissions was only about 3 % in Canada in 2012. Potential impacts of transit vehicle technologies in reducing transit fleet contributions to overall GHG emissions will be small.

A study by the California Energy Commission in 2007 ranked the life-cycle GHG emission reduction potential for a range of bus propulsion technologies, with battery electric systems having the greatest potential (California Energy Commission, 2007):

- Biodiesel (B20) – 12%
- LNG – 16%
- Methanol – 18%
- Hybrid Electric Vehicle – 20%
- CNG – 23%
- Fuel Cell – 24%
- Electric – 55%

Similarly, a study by McKinsey and Company (2012) entitled *Urban Buses: Alternative Powertrains for Europe* evaluated hybrid and zero-emission bus technologies against a range of performance and cost criteria. Authors found that diesel-hybrids were a viable, short term bridging technology to zero-emission technologies, as they are able to achieve up to 20% reduction in lifecycle GHG emissions compared with a conventional diesel bus while maintaining the same route and operational flexibility without the need for any new infrastructure. Fuel cell buses can achieve more significant GHG emissions reductions and have the same operational flexibility as conventional buses, but require hydrogen charging infrastructure and supply to be established. Battery electric buses and trolley buses can also achieve significant GHG emissions reductions, especially where grid energy production is less fossil-fuel intensive, but are confined to the location and coverage of charging infrastructure. The same study projects that the cost[37] of GHG abatement for these technologies by 2030 would be approximately:

- \$0.13 – \$0.65/kg $CO_2e$ - diesel-electric buses
- \$0.26 to \$1.30/kg $CO_2e$ – battery electric buses
- \$0.65 – \$0.91/kg $CO_2e$ – fuel cell buses
- \$0.78/kg $CO_2e$ – CNG buses
- \$0.91/kg $CO_2e$ – trolley buses

From 2008 to 2009, Gatineau and Montreal transit agencies completed testing of hybrid-electric bus technologies through Transport Canada's Urban Transportation Showcase Program. In Gatineau, hybrid-electric buses were tested on two urban routes and operated at an average speed of 25 km/h. Fuel and GHG reductions were 12 % compared to a standard 12 m diesel bus, or 15 t $CO_2e$ per year for a bus running 70,000 km annually. In Montreal, average bus operating speeds were 18 km/h, and fuel and GHG emissions reductions were higher at 30% compared to standard diesel bus, resulting in nearly 36 t $CO_2e$ per year for a bus running 70,000 km annually (STO, 2009).

Between 2010 and 2014, BC Transit operated a fleet of 20 fuel cell electric buses in the Resort Municipality of Whistler. The fleet accumulated more than 4 million km of revenue service and avoided more than 6,000 tonnes of GHG emissions at the point of use with no other local air emissions.

The use of lightweight materials for buses may reduce fuel consumption by one-tenth of a gallon per mile (Transportation Research Board, 2010). Electric cooling systems retrofitted to diesel buses have been shown to increase fuel economy by 3-10%, and is a less expensive alternative (Federal Transit Administration, 2012).

With respect to rail, wayside energy storage systems may reduce energy consumption by up to 30% (Federal Transit Administration, 2012).

### Constraints and Barriers to Implementation

- There is currently a total cost of ownership premium for hybrid and zero-emission bus technologies (McKinsey and Company, 2012; Transportation Research Board, 2010) compared to conventional diesel buses. Battery electric and fuel cell vehicles are currently estimated to be close to double the total cost of ownership over conventional diesel buses, but total cost of ownership is expected to reach parity in the 2030s due to factors such as technological improvements and potential increases in the price of fossil fuels. (McKinsey and Company, 2012; NREL, 2014). On the other hand, diesel-electric buses currently have a total cost of ownership price premium between 5 - 15%, but are less effective than the zero-emission technologies in reducing GHG emissions;

[37] *Calculated at an exchange rate of approximately CAD 1.3 = EUR 1, in 2012 when the study was completed.*

- Fuel cell electric vehicle technology is at a pre-commercial technology demonstration / commissioning phase (NREL, 2014), but the lack of hydrogen refueling infrastructure remains a barrier to wider adoption of this technology;
- Electrical charging infrastructure for battery electric, overhead catenary infrastructure for trolley bus and electric locomotives, or wayside electrical energy storage solutions are capital intensive (Transportation Research Board, 2010; Mui, 2014);
- Public may be opposed to installation of overhead catenary lines for buses where they are not present;
- Staff capacity and training to procure, operate and maintain new vehicle technologies (Transportation Research Board, 2010).

## 6.3 Encourage New Heavy-Duty Vehicle Technologies

| | | |
|---|---|---|
| **Responsibility** | | Trucking Industry, all levels of government. |
| **Applicability** | S, M, L | Trucking measures are appropriate for all sizes of municipalities. |
| **Cost** | $$$ - $$$$$ | Trucking Industry, federal and provincial governments. |
| **GHG Reduction Potential** | 4 - 5 | Widespread adoption of efficient heavy-duty vehicle technologies may contribute to significant GHG emissions reductions. |
| **Tech Feasibility** | 1 – 3 | Technology development. |
| **Social Acceptability** | 3 – 4 | Generally little impact to end users, but technology adoption costs may translate into higher costs to consumers if payback does not occur within the expected timeframe. |
| **Application Timeframe** | Immediate, ongoing | Financial incentives, building support infrastructure, vehicle acquisitions can be implemented immediately. |
| **GHG reductions Timeframe** | Medium to long term | Emissions reductions would likely only be realized in the medium to long term due to slow turnover of existing vehicle fleets. |

### Description

Heavy-duty vehicle technologies can be broadly categorized into physical technologies and information and communication (ICT) technologies.

***Physical Technologies***

While diesel engines have become an industry standard for heavy-duty vehicles and are already considered efficient in comparison to gasoline engines, improvements in engine technology such as increased cylinder pressure and adjusted shift points for automatic transmissions may contribute to further increasing diesel engine efficiency. Changing from a traditional 6x4 to a 6x2 axle configuration may also increase efficiency as less power is required to drive two wheels. Exhaust emissions may be reduced through improved fuel injection technologies, new combustion modes such as low-temperature combustion (LTC), improved air handling and exhaust gas recirculation, and the use of catalyst-based diesel particle filters (DPFs).

Speed limiters are widely used to regulate speed and therefore fuel consumption. In addition, adaptive cruise control devices which employ a radar or laser sensor may enhance traditional cruise control by adjusting speed to maintain a safe distance from traffic. Predictive cruise control devices build on this technology by employing a global positioning system (GPS) receiver to download topography data and regulate speeds on a gradient.

Idle-Reduction (IR) technologies may include diesel or electric auxiliary power units (APUs) which replace the need to idle engines to cool or heat the cabin, a common practice in the trucking industry. Other devices may include direct-fired heaters which warm the engine block and provide cabin heat. Electrified parking spaces (EPS) or “shorepower” may also be used at truck stops to provide power to heating or cooling systems without idling. EPS are generally owned and maintained by private companies and are currently prevalent across the US, particularly in Texas.

External vehicle technologies may be factory-manufactured or retrofitted to heavy-duty vehicles. Roof fairings (an air deflector mounted on top of the cab), gap reducers, side skirts and trailer boat tails all seek to reduce aerodynamic drag by creating a more streamlined shape and reducing air flow underneath the truck and between the truck and trailer. Aerodynamic mirrors, cameras in place of mirrors, and bumpers also serve to streamline air flow around the truck and reduce air flow beneath it. Tire rolling resistance is another area where efficiencies may be achieved. Automatic tire inflation systems monitor and continually optimize tire pressure, while low rolling resistance tires reduce friction created with the road and therefore minimize wasted energy.

Liquefied natural gas (LNG) and compressed natural gas (CNG) options as also available as an alternative to diesel fuel for heavy-duty vehicle propulsion. Although natural gas propulsion technologies are continually undergoing development and refinement, natural gas refueling station technology as well as medium and heavy-duty vehicle technologies are already available, mature, reliable, economical and performance competitive with conventional fuelled vehicles (Natural Gas Use in Transportation Roundtable, 2010). Natural gas use emits between 20 % – 30 % fewer GHG emissions on a lifecycle basis compared with diesel fuel (Natural Gas Use in Transportation Roundtable, 2010). In Canada, refueling infrastructure for natural gas fuel sources is already available, although more limited than their diesel fuel counterpart. The Route Bleu network is the first natural gas refuelling network of public and private stations in Canada. They are currently only found in Quebec and Ontario, especially along Highway 401 and Highway 20, two of the busiest truck corridors on the east side of the country. CNG is also being deployed in municipalities for refuse collection vehicles (Natural Gas Use in Transportation Roundtable, 2010).

While hybrid electric vehicle (HEV) technology is familiar in the context of light-duty vehicles, there are fewer hybrid diesel-electric heavy-duty vehicles on the market to date. Ongoing research and development is moving towards increasing the effectiveness and feasibility of these technologies for heavy-duty vehicles. HEV technology may use an internal combustion engine and rechargeable energy storage system such as a battery. In 'stop-start' hybrid systems, which could be effective for heavy-duty vehicle movements in urban locations, hydraulic energy is stored from braking and supplemented with engine power when needed.

***ICT Technologies***

ICT technologies, including Intelligent Transport Systems (ITS), include devices to optimize route planning, provide dynamic traffic information and mobile communications, and track driver movements. ICT technologies may employ an on-board GPS unit linked to a central data system. This device can alert the driver to potential traffic delays, therefore allowing for live route optimization to reduce fuel consumption. Data from the GPS unit may also be analyzed by the operating company to assess driver behaviour, vehicle performance, and efficiency of other emission reduction technologies, therefore allowing operators to constantly optimize their logistics management.

## Measures to Encourage

**Federal and Provincial Level**

***Adopt regulations to control and reduce GHG emissions from medium and heavy-duty vehicles***

The majority of measures to encourage the uptake of these technologies have been established at the federal level and are largely driven by emissions standards and regulations for the heavy-duty trucking industry. In Canada, the Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations (Environment Canada, 2013) seek to reduce $CO_2$ emissions by 6-23% for a range of 2014-2018 model year vehicles based on the 2010 model year baseline. To help achieve these targets, special provisions and crediting options are available to vehicle and engine manufacturers and importers, such as advanced technology and innovation credits for hybrid, all-electric or fuel cell vehicles. The administrative burden placed on manufacturers and importers has also been reduced by Environment Canada by adopting a streamlined reporting procedure, while the program is designed to align with the US Environmental Protection Agency (EPA) program to allow for better coordination.

***Facilitate technology development and adoption through research, demonstration, awareness and financial support***

Government agencies can facilitate the adoption of new heavy-duty vehicle technologies through programs to fund or undertake research and demonstration projects, increase awareness, and provide financial support to trucking manufacturers and operators. Several examples of such a program include:

- The US SmartWay program was established in 2004 and is widely considered to be a leading example of a federal government-led initiative to encourage improved environmental performance in the heavy-duty trucking industry. It is a public-private initiative between the US EPA, trucking and logistics companies, and federal and state agencies. Notably, the SmartWay Technology Program seeks to evaluate and verify the performance of new emission reduction technologies through grants, cooperative agreements and demonstration projects (United States Environmental Protection Agency, 2014);

- Natural Resources Canada (NRCan) established its own program in 2012 called FleetSmart. Similar to SmartWay, FleetSmart seeks to provide freight operators with best-practice information on a range of issues including emissions reduction. Specifically, FleetSmart has developed publications and toolkits to encourage the uptake of measures such as aerodynamics and IR technologies, including its Idle-Free Destination Program to reduce heavy-duty truck idling at international borders;
- The Quebec Government established the Eco-trucking ("Ecocamionnage") program to support the reduction of GHGs for goods transport[38]. Running from 2014 – 2017, the program provides financial support for the truck manufacturing or transportation industries for acquiring new and proven technologies that reduce GHG emissions, funding technology demonstration and testing, or improving logistics operations to reduce fuel consumption and GHG emissions. It also provides incentives to the industry for the acquisition of heavy-duty vehicles using alternative propulsions systems such as hybrid technology, or liquid or compressed natural gas[39].

**Provincial and Municipal Level**

***Integrate heavy-duty vehicle technology within government vehicle fleets***

Government agencies can enhance the environmental and financial performance of their heavy-duty vehicles fleets and demonstrate leadership by procuring new vehicles or retrofitting existing vehicles incorporating fuel efficiency and GHG reduction technologies. For example:

- The Quebec Ministry of Transportation is testing and adopting a host of heavy-duty vehicle technologies including IR, LED lighting, engine power attenuators and advanced transmissions systems across its fleet of over 1700 light and heavy-duty vehicles;
- Within the Greater Toronto Area (GTA), IR technologies have been employed in municipal heavy-duty vehicles by the Cities of Burlington, Hamilton, Markham, Oshawa and Toronto, Town of Richmond Hill, and Peel Region.
- The City of Edmonton operates its own Fuel Sense program, which among other measures to reduce fleet emissions includes the testing of IR technologies;
- The City of Winnipeg has trialled the use APU technology on water and waste vehicles and found that it could save up to 85% of the fuel used during a period of idling (FCM, 2010).

***Encourage municipal service fleets to adopt fuel-saving technologies***

Municipal fleets for garbage and recycling collection are often subcontracted to private service providers. Municipalities can encourage the adoption of heavy-duty vehicle technologies by increasing awareness of technology options among their service providers, and integrating technology or fuel efficiency based performance clauses into service procurement contracts.

## Pros and Cons

Benefits include:

- Technologies are increasingly factory-installed but may also be retrofitted to vehicles and provide flexibility to suit specific needs;
- Technologies may contribute to lower fuel consumption and reduced GHG emissions;

[38] *The program does not support vehicles that transport passengers.*

[39] *More information about the program can be obtained at www.mtq.gouv.qc.ca/usagers/vehiculelourd/Pages/programme-aide-ecocamionnage.aspx*

- Technologies can lower fuel and operating costs, time savings for truck operators;
- Reducing emissions can contribute to improved air quality and human health;
- Certain technologies such as speed limiters and enhanced cruise control devices may help to increase road safety.

Disadvantages include:

- Advanced materials and processing techniques involved in some technologies may result in an expensive cost to the end user. The heavy-duty trucking industry has traditionally operated on narrow margins and seeks a relatively quick return on investment;
- The effectiveness of these technologies also relies on the continuous training of drivers to ensure their correct use in accordance with best-practice driving behaviours.

## Impacts

Road transportation accounts for 19% of Canada's total GHG emissions and is the single largest contributing factor. Of this, 29% (roughly 5.5% of the national total) is attributable to heavy-duty diesel trucks (WWF, 2012).

***Physical Technologies***

Several recent studies have explored the ability of heavy-duty vehicle technology options in reducing fuel consumption. They found that individually, powertrain (e.g. engine and transmission) technologies can lead to 5 to 50 % decreases in fuel consumption, while vehicle technologies (e.g. aerodynamics, IR, ICT, rolling resistance tires, etc.) contributed between 0 and 15 % reductions in fuel consumption (NAP, 2010; PIT, 2012; Office of Energy Efficiency, 2011; EPA, 2010; Woodrooffe, 2014). However, potential fuel economies are highly dependent on vehicle type and duty cycle (e.g. start-stop, steady state, load variation, etc.) (NAP, 2010). Measures such as engine and transmission efficiency worked equally well across a range of vehicle types and duty cycles, hybrid drive and support systems are more effective for vehicles which undertake stop-and-go driving, and aerodynamic measures and low-rolling resistance tires are more effective for long haul vehicles (NAP, 2010).

The cost of adoption of new vehicle technologies has been cited as a barrier to uptake. However, some studies indicate that the payback period for heavy-duty truck technology, especially aerodynamic drag reduction measures for tractor-trailer vehicles, have a payback period between one and three years (Surcel, Michaelsen, & Provencher, 2008; Surcel, Provencher, & Michaelsen, 2009; NAP, 2010).

Speed limiting devices and adaptive or predictive cruise control may have a significant impact in reducing emissions. It is estimated that fuel efficiency decreases by 0.1mpg for every 1mph increase above 55mph (~89km/h), with a speed reduction from 68mph (~109km/h) to 63mph (~101km/h) leading to a 9% increase in efficiency (North American Council for Freight Efficiency, 2011). Bringing the average highway speed of heavy-duty vehicles in the US down from 75mph (~121km/h) to 65mph (~105km/h) would save over 30 million tons of $CO_2$ emissions over the next decade (American Trucking Association, 2008).

Each year it is estimated that truck and locomotive engines at rest in the U.S. consume more than one billion gallons of diesel (about 264 million litres) and emit 11 million tons of $CO_2$ and 5000 tons of particulate matter (United States Environmental Protection Agency, 2014). The factory installation or retrofitting of IR devices is estimated to reduce emissions by a magnitude of 5-9% (Carbon War Room, 2012).

Current truck HEV technology may be able to reduce fuel consumption and GHG emissions anywhere from 5 to 50 %, depending on the vehicle type and duty cycle (21st Century Truck Partnership, 2006; NAP, 2010; PIT, 2012).

***ICT Technologies***

It is estimated that the optimization of logistics through the use of Intelligent Transport Systems applications could result in an 8% to 16% reduction in emissions by 2020 (SE Consult, 2009; NAP, 2010). Further, if an additional 10% of Class 8 long-haul fleets in the U.S. increased their efficiency by just 1% through GPS routing, the sector would save over 20 million tons of $CO_2$ emissions in ten years (Carbon War Room, 2012).

Overall, and using the United States as a case study, the aggressive implementation of five types of physical technologies across the Class 8 truck fleet could reduce $CO_2$ emissions by up to 404 million tons over ten years. If a further two ICT-based technologies were also aggressively pursued, it is estimated that a further 185 million tons of $CO_2$ could be reduced over the same period. This would see annual emissions from heavy-duty trucks fall to 10% below current levels, while the sector would still experience a 2% growth rate. Based on the business as usual case, the sector will continue to experience strong annual growth, but this will be in the context of a 29% increase in $CO_2$ emissions by 2021 (Carbon War Room, 2012).

**Constraints and Barriers to Implementation**

- While the cost, durability and reliability issues are have largely been worked out for some systems (e.g. low rolling resistance tires, aerodynamic measures), they require further research and development for others (e.g. engine, transmission);
- Low level of awareness among vehicle owners and operators about the business case for vehicle efficiency investments (Aarnink, Faber, & den Boer, 2012; Ricardo-AEA, 2012);
- Split incentives: Truck owners typically pay for a technological upgrade but do not necessarily pay for fuel costs. Therefore, they may not see the benefits from the investment (Carbon War Room, 2012);
- For heavy trucks, the owner of the truck and trailer may not be the same, and so the benefits of technological upgrades made to each component may not be realized by both parties. Upgrades to trucks and trailers may also not be entirely compatible with one another (e.g. roof fairings and gap closers between truck and trailer).
- Barriers to uptake of natural gas powered vehicles include uncertainty regarding fuel availability and pricing, vehicle availability, unfamiliarity with the technology, and perceptions and attitudes about risk, reliability and adequately short payback periods. Consultations of transportation industry stakeholders concluded that significant information diffusion about natural gas technology to vehicle end-users, among other things, was required to overcome these challenges (Natural Gas Use in Transportation Roundtable, 2010).

## 6.4 Use Low Carbon Fuels

| | | |
|---|---|---|
| **Responsibility** | | Federal and provincial governments responsible for regulating use of low carbon fuels. |
| **Applicability** | S, M, L | Appropriate for all sizes of municipalities. |
| **Cost** | $$$ - $$$$$ | Costs largely born by fuel production and distribution industry, vehicle manufacturing industry. |
| **GHG Reduction Potential** | 2 | Small percentages of biofuels are already blended into conventional fuels in many jurisdictions in North America, but the ability of biofuels to replace a significant portion of conventional fuels is unlikely due to fuel feedstock requirements. |
| **Tech Feasibility** | 1 | Large scale agriculture-based biofuel production may not be possible, while use of non-edible feedstock for biofuel requires further development. |
| **Social Acceptability** | 3 | Competition for feedstocks between biofuel and food production. |
| **Application Timeframe** | Immediate, ongoing | Pursuing low carbon fuels as a means to reduce transportation GHG emissions is already an ongoing activity, although greater penetration will need 10-20 years as the current fleet is renewed, and as infrastructure / availability comes online. |
| **GHG reductions Timeframe** | Short term | Biofuel use immediately reduces fossil-based petroleum fuels, although land use impacts of biofuel production may result in loss of natural land and biodiversity over the medium to long term. |

### Description

This section describes the use of low carbon fuels as a means to reduce GHG emissions. The regulation of fuel content is a federal and provincial jurisdiction. Thus, this section provides complementary information to the toolbox of measures, but does not prescribe any role for local and regional governments.

The concept of low carbon fuel can be broadly categorized into two categories: implementation of a low carbon fuel standard (LCFS) and the use of biofuels. Biofuels are often used by producers subject to LCFS regulations as a means of developing low carbon fuel products, but they are also used in jurisdictions not subject to a LCFS.

***Low Carbon Fuel Standard***

A low carbon fuel standard (LCFS) is a policy instrument designed to reduce GHG emissions by reducing the carbon intensity of transportation fuels and emissions on a life-cycle basis. A LCFS seeks to encourage improvements in fuel production and refining efficiency while at the same time promoting a broader range of fuel alternatives and innovation in vehicle technology. A LCFS is generally designed as a performance-based standard using flexible market-based mechanisms that allow fuel producers to select the most cost-effective methods of achieving compliance. Producers generate LCFS credits when their fuels have a lower carbon intensity than conventional gasoline or diesel. Those who are not able to meet prescribed fuel carbon intensity limits will receive LCFS debits equal to the difference between their products and the prescribed limits. Fuel producers have the option of producing or blending low carbon fuels, or purchasing credits from other fuel producers, including biofuel producers, natural gas infrastructure providers, electric utilities and hydrogen producers. At the end of each compliance period, fuel producers need to ensure that they have at least as many credits as debits, otherwise they will be subject to penalties.

California was one of the first jurisdictions in North America to implement a LCFS in 2007. California's LCFS required producers of petroleum-based fuels to reduce the carbon intensity of their products, beginning with a 0.25% reduction in 2011 and peaking with a 10% total reduction by 2020. Suppliers can either develop their own low carbon fuel products or purchase credits from other companies that develop and sell low carbon alternative fuels, such as biofuels, electricity, natural gas or hydrogen.

British Columbia (BC) implemented its own LCFS in 2008 with the introduction of the *Greenhouse Gas Reduction (Renewable and Low Carbon Fuel Requirements) Act* (the Act) and the *Renewable and Low Carbon Fuel Requirements Regulation* (the Regulation). The Act sets requirements for renewable content in gasoline and diesel fuels used for transportation and heating, and requires fuel suppliers to reduce the carbon intensity of their products. Through these policies, BC has committed to reducing transportation life-cycle emissions by 10% by 2020, which will help support the province's larger target of reducing GHG emissions from transportation by at least 33% below 2007 levels by 2020.

***Biofuels***

Biofuels are derived from biomass that is commonly produced from plants, animals, micro-organisms and organic waste. The key distinction between fossil fuels and biofuels is that biofuels use recently living biomass, whereas fossil fuels use ancient biomass that has been chemically altered to its current state. The two main types of biofuels used in the transportation sector are ethanol and biodiesel. Emerging technologies like algae based biofuel production are also currently being explored.

Ethanol production involves the fermentation of starchy, sugar-filled food, such as corn, grains and potatoes, to create alcohol. A blend of 10% ethanol and 90% gasoline is known as E10. E10 Unleaded is the most common blend of ethanol and gasoline and is approved for use by every major vehicle manufacturer. E85, a ratio of 85% ethanol and 15% gasoline is a type of alternative fuel that can only be used in flexible fuel vehicles (FFVs), which are designed to run on gasoline, E85, or any combination of the two. The use of ethanol-diesel fuel blends is also growing around the world and is designed to provide cleaner burning fuel for off-road equipment, buses, semi-trucks and other vehicles that run on diesel fuel.

Biodiesel is a non-toxic, biodegradable, and renewable fuel that is converted from oils such as canola and soy-based oils, animal fats, recycled cooking oils and restaurant waste grease[40]. Biodiesel used in its pure form is called B100 and can be used in place of conventional diesel. Biodiesel can also be blended with conventional diesel (B2, B5 or B20) and used in most engines that run on diesel.

In Canada, regulations are already in place mandating minimum biofuel content in fuel supplies. Canada's *Renewable Fuels Regulations*, which became effective in September 2010, seeks to reduce GHG emissions by mandating an average of 5% renewable fuel content based on gasoline volume. Since 2002, British Columbia, Alberta, Saskatchewan, Manitoba and Ontario have all enacted active regulations requiring that a minimum percentage of biofuels (primarily ethanol) be blended into conventional fossil fuels used in transportation.

## Measures to Encourage

Incentives can be offered for the continued development of biofuel production and use by vehicle engines. One example of a federal program in place supporting the development of biofuels in Canada is the ecoENERGY for Biofuels Program, which offers incentives to producers of biofuels based on production levels. Incentives start $0.10/L for renewable alternatives to gasoline and $0.26/L for renewable alternatives to diesel. While recipients can receive funds for up to seven consecutive years, the incentive rates decline over the life of the program. Another federal program that was in place was the NextGen Biofuels Fund, which supported the establishment of large demonstration-scale renewable fuel production facilities[41] and funded up to 40% of project costs, to a maximum of $200 million over six years. The NextGen Biofuels Fund is now closed for new applications.

## Pros and Cons

Benefits include:

- A LCFS is a holistic, performance based approach that allows fuel producers to consider a range of options to achieve overall lower carbon fuel content;
- More than 50% of the gasoline that is available in the United States contains at least 10% ethanol, and in Canada, there are a large number of service stations where E10 fuels can already be purchased.

Disadvantages include:

- Market variables, including uncertainties in feedstock availability and costs, carbon intensity values of alternative fuels, the need for investment in alternative fueling infrastructure and consumer preferences, can impact the effectiveness of the LCFS in achieving emissions reductions;
- LCFS's fail to take into account the possibility that fuel producers can shuffle sales and production between markets that do and do not have LCFS's, something that can only be addressed if all jurisdictions have similar standards;
- The demand for crops like corn and canola for biofuel production puts pressure on the food production sector and creates a risk for competition between food and fuel.

[40] *Biodiesel is produced through a process called transesterification, in which the oil is brought into contact with an alcohol (such as methanol) and a catalyst (such as sodium hydroxide)*

[41] *https://www.sdtc.ca/en/funding/funds/nextgen*

- Land for biofuel production is expected to come from the conversion of forests into agricultural land, which would have detrimental effects on animal habitats, biodiversity, the hydrological cycle, and the ability of forests to absorb carbon dioxide;
- E85 has a lower energy content than conventional fuel equivalent to about 25-30% fewer miles per gallon (U.S. Department of Energy, 2011);
- Ethanol is not compatible with existing pipeline infrastructure used to transport crude oil produces and natural gas because of its tendency to absorb water[42];
- Lower performance of ethanol blends under winter climate conditions. Maximum Ethanol blend is reduced to E75 or lower for cold temperatures, as higher concentrations can become difficult to ignite (Royal Society, 2008). Similarly only low biodiesel blends are recommended for winter driving, since the fuel forms crystals more readily than petroleum diesel[43].

## Impacts

### *LCFS*

UC Davis Institute of Transportation Studies (UC Davis ITS, 2014) analysis states that the carbon emissions reduction in the first two and a half years of California's LCFS is equal to taking 500,000 vehicles off the road. Other studies have shown that from 2011 through 2013, California expanded the use of low-carbon alternative fuels (including non-biofuels) by 0.22 billion gasoline gallon equivalents (GGE)/year, and reduced total carbon emissions by 6.4 million MT $CO_2$e, which is equal to taking close to a million cars off the road for a year (LCFS Status Review, July 2014).

The *Renewable and Low Carbon Fuel Requirements Regulation* in British Columbia is said to have increased alternative fuel consumption to 4.5% of total transportation fuel consumption (in units of energy), decreased the average carbon intensity of transportation fuels by approximately 3.5% and saved 905 kt/yr in GHG emissions in 2012 (Navius Research, 2014). This was estimated to be equivalent to 190,499 cars being removed from the road according to the provincial government (Globe and Mail, 2014).

### *Biofuels*

Canada's *Renewable Fuels Regulations* are estimated to have resulted in an incremental reduction of GHG emissions of about 1 MT $CO_2$e per year over and above the reductions attributable to existing provincial requirements already in place.

However, the true impacts of the use and production of biofuels is a controversial subject. For example, a study by Navius Research (2014) stated that substituting a unit of energy from gasoline or diesel with a unit of energy from a biofuel will typically reduce GHG emissions by 30-90% (Navius Research, 2014). However, it has also been claimed that the contribution of different biofuels to reducing fossil-fuel consumption varies widely when the fossil energy used as an input in their production is also taken into account, that different biofuels perform very differently in terms of their contribution to reducing GHG emissions, that GHG balances are not positive for all feedstocks, and that GHG's can also be emitted by direct or indirect land-use changes triggered by increased biofuel production.

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[42] *https://www.nrcan.gc.ca/energy/infrastructure/5897*

[43] *https://www.nrcan.gc.ca/energy/alternative-fuels/fuel-facts/biodiesel/3521*

A similar controversy exists as far as the economic impacts associated with the production of biofuels. For example, some economic models show that biofuel use can result in higher crop prices, though the range of estimates in the literature is wide. For example, a 2013 study found projections for the effect of biofuels on corn prices in 2015 ranging from a 5 to a 53 percent increase (Zhang et al. 2013). The National Research Council's (2011) report on the Renewable Fuel Standard included several studies finding a 20 to 40 percent increase in corn prices from biofuels during 2007 to 2009. An NCEE working paper found a 2 to 3 percent increase in long-run corn prices for each billion gallon increase in corn ethanol production on average across 19 studies (Condon et al. 2013).

**Constraints and Barriers to Implementation**

- Biofuel feedstocks, especially corn for ethanol, require large amounts of land. For example, energy experts state that replacing all fossil fuels with biomass energy would require twice as much farmland than exists on earth (Energy BC, 2012). Consequently, it is highly uncertain that more widespread use of gasoline with high ethanol content, such as E85, would be feasible throughout North America without detrimental impacts on natural forests, food production and food prices;
- While the use of non-edible biomass (i.e. cellulosic biomass) as a feedstock is becoming an appealing alternative for biofuel production to more conventional, edible feedstocks like corn and sugarcane, it is still in the early stages of technological development and the conversion process remains both extensive and costly. Cellulosic biofuel production also uses biomass with relatively low energy densities. Storing and transporting these materials would likely require significant changes to current transportation infrastructure (Richard, 2010);
- Uncertainty with respect to effectiveness of biofuels in reducing GHG emissions. Calculating the total amount of emissions created or avoided in the use of biofuels cannot be done simply by burning the fuel in a test facility, as determining the relative carbon intensity of ethanol and gasoline and/or differences in modelling assumptions of the effect of land use changes can result in sizable differences in emissions estimates for each stage of the full fuel cycle. The result is uncertainty associated with ensuring compliance and the effectiveness of biofuels in actually reducing GHG emissions;
- A LCFS can be administratively complex to implement. In addition to the need for robust compliance and enforcement mechanisms, a LCFS needs to be flexible enough to respond to market dynamics but predictable and consistent in design to minimize uncertainty;
- Canada has a patchwork of provincial and federal biofuel mandates requiring fuel suppliers to include renewable fuel content (primarily ethanol) in gasoline and diesel. This system of fuel mandates results in increased costs for fuel producers as well as distribution inefficiencies that could impact the availability of fuel in any particular market. Harmonization of the provincial and federal mandates would allow suppliers to place renewable fuels in the marketplace at the lowest cost and in the most efficient manner, as each supplier would be able to strategically integrate renewable fuels into their current distribution configuration and geographic orbits.

# 7 – Synthesis and Evaluation of Measures

To help readers identify measures to reduce urban transportation GHG emissions that are suitable to their jurisdiction and area(s) of responsibility, this chapter presents a synthesis of the implementation considerations and performance indicators presented in the previous three chapters. It also provides a comparative evaluation of the GHG reduction potential of measures, as well as their performance relative to costs, technical feasibility and social acceptability of implementation. This synthesis and comparative evaluation provides a starting point to select and adapt measures according to the reader's local context.

Readers can use the information provided in this chapter to:

- Identify a list of measures which are applicable to their jurisdiction based on the size of their municipality and to their area of responsibility (e.g. as a transit agency, municipality, etc.);
- Use comparative analysis based on GHG reduction potential to shortlist measures which are most promising;
- Consider measures based on the trade-offs between GHG reduction potential and costs, technical feasibility and social acceptability tied to implementation.

To facilitate the reading of tables and figures in this chapter, measures are divided into the three complementary transportation GHG reduction approaches, and colour coded according to the legend below.

**Reduce Vehicle Kilometres Travelled**

*Land Use*

*Transportation Supply-Side Alternatives*

*Pricing Mechanisms*

*Parking Mechanisms*

*Trucking*

**Improve Transportation System and Driver Efficiency**

*Infrastructure Based Optimizations and Driver Training*

**Encourage Alternative Fuel and Vehicle Technologies**

*Light-Duty, Transit and Heavy-duty Vehicle Technologies, Low Carbon Fuels*

## 7.1 Summary of Applicability, Responsibility and Timing of Implementation

A summary table on applicability of measures by size of municipality, the agency or agencies best positioned to implement them, and when implementation could begin, is presented in Table 7-1.

### 7.1.1 Responsibility for Implementation

Reducing transportation GHG emissions will require efforts by a wide range of actors. However, as owners and operators of infrastructure and transportation services, municipalities and transit agencies have an important role to play in the majority of the transportation supply side and transportation system optimization measures described in this toolbox. Land use planning, parking controls, transit provision, active transportation, traffic control and roads and transportation system optimizations are key responsibilities of local and regional agencies.

Several measures do however fall outside the jurisdiction of local agencies. Economy wide pricing measures such as carbon taxes and VKT fees, vehicle fuel-economy standards and carbon fuel content are generally the responsibility of provincial and federal governments. Provincial or federal agencies are also responsible for some of the toll pricing and infrastructure measures applicable to provincial highways or bridges within urban areas.

For several measures, the lead responsibility for implementation has typically fallen on non-public sector actors, although public actors may serve as important partners for implementation. For example, taxi-bus transit or carsharing programs are typically operated by private or not-for profit corporations who own and operate the vehicle

## Table 7-1 – Summary of the Applicability, Responsibility and Timing of Implementation

| | Measure | Responsibility for Implementation | Applicability | Timing of Implementation |
|---|---|---|---|---|
| **Reduce Vehicle Kilometres Travelled** | | | | |
| | **Land Use** | | | |
| **1** | Land Use Planning and Smart Growth | Municipalities, Transit Agencies | All | Immediate, ongoing |
| | **Transportation Supply-Side Alternatives** | | | |
| **2a** | Expand Transit Service | Transit Agencies, Municipalities | All | Short |
| **2b** | Enhance Existing Transit Services | Transit Agencies, Municipalities | All | Immediate, ongoing |
| **3** | Provide Taxibus Transit Service | Taxi Operators, Transit Agencies | S | Short |
| **4** | Encourage Active Transportation | Municipalities | All | Immediate |
| **5** | Provide Carsharing Services | Private Operator, Municipalities | M, L | Immediate |
| **6** | Encourage Carpooling | Employers, Local and Regional Agencies | All | Immediate |
| **7** | Encourage Telecommuting | Employers | All | Immediate |
| | **Pricing Mechanisms** | | | |
| **8** | Implement Toll Roads and Cordon/Area Pricing | All Levels of Government | M, L | Short |
| **9** | Implement Distance Travelled Fees | Regional or Provincial Agencies | All | Short to Medium |
| **10** | Charge Distance-based Insurance Costs | Insurance Companies, Provincial Agencies | All | Short to Medium |
| **11** | Implement a Fuel Sales or Carbon Tax | Regional or Provincial Governments | All | Short |
| **12** | Increase Parking Costs | Local Municipality, Private Parking Operators | M, L | Immediate |
| **13** | Offer Fees in Lieu of Travel, Parking | Employers | M, L | Immediate |
| | **Parking Mechanisms** | | | |
| **14** | Optimize the Use of Existing Parking Spaces | Municipalities, Parking Lot Operators | M, L | Immediate, ongoing |
| **15** | Reduce Minimum Parking Requirements | Municipalities | M, L | Immediate, ongoing |
| | **Trucking** | | | |
| **16** | Enhance Logistics Management | Transport Co., Facility Operators | M, L | Immediate, ongoing |

| | Measure | Responsibility for Implementation | Applicability | Timing of Implementation |
|---|---|---|---|---|
| 17 | Encourage Modal Shift for Freight | Private Transportation Co. | Limited | Immediate |
| 18 | Enhance Truck Inspection and Maintenance | Municipalities, Truck Operators | All | Immediate, ongoing |
| **Improve Transportation System and Driver Efficiency** | | | | |
| 19 | Increase Infrastructure Capacity | Local, Regional and Provincial Agencies | All | Short |
| 20 | Manage Roadway Capacity Dynamically | Municipalities, Provincial Transport Agencies | All | Immediate, ongoing |
| 21 | Implement Speed Change Policies | Municipalities, Provincial Transport Agencies | All | Immediate, ongoing |
| 22 | Optimize Traffic Signal Operation and Timing | Municipalities | All | Immediate, ongoing |
| 23 | Implement Ramp Metering | Municipalities, Provincial Transportation | M, L | Immediate |
| 24 | Improve Traffic Incident Management | Municipalities, Response Agencies | All | Immediate, ongoing |
| 25 | Provide Transit Priority Measures | Transit Agencies, Municipalities | All | Immediate, ongoing |
| 26 | Encourage Eco-driving | Government Agencies, Drivers | All | Immediate, ongoing |
| **Encourage Alternative Vehicle and Fuel Technologies** | | | | |
| 27 | Encourage Adoption of Efficient Vehicle Tech. | Industry, Government, Local Electrical Co. | All | Immediate, ongoing |
| 28 | Implement New Transit Vehicle Technologies | Industry, Government, Transit Agencies, Local Electrical co. | All | Immediate for hybrid, Medium for FCV / EV. |
| 29 | Encourage New Heavy-Duty Vehicle Tech. | Trucking Industry, Government | All | Immediate to Medium |
| 30 | Use Low Carbon Fuels | Provincial and Federal Governments | All | Immediate |

fleets. Transit agencies or local municipalities may specify operational requirements through service contracts, and municipalities may facilitate these services through permissive parking regulations on public roads. Commuting

programs, such as carpooling and offering fees in lieu of travel, or parking cash-out, are the responsibility of public and private sector employers. Public agencies can support awareness and coordination or even provide funding for such programs. Enhancing vehicle fuel efficiencies through vehicle technology development has been led by private vehicle industry, although provincial or federal governments typically set the regulations and incentives that drive this development. Municipalities and regional agencies can support the deployment and adoption of advanced vehicle technology by deploying charging infrastructure, allowing access to dedicated travel lanes (e.g. HOV lanes), enacting supportive parking bylaws, and demonstrating leadership through fleet vehicle procurement. Similarly, truck logistics management, modal shift and heavy-duty vehicle efficiency developments have typically been led by the trucking industry, although public agencies have played a supporting role in information diffusion, financial subsidies or regulations.

### 7.1.2 Applicability By Size of Municipality

There are a large number of measures which are suitable for municipalities of all sizes. Land use planning and transportation supply alternatives such as transit, active transportation, carpooling and telecommuting can be applied in any size of municipality, although the extent and intensity of implementation may vary (e.g. geography and level of service). Economy wide pricing measures such as carbon or fuel taxes, VKT fees, or distance based insurance fees, apply irrespective of size of municipality. Most transportation system and vehicle operation efficiency measures can be applied in all sizes of municipalities, although those with greater congestion issues will tend to see greater benefits from these traffic-flow and congestion relief measures (i.e. medium and large municipalities). Finally, more efficient vehicle technologies are universal measures that do not depend on municipal size.

The application of some measures will likely be restricted to medium and large municipalities where population densities, travel demand to specific areas and traffic congestion are greater. For example, carsharing services are likely only to be feasible in areas where a sufficient population base is living in close proximity to vehicles to ensure sufficient use and financial viability of maintaining carsharing vehicles. Toll roads, cordon/area pricing, as well as increased parking costs become viable options to reducing GHG emissions where travel demand and congestion around specific areas, such as downtowns and major employment centres, are high. The implementation of such measures raises travel costs to specific areas and can affect their economic competitiveness. Therefore, travellers must choose to continue travelling over the medium to long term to these areas via other modes, rather than simply choosing to drive elsewhere (e.g. work or shop elsewhere), in order for sustained emission reductions to occur. Furthermore, travel time savings from choosing active transportation or transit is typically only realized where road congestion is present. Finally, ramp metering is typically going to be suitable where urban highways are congested. Thus, such measures are typically more appropriate for medium and large municipalities because of population density, travel demand and congestion issues.

### 7.1.3 Timing of Implementation

Most of the measures described in this toolbox can be implemented by the appropriate agencies in the immediate or short term under the assumption that political will and financial constraints have been addressed (e.g. availability of funding and support from upper levels of government). Generally, there are few overarching knowledge gaps or technical barriers to implementing transportation supportive land use planning, transit, active transportation, carpooling, carsharing, pricing mechanisms, parking and transportation system optimization policies, programs or projects in the immediate or short term. Furthermore, certain measures, such as land use planning, optimizing existing transit services and roadway use, and parking management, require ongoing and sustained implementation over the long term. Site specific planning, design and construction considerations may slow implementation. However, the fact that there are many examples of measures implemented across North America shows that they are “technically-ready” for adoption and integration within policies and plans when the opportunity arises (e.g. at planning review cycles).

Certain measures may not be ready for immediate or short term implementation. Of note, comprehensive or region-wide pricing mechanisms may take a longer timeline for implementation in certain jurisdictions, since they need to be complemented by viable, attractive, alternative transportation options (i.e. mature transit system) in order to produce significant GHG reductions. Otherwise, travellers may continue to drive while also incurring higher travel costs. More sophisticated distance based pricing or insurance schemes based on tracking traveller time of day or area of travel may also not be ready for implementation in the short term, as they still require the development of more sophisticated tracking devices and systems to collect fees.

This is also the case with respect to new vehicle propulsion technologies. Light-duty HEV, PHEV, and BEV models are already commercial available in Canada, although vehicle choice is still limited compared to their fossil-fuel counterparts. Travel distance constraints for BEV, up-front acquisition costs and limited recharging infrastructure are also slowing adoption. The testing and deployment of charging infrastructure has begun in earnest in many cities, although it will still be some time before they become widespread. Fuel cell and fully electric buses (except trolley bus) may enter full commercial operation in the medium term (3 – 10 years), and the fuel or energy support infrastructures are not yet in place widely across North America. Aerodynamic enhancements, low-rolling resistance tires, and natural gas fuel options for heavy-duty trucks have been shown to be effective and commercially viable today, but hybrid-electric propulsion systems for heavy-duty vehicles are still in development and may not be ready for full scale commercial deployment until the medium term.

## 7.2 GHG Reduction Potential and Timeframe of Reductions

### 7.2.1 GHG Reduction Potentials

The potential of measures to reduce overall urban transportation GHG emissions was evaluated qualitatively in this report. Scores were derived based a review of two key works comparing GHG emissions reductions potential from transportation: the Moving Cooler Study, published by the Urban Land Institute in 2009, and the Cost-Effectiveness of BART Actions to Reduce GHG Emissions Study, completed by Nelson\Nygaard Consulting Associates in 2008. Their studies' results were compared against current Canadian transportation modal share and GHG contributions. The details of the analysis are described in **Appendix B**. General findings from this analysis were, presented in order of highest to lowest potential to reduce overall urban transportation GHG emissions:

- Economy wide pricing mechanisms which provide strong pricing signals for changing travel behaviour across a broad range of economic sectors;
- Regional and local pricing mechanisms which provide strong pricing signals, but apply to a more limited number of travellers;
- Light-duty and heavy-duty vehicle technologies that increase vehicle fuel efficiency, or eliminate fossil fuel use altogether;
- Eco-driving strategies to encourage more energy and fuel efficient driving practices;
- Comprehensive transportation-efficient land use planning;
- Employer-based commute strategies that target a large portion of urban travel;
- Transportation supply side alternatives like transit, active transportation, car pooling and car sharing;
- Transportation system improvements to promote smoother traffic flow and reduce causes of congestion; and,
- Measures to reduce freight VKT in urban areas.

The Moving Cooler Study found that all infrastructure capacity expansions, including targeted bottleneck relief, would eventually contribute to a net increase in cumulative GHG emissions. Emissions reductions and smoother traffic flow may result immediately after construction, but induced traffic in the longer term ultimately erases initial reductions in GHG emissions.

A summary table on qualitative scores of 1 (very low) to 5 (very high) assigned to each measure is presented in Table 7-2. When emissions reductions might be expected to occur after implementation is also presented in the same table.

### 7.2.2 Timeframe for Reductions to Occur

Implementing transportation efficient land use patterns may begin to result in some emissions reductions in the short term, but the maximum potential of land use planning is not likely to occur until the long term due to the long time it takes for full build out. Similarly, while encouraging more trips to be made by transit and active transportation can result in immediate reductions in GHG emissions, the full potential of these measures on a region wide scale will likely not be achieved until the medium to long term in conjunction with supportive land use development.

Pricing mechanisms and parking control mechanisms can result in GHG emissions reductions in the short term due to the direct financial impact to drivers. Similarly, transportation system optimizations such as speed control policies, traffic signal and corridor optimization and incident management can improve traffic flow rapidly after implementation. Roadway and intersection capacity expansion can lead to immediate improvements in traffic flow

## Table 7-2 – Summary of GHG Reduction Potential and Timeframe for Reductions

| | Measure | GHG Reduction Potential | GHG Reduction Timeframe |
|---|---|---|---|
| **Reduce Vehicle Kilometres Travelled** | | | |
| | **Land Use** | | |
| **1** | Land Use Planning and Smart Growth | 4 | Long |
| | **Transportation Supply-Side Alternatives** | | |
| **2a** | Expand Transit Service | 3 - 4 | Medium to Long |
| **2b** | Enhance Existing Transit Services | 3 - 4 | Medium to Long |
| **3** | Provide Taxibus Transit Service | 1 | Short |
| **4** | Encourage Active Transportation | 3 | Medium to Long |
| **5** | Provide Carsharing Services | 2 – 3 | Short |
| **6** | Encourage Carpooling | 2 - 3 | Short |
| **7** | Encourage Telecommuting | 2 | Immediate |
| | **Pricing Mechanisms** | | |
| **8** | Implement Toll Roads and Cordon/Area Pricing | 3 | Short |
| **9** | Implement Distance Travelled Fees | 5 | Short |
| **10** | Charge Distance-based Insurance Costs | 3 - 5 | Short |
| **11** | Implement a Fuel Sales or Carbon Tax | 5 | Short |
| **12** | Increase Parking Costs | 2 – 3 | Immediate |
| **13** | Offer Fees in Lieu of Travel, Parking | 2 – 3 | Immediate |
| | **Parking Mechanisms** | | |
| **14** | Optimize the Use of Existing Parking Spaces | 1 – 2 | Immediate |
| **15** | Reduce Minimum Parking Requirements | 1 – 2 | Medium to Long |
| | **Trucking** | | |
| **16** | Enhance Logistics Management | 2 - 3 | Short to Medium |
| **17** | Encourage Modal Shift for Freight | 1 | Short to Medium |
| **18** | Enhance Truck Inspection and Maintenance | 1 - 2 | Short |

| | Measure | GHG Reduction Potential | GHG Reduction Timeframe |
|---|---|---|---|
| **Improve Transportation System and Driver Efficiency** | | | |
| **19** | Increase Infrastructure Capacity | 1 | Short, but Diminish over Long Term |
| **20** | Manage Roadway Capacity Dynamically | 1 – 2 | Short |
| **21** | Implement Speed Change Policies | 3 – 4 | Short |
| **22** | Optimize Traffic Signal Operation and Timing | 2 – 3 | Short |
| **23** | Implement Ramp Metering | 3 – 4 | Short |
| **24** | Improve Traffic Incident Management | 3 – 4 | Short |
| **25** | Provide Transit Priority Measures | 2 | Short |
| **26** | Encourage Eco-driving | 3 - 4 | Short to medium |
| **Encourage Alternative Vehicle and Fuel Technologies** | | | |
| **27** | Encourage Adoption of Efficient Vehicle Tech. | 4 – 5 | Medium to Long |
| **28** | Implement New Transit Vehicle Technologies | 1 | Medium to Long |
| **29** | Encourage New Heavy-Duty Vehicle Tech. | 4 - 5 | Medium to Long |
| **30** | Use Low Carbon Fuels | 2 | Short |

and GHG reduction. However, in the absence of other control measures (e.g. travel pricing, bus priority measures), induced traffic over the long term can negate early reductions in GHG emissions.

The full potential of vehicle propulsion and efficiency technologies are not likely to be achieved before the medium to long term due to the long time required before a significant turnover of light-duty, transit and heavy-duty vehicle fleets occur. Technological readiness and energy distribution or charging infrastructure for these new vehicles are also less mature or widespread than current fossil-fuel based systems, thereby slowing adoption rates and any significant short to medium term GHG reductions.

## 7.3 Cost of Implementation, Technical Feasibility and Social Acceptability

A summary table on the relative costs of implementation, technical feasibility considerations, and socially acceptability of measures is presented in Table 7-3.

## Table 7-3 Summary of Cost of Implementation, Technical Feasibility and Social Acceptability

| | Measure | Cost of Implementation | Technical Feasibility | Social Acceptability |
|---|---|---|---|---|
| **Reduce Vehicle Kilometres Travelled** | | | | |
| | **Land Use** | | | |
| **1** | Land Use Planning and Smart Growth | $ - $$$ | Variable | Variable |
| | **Transportation Supply-Side Alternatives** | | | |
| **2a** | Expand Transit Service | $$$$ - $$$$$ | 2 - 3 | 3 - 4 |
| **2b** | Enhance Existing Transit Services | $$-$$$ | 4 - 5 | 5 |
| **3** | Provide Taxibus Transit Service | $ - $$ | 3 | 4 – 5 |
| **4** | Encourage Active Transportation | $ - $$$ | 3 -5 | 4 – 5 |
| **5** | Provide Carsharing Services | $ - $$ | 4 | 4 – 5 |
| **6** | Encourage Carpooling | $ | 5 | 3 - 4 |
| **7** | Encourage Telecommuting | $ | 4 | 5 |
| | **Pricing Mechanisms** | | | |
| **8** | Implement Toll Roads and Cordon/Area Pricing | $$$ | 3 – 4 | 1 – 2 |
| **9** | Implement Distance Travelled Fees | $$$ | 3 | 1 |
| **10** | Charge Distance-based Insurance Costs | $$ | 4 -5 | 3 – 4 |
| **11** | Implement a Fuel Sales or Carbon Tax | $ | 5 | 1 – 2 |
| **12** | Increase Parking Costs | $ - $$ | 5 | 2 |
| **13** | Offer Fees in Lieu of Travel, Parking | $ - $$ | 4 | 5 |
| | **Parking Mechanisms** | | | |
| **14** | Optimize the Use of Existing Parking Spaces | $, $$$ | 3, 5 | Variable |
| **15** | Reduce Minimum Parking Requirements | $ | 5 | 1 – 3 |
| | **Trucking** | | | |
| **16** | Enhance Logistics Management | $$ - $$$ | 3 | 4 – 5 |
| **17** | Encourage Modal Shift for Freight | $$$- $$$$ | 1 – 2 | 4 – 5 |

| | Measure | Cost of Implementation | Technical Feasibility | Social Acceptability |
|---|---|---|---|---|
| 18 | Enhance Truck Inspection and Maintenance | $$$ | 2 – 3 | 3 |
| **Improve Transportation System and Driver Efficiency** | | | | |
| 19 | Increase Infrastructure Capacity | $$$$ - $$$$$ | 2 | 3 |
| 20 | Manage Roadway Capacity Dynamically | $$$ | 3 | 4 |
| 21 | Implement Speed Change Policies | $$ - $$$ | 2 – 3 | 2 – 3 |
| 22 | Optimize Traffic Signal Operation and Timing | $ - $$$ | 4 – 5 | 5 |
| 23 | Implement Ramp Metering | $$ - $$$$ | 3 – 4 | 2 - 3 |
| 24 | Improve Traffic Incident Management | $$ -$$$ | 3 – 4 | 5 |
| 25 | Provide Transit Priority Measures | $ - $$$ | 2 – 3 | 3 – 4 |
| 26 | Encourage Eco-driving | $ - $$$ | 4 – 5 | 3 |
| **Encourage Alternative Vehicle and Fuel Technologies** | | | | |
| 27 | Encourage Adoption of Efficient Vehicle Tech. | $$$ -$$$$$ | 1 - 3 | 4 – 5 |
| 28 | Implement New Transit Vehicle Technologies | $$$ - $$$$$ | 2 - 3 | 5 |
| 29 | Encourage New Heavy-Duty Vehicle Tech. | $$$- $$$$$ | 1 - 3 | 3 – 4 |
| 30 | Use Low Carbon Fuels | $$$ - $$$$$ | 1 | 3 |

To further illustrate the relative performance of measures, their GHG reduction potential was plotted against costs of implementation, technical feasibility and social acceptability. A discussion of results follows.

### 7.3.1 Comparing GHG Reduction Potential versus Cost of Implementation

The scores for the GHG reduction potential of measures were plotted against cost of implementation (for the agency or agencies responsible for implementation)[44]. Where a range of scores was determined

[44] *The metric, GHG reduction potential / cost of implementation, should not be confused with the term "cost-effectiveness". Cost effectiveness describes the cost of reducing a given quantity, for example 1 tonne of GHG emissions ($ / tonne of GHG). Measures can be cost-effective, but may only have a small impact on total GHG emissions. For example, eliminating diesel bus vehicle emissions through the adoption of other vehicle technologies may be cost-effective. However, since transit vehicles contribute little to overall transportation GHG emissions in Canada, the total GHG reduction potential is low.*

*Cost-effectiveness was not evaluated in this report, as the scope of the undertaking was beyond the resources available to this mandate. Information that was found in the literature and document review was not sufficient to support a comparison of cost-effectiveness across all measures. A study completed by Nelson/Nygaard provides some information about the cost-effectiveness of different measures as relevant to the Bay Area Rapid Transit System. This information is presented in Appendix B of this report.*

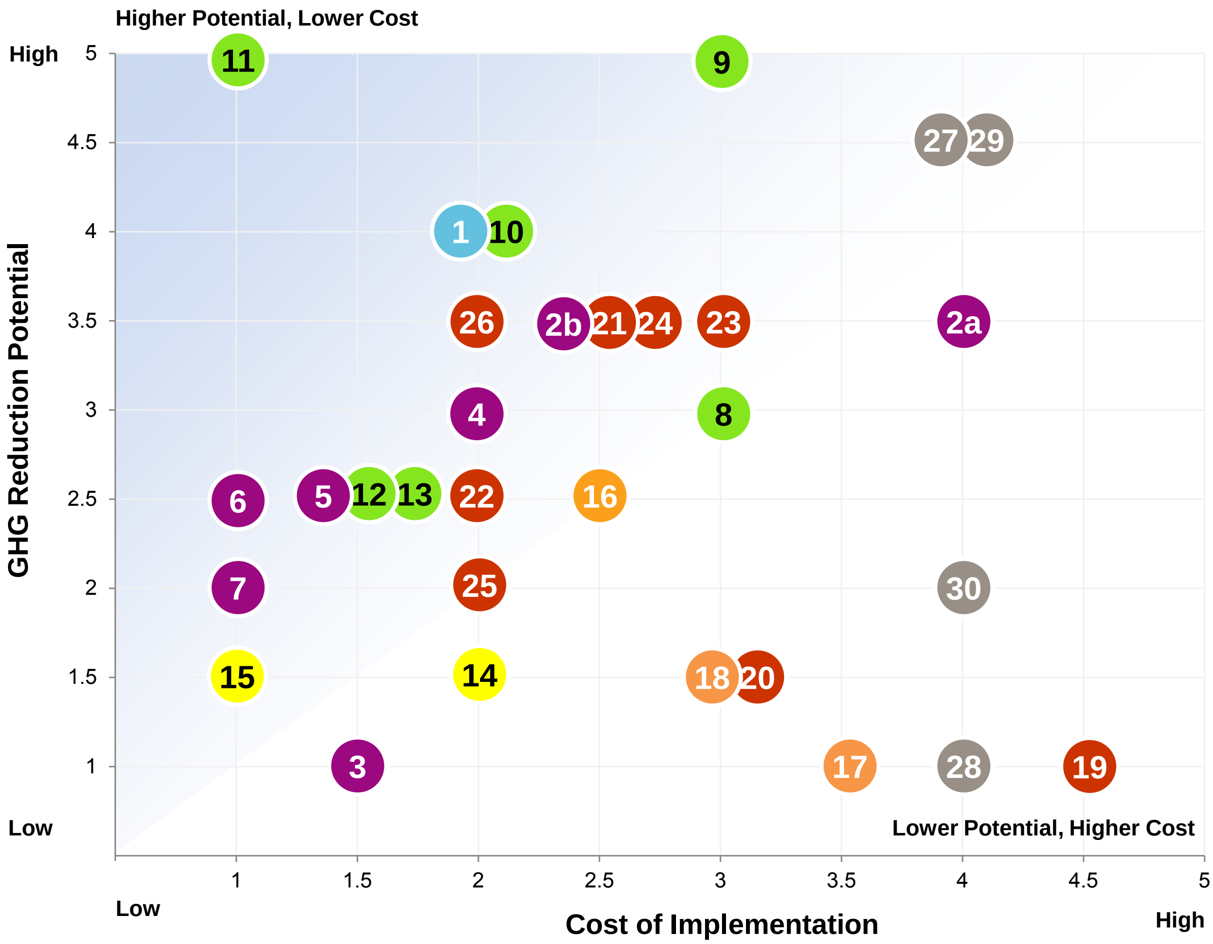
for an indicator, the average score was plotted (e.g. cost rated $ - $$ was plotted as 1.5$, while a GHG reduction potential score of 2- 4 was plotted as 3). The plot is shown in Figure 7-1 on the next page.

Measures which have the greatest overall GHG reduction potential, but are cheaper to implement are located in the top left side of the plot and fall within the light blue shading. Measures which have a lower overall GHG reduction potential and incur significant implementation costs are located to the bottom right of the plot. Due to the qualitative and subjective nature of the scoring applied in this study, the locations of the measures on the plot should not be read as absolute, but indicative of their positions relative to other measures. Observations that can be drawn include:

- Land-use planning (1) scores highly in terms of overall GHG reduction. Implementation costs will vary depending on the scope of the changes to policy, program or regulations being considered. However, compared to other capital intensive measures such as transit or road capacity expansion, implementing land use policies could generally be considered a high potential - lower cost measure;
- In terms of transportation supply side alternatives, public transit optimizations (2b) score well in terms of overall reduction potential and cost. Transit expansion (2a) has a similar potential for significant GHG emission reductions, but may require substantial investments to implement. Improving active transportation (4), carpooling (5), carsharing (6), and telecommuting (7) do not generally have the same potential to reduce GHG emissions as transit, but lower costs of implementation mean they generally score well in terms of reduction potential / implementation costs;
- Pricing mechanisms (Measures 8 – 13) generally fall into the top left half of the plot. This is supported by the literature (Cambridge Systematics Inc., 2009), which finds that financial mechanisms can be strong incentives for achieving significant GHG reductions. They are also relatively cheap to implement, as they generally only require programmatic and administrative changes, and capital costs for equipment acquisition are relatively low;
- Parking control measures (14, 15) score moderately low in terms of overall GHG reduction potential / cost of implementation. While they are relatively cheap to implement, their effect is limited to central areas where parking demand is high;
- Measures to reduce truck VKT fall into the middle and bottom of the plot. Of the three main measures considered, logistics management (16) scores highest, as optimizations of existing deliveries prove to be relatively low cost. Modal transfer (17) and truck inspections (18) do not result in significant impacts for urban transportation. The former is typically not viable for short distance, intra-urban travel. Both also require moderate costs for operations of trans-shipment centres or inspection facilities;
- Increasing the capacity of the transportation system to reduce congestion and smooth traffic flow scores low in terms of GHG reduction potential / cost of implementation (Measures 19, 20). While there may be other reasons to increase infrastructure capacity (e.g. economic development) and enhance traffic flow, these measures require more significant capital and operational investments. Furthermore, making driving easier and more fluid acts as incentives to vehicle use and can, in the medium and long terms, induce further vehicle travel;
- Measures to improve traffic flow and relieve congestion which score well are speed change policies (21), incident management (24), ramp metering (23), and traffic signal operation and timing optimization (22). These measures do not rely on building additional lane capacity, and municipalities already implement these measures on an ongoing basis to make the most use out of their existing infrastructure. Similarly, implementing transit priority measures (25) proves to be relatively low cost.

The contributions of transit vehicles to overall transportation GHGs are low, but improvements to travel time and service reliability can play an important part in encouraging modal transfer;

**Figure 7-1 – GHG Reduction Potential versus Cost of Implementation for Responsible Agency**




| | | | | | |
|---|---|---|---|---|---|
| 1 | Land Use | 11 | Fuel / Carbon Tax | 21 | Speed Change Policies |
| 2a | Transit Expansion | 12 | Parking Costs | 22 | Traffic Signal Optimization |
| 2b | Transit Service Optimization | 13 | Fees in Lieu of Travel / Parking | 23 | Ramp Metering |
| 3 | Taxibus | 14 | Parking Optimization | 24 | Traffic Incident Management |
| 4 | Active | 15 | Parking Requirements | 25 | Transit Priority Measures |
| 5 | Carsharing | 16 | Truck Logistics | 26 | Eco-driving |
| 6 | Carpooling | 17 | Modal Shift | 27 | Efficient Vehicle Technologies |
| 7 | Telecommuting | 18 | Truck Inspection Maintenance | 28 | Transit Vehicle Technologies |

| | | | | | |
|---|---|---|---|---|---|
| 8 | Tolls | 19 | Road Infrastructure Expansion | 29 | Heavy-Duty Vehicle Technologies |
| 9 | Distance Travelled Fee | 20 | Dynamic Capacity Management | 30 | Low Carbon Fuels |
| 10 | Distance-Based Insurance | | | | |

- Encouraging eco-driving (26) for all drivers through awareness and training scores well in terms of potential GHG reductions and cost of implementation. Awareness and training programs are relatively inexpensive to apply, and can lead to important reductions in fuel consumption if eco-driving achieves widespread adoption;
- Improvements to light-duty and heavy-duty vehicle technologies (27, 29) are generally high-cost/high impact measures. They can yield significant fuel consumption and GHG emission reductions, but require significant investment in technology development by manufacturers, acquisition costs for vehicle operators or owners, and deployment of support infrastructure by local and regional agencies. However, vehicle operating cost savings were not estimated or considered in this evaluation. These vehicle operating cost savings to car and truck operators may off-set initial acquisition costs, increasing the attractiveness of these measures;
- Improving transit bus vehicle technologies (28) scores low in terms of overall GHG reduction potential because transit vehicles currently contribute little to overall transportation GHG emissions. These measures are however still relevant to transit agencies to demonstrate environmental leadership and reduce their own GHG emissions;

### 7.3.2 Comparing Technical Feasibility versus GHG Reduction Potential

The ratings for technical feasibility of measures were plotted against their GHG reduction potential scores in the same manner as just described in the previous section. As shown in Figure 7-2, measures which have a greater GHG reduction potential while being more technically feasible fall in the top right quadrant of the plot (i.e. in the light blue shaded area), while those with lower GHG reduction potential and are more technically difficult fall in the bottom left.

Measures that were judged to be technically easier to implement tend to involve changes at policy, program or regulatory levels (political support and financial constraints notwithstanding). They generally apply to measures where knowledge gaps are not a significant barrier due to widespread practice and implementation.

Measures which involve the optimizations of existing systems and services tended to fall into the middle of the pack (e.g. transit service optimization, traffic signal optimization, traffic incident management, freight logistics management). These measures can be thought of as “tweaking” existing systems.

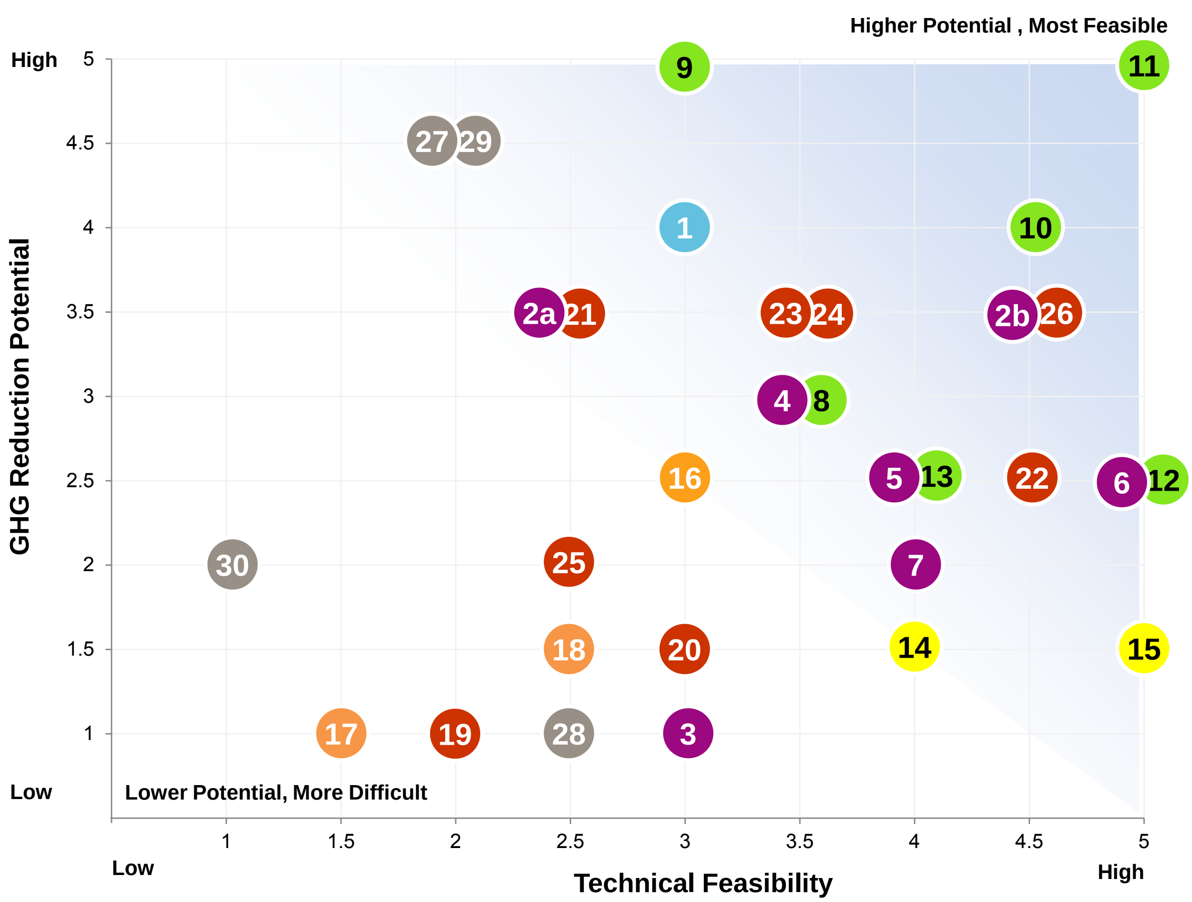
Finally, measures which are were judged to be more technically difficult tended to require more planning, engineering design, technology development or construction (e.g. increasing infrastructure capacity, transit service expansion, speed change policies, freight modal shift, development in light-duty and heavy-duty vehicle propulsion systems).

In many ways, the relative performance of measures in terms of GHG reduction potential / technical feasibility is similar to their performance in terms of cost of implementation. Cost can sometimes serve as a proxy for technical feasibility, as more complex and technically difficult projects would be expected to cost more.

Due to the similar relative performance of measures in terms of GHG reduction potential / technical feasibility and cost of implementation, it is not necessary to present a full summary of measures. However, top performing measures on this metric are worth reiterating:

- Once again, many pricing mechanisms come out on top in terms of technical feasibility versus GHG reduction potential. Economy wide pricing measures such as carbon and fuel taxes (11), VKT fees (9) and distance based insurance costs (10) score highly. They have a significant potential to reduce GHG emissions, while implementation is more programmatic and administrative in nature. It should be noted however that, with the exception of a regional fuel tax, these economy wide pricing measures are typically areas of provincial or federal responsibility;
- Encouraging eco-driving through training programs (26), increasing parking costs (12), and encouraging carpooling (6) perform relatively well. Implementation is policy or program oriented, while the potential for significant GHG reductions are high;
- Land use planning (1), enhancing existing transit services (2b), traffic signal optimization (22), incident management (23) fall into the middle of the pack. There are no knowledge gaps and these are generally activities that are already being undertaken by many local agencies.

**Figure 7-2 – GHG Reduction Potential versus Technical Feasibility of Implementation**

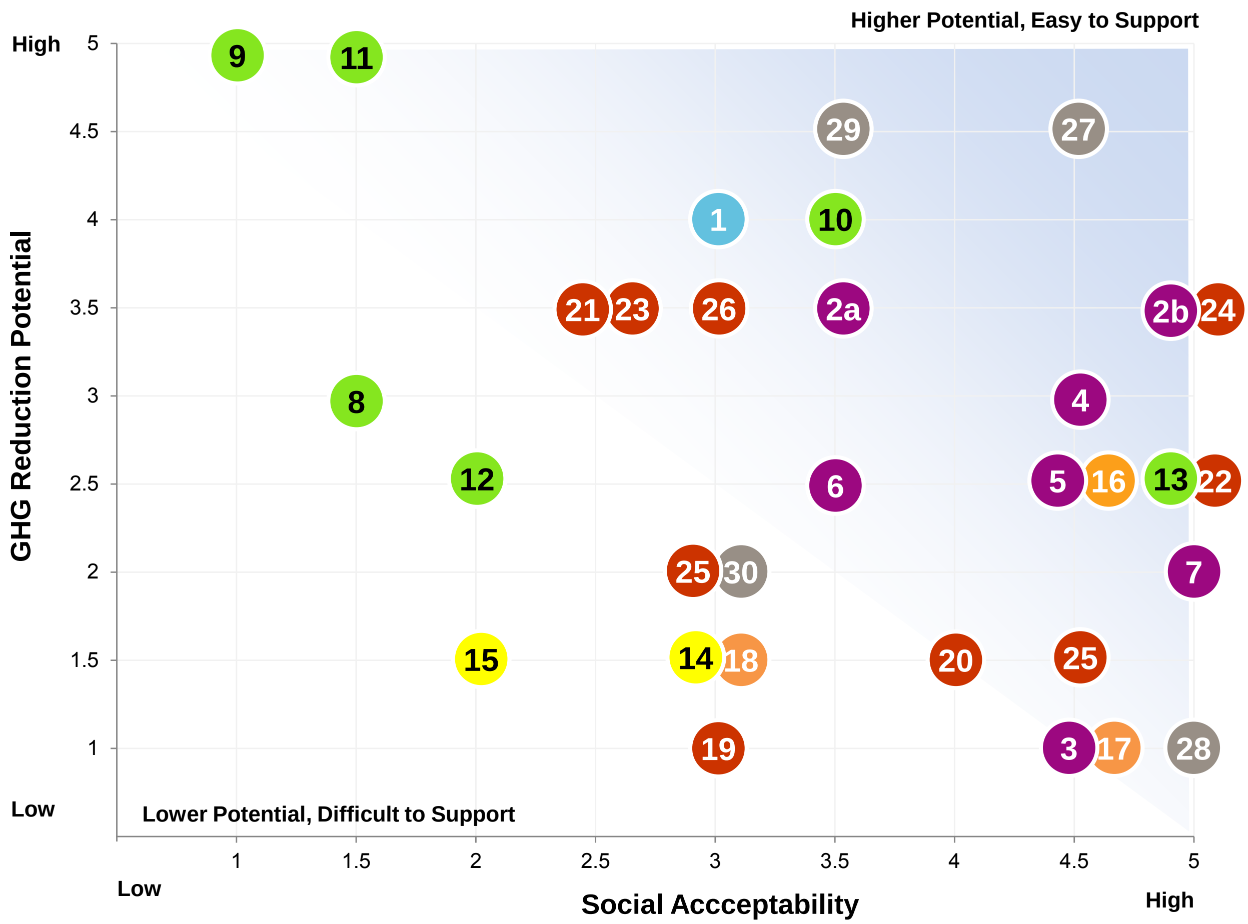


| | | | | | |
|---|---|---|---|---|---|
| 1 | Land Use | 11 | Fuel / Carbon Tax | 21 | Speed Change Policies |
| 2a | Transit Expansion | 12 | Parking Costs | 22 | Traffic Signal Optimization |
| 2b | Transit Service Optimization | 13 | Fees in Lieu of Travel / Parking | 23 | Ramp Metering |
| 3 | Taxibus | 14 | Parking Optimization | 24 | Traffic Incident Management |
| 4 | Active | 15 | Parking Requirements | 25 | Transit Priority Measures |
| 5 | Carsharing | 16 | Truck Logistics | 26 | Eco-driving |
| 6 | Carpooling | 17 | Modal Shift | 27 | Efficient Vehicle Technologies |
| 7 | Telecommuting | 18 | Truck Inspection Maintenance | 28 | Transit Vehicle Technologies |
| 8 | Tolls | 19 | Road Infrastructure Expansion | 29 | Heavy-Duty Vehicle Technologies |
| 9 | Distance Travelled Fee | 20 | Dynamic Capacity Management | 30 | Low Carbon Fuels |
| 10 | Distance-Based Insurance | | | | |

### 7.3.3 Comparing GHG Reduction Potential versus Social Acceptability

Another method to understand the relative performance of measures is to examine GHG reduction potential against an evaluation of how socially acceptable they may be (e.g. political will). Once again, scores for GHG reduction potential and social acceptability were plotted (Figure 7-3). The measures which are judged as having greater GHG reduction potential while being easier to support are located to the top right side of the plot (i.e. in the light blue shaded area), while measures with less potential and are more difficult to support are located to the bottom left of the plot.

## Figure 7-3 – GHG Reduction Potential of Measures versus Social Acceptability of Implementation




| | | | | | |
|---|---|---|---|---|---|
| 1 | Land Use | 11 | Fuel / Carbon Tax | 21 | Speed Change Policies |
| 2a | Transit Expansion | 12 | Parking Costs | 22 | Traffic Signal Optimization |
| 2b | Transit Service Optimization | 13 | Fees in Lieu of Travel / Parking | 23 | Ramp Metering |
| 3 | Taxibus | 14 | Parking Optimization | 24 | Traffic Incident Management |
| 4 | Active | 15 | Parking Requirements | 25 | Transit Priority Measures |
| 5 | Carsharing | 16 | Truck Logistics | 26 | Eco-driving |
| 6 | Carpooling | 17 | Modal Shift | 27 | Efficient Vehicle Technologies |
| 7 | Telecommuting | 18 | Truck Inspection Maintenance | 28 | Transit Vehicle Technologies |
| 8 | Tolls | 19 | Road Infrastructure Expansion | 29 | Heavy-Duty Vehicle Technologies |
| 9 | Distance Travelled Fee | 20 | Dynamic Capacity Management | 30 | Low Carbon Fuels |
| 10 | Distance-Based Insurance | | | | |

Observations that can be drawn based on qualitative evaluation of GHG reduction potential against social acceptability are:

- Many measures across intervention categories score highly on social acceptability. Notably, enhancing existing transit services (2b), reducing congestion through more rapid responses to incidents (24) and optimizing traffic signal timing and synchronization (22), stand to benefit road and transit users while having little or no impact on habits or costs to users. Similarly, investments in walking and cycling and other active transportation modes (4) generally score well when considered from a social acceptability perspective and also score moderately high in terms of GHG reduction potential;
- Carsharing (5) services, telecommuting (7) and optimizing freight logistics management (16) are easy to adopt, as they generally function on a voluntary basis, provide options, convenience and financial savings to travellers and shippers who can employ such measures;
- Land use planning and smart growth (1) was plotted in the middle in terms of social acceptability. However, it is important to note that the social acceptability of land use planning developments can be extremely variable. Region wide policies may achieve high social acceptability because they are seen as smart, forward thinking avenues for development. However, local development projects may face opposition to densification, congestion, parking, etc.;
- Pricing and parking pricing mechanisms have high GHG emission reduction potential, but tend to impose constraints or financial penalties on users, factors which explain their generally lower social acceptability ratings. In particular, implementing VKT fees (9), fuel and carbon taxes (11) and distance based insurance costs (10) have a high reduction potential but score less well from a social acceptability perspective. This may be partially due to the fact that many people are not familiar with such systems. Education and pilot testing would be required to increase awareness, understanding and acceptability by potential users and to refine the implementation of such systems to increase their overall acceptability. For example, demonstrating that distance-based pricing and insurance costs are fair could increase their acceptability. They are generally considered to be fair relative to other mechanisms such as bridge tolls or parking fees, which target particular drivers, routes and areas. They also capture all travel, whether by electric or gasoline powered vehicle. Finally, offering compensation for lower-income earners or structuring pricing and collection schemes to be revenue neutral (e.g. as is done with some carbon taxes) can reduce equity concerns and increase acceptability. Through education and awareness, as well as revenue compensation, these pricing measures may become more socially acceptable;
- Improving light-duty (27), transit (28) and heavy-duty vehicle efficiencies (29) through vehicle technologies generally score well on social acceptability. These alternatives are industry driven, and end-user adoption tends to be gradual, voluntary and can result in longer term operating cost savings for users. While transit vehicle technologies (28) were judged to be highly socially acceptable to transit agencies and riders, their effect on overall transportation GHG emissions is low, which explains why this measure falls into the bottom right corner of figure 7-3;
- The social acceptability of infrastructure capacity expansion (19) is variable and will depend on the extent of the project (rated 3 for social acceptability on figure 7-3). Small scale measures may be relatively easy to integrate into the existing urban environment, although highway capacity expansions require space and can create opposition due to increased vehicle use. However, in the long term, these measures also tend to induce vehicle traffic, which eventually leads to further congestion. This explains their position at the middle/bottom of figure 7-3.

# 8 – Conclusions

Canada's transportation GHG emissions, which currently account for about a quarter of the country's total emissions, are projected by the federal government to increase to 2030. Road-based transportation accounts for most of the transportation sector's GHG emissions, and total light-duty and heavy-duty VKT are increasing. Improvements in vehicle fuel efficiency are only expected to slow emissions growth rates, as continued population, economic growth and travel demand will lead to continued increases in VKT that will off-set vehicle fuel efficiency gains. Despite current policies and measures put in place, Canada is not on track to meet its Copenhagen target of reducing its total emissions by 17 % below 2005 levels by 2020. Significant changes to land use, travel behavior and travel modes are needed if the transportation sector is going to make any meaningful contributions to Canada's overall GHG emission reduction efforts.

This report presented a range of measures which can be applied by local and regional agencies to reduce urban transportation GHG emissions. Measures which can be applied by private enterprise or senior levels of government were also presented in order to provide an overview of the range of possible actions, and highlight the supporting role that local and regional agencies can play. To help readers sort through the wealth of available information, an overview of the benefits, GHG reduction potentials, implementation considerations, constraints and barriers, and how they may be overcome, were also presented. Through this discussion, this report aimed to help readers understand and assess potential measures which may be applicable to their jurisdiction.

There are three principal approaches to reducing urban transportation GHG emissions. They can be reduced by focusing on reducing VKT, by improving the efficiency of the transportation system and driving habits, or by encouraging the adoption of alternative vehicle and fuel technologies to improve the fuel economy of vehicles. Measures that lead to a reduction in VKT tend to have the most enduring effects on energy consumption and GHG emissions because they encourage a change in travel behaviour towards more fuel and energy efficient modes and patterns of transportation. Improving the efficiency of the transportation system is important to maximizing the utility and benefits of existing infrastructure investments. Technology development in vehicle propulsion, aerodynamics, and fuel carbon content can also bring about a significant shift away from fossil fuel dependence for urban transportation. This toolbox presents a range of 30 different measures falling under one of these three approaches to reducing transportation GHG emissions. Most measures can be implemented by local and regional municipalities or transportation agencies, given their significant responsibility over urban infrastructure and service provision. Measures that rely on higher levels of government, as well as private operators, employers and the vehicle industry are also presented to illustrate the breadth of efforts that can be made in reducing transportation GHG emissions.

The potential of measures to reduce urban transportation GHG emissions was evaluated qualitatively in this report. The evaluation was completed based on a review of two major US works comparing GHG reduction potentials of a broad range of measures, and an examination of current Canadian transportation modal share and GHG contributions. Based on this review, pricing mechanisms were judged as having the highest potential for reducing GHG emissions. Pricing measures aim to make it more expensive to travel by private vehicle. Furthermore, these direct financial impacts can lead to rapid changes in travel patterns and significant GHG emission reductions where alternative modes of travel are readily available. However, these mechanisms can present equity and social acceptability issues because they disproportionately affect low-income individuals. Mitigation measures such as using revenues to enhance transit and active transportation, or decreasing income taxes for low-income earners, are necessary to address equity challenges.

Local and regional agencies can implement more regionally-based pricing measures such as tolls and cordon/area pricing, and parking cost increases in order to reduce VKT. In the past, these pricing mechanisms have typically been used as revenue generators or for financing infrastructure construction and operation. Applying such mechanisms towards the goal of reducing VKT and GHG emissions has not yet occurred in Canada, although other jurisdictions in the world such as the UK and Singapore have used them successfully for urban congestion relief. These measures tend to be more effective in reducing GHG emissions where travel demand and road congestion to and around targeted areas are high, and where a shift towards more energy efficient forms of transportation such as transit can occur. If travel demand to a specific area is not sufficiently high, road tolls, cordon/area pricing, and parking cost increases may result over the medium and long term to shifts in vehicle travel to other un-tolled areas, and GHG emissions reductions will not be realized. Therefore, regional pricing mechanisms would also need to be reinforced by improvements to alternative modes such as transit and active transportation in order to maintain area accessibility and reduce GHG emissions.

Land use planning and Smart Growth policies are key to reducing transportation GHG emissions because they set up the necessary conditions to facilitate more efficient travel behaviour. Creating compact, diverse and high quality urban environments that facilitate alternative modes of transportation such as transit and active transportation is key to reducing the need to make trips by vehicle, or when vehicle travel is necessary, to making trips shorter. Land use planning policies can be relatively cheap to implement as they tend to require only policy, programmatic and regulatory changes. While land use policies can result in GHG emission reductions in the short term, the full potential to alter travel behaviour will not be achieved before the long term when full buildout and supportive transportation supply alternatives such as transit are in place.

It is equally important to provide transportation supply-side alternatives to travellers such that trips by single occupant vehicles can be avoided. Local and regional agencies are largely responsible for expanding and enhancing transit services and providing efficient and safe active transportation infrastructure, while also recognizing that funding support from provincial or federal governments would often be required. Local and regional agencies can also play a role in encouraging the adoption of carsharing services, which can contribute to a more considered vehicle use, as well as carpooling practices. Finally, allowing local government employees to telecommute, adopting compressed work week schedules, and encouraging other employers to do the same, are potential avenues to reduce commuter travel. These supply side alternatives constitute a cocktail of options that are critical to meeting the mobility demands of a growing population, while also providing viable alternatives in the event that travel pricing mechanisms are applied.

Due to the ubiquity of urban road infrastructure and vehicle travel, maximizing the efficiency of the existing transportation system is key to reducing transportation GHG emissions. Modulating speed limits as a function of congestion, reducing maximum highway speed limits, optimizing traffic signals to improve flow along corridors and improving incident management are relatively low cost/high impact measures to reduce urban congestion. Similarly, enhancing eco-driving through training for drivers was found to be a relatively effective strategy if it can reach a significant portion of these vehicle drivers. Transit vehicle GHG emissions can be reduced through transit signal priority measures, dedicated lanes, queue-jumping and limited or consolidated stops. These measures are also important because they can make transit systems more attractive, and encourage greater mode transfer for urban passenger transportation. Of all the transportation system efficiency measures examined, infrastructure capacity expansion through new construction was the only measure to rank poorly in terms of GHG reduction potential. While it can result in enhanced traffic flow immediately after construction, induced vehicle flow over the longer term, in the absence of future vehicle technologies, will negate early GHG reductions.

Freight transportation is an essential component to the economy of urban areas. However, trucks circulating in towns and cities can contribute to traffic congestion while generating air pollution and noise impacts. Encouraging companies to enhance logistics management, ensuring trucks are loaded to capacity, optimizing routes to minimize travel distance or avoid congested areas, and establishing urban freight consolidation and delivery centres can help to minimize truck based VKT.

Most of the measures described in this toolbox can be implemented in the immediate or short term if political will and financial constraints have been addressed. Generally, there are few overarching knowledge gaps or technical barriers to implementing transportation supportive land use planning, transportation supply side alternatives, and transportation system and driver efficiency enhancements. The fact that there are many examples of these measures implemented across North America demonstrates that they are "technically-ready" for adoption. The same observation can be made for the majority of travel pricing mechanisms discussed in this toolbox (carbon or fuel taxes, tolls, parking fees) with the exception of more sophisticated distance-based pricing schemes that charge based on time of day or area of travel. The latter still requires further development of tracking devices and systems. Alternative vehicle propulsion system technologies are slowly coming into the market, but limited vehicle choice options, travel distance constraints, up-front acquisition costs, and limited recharging infrastructure are slowing adoption of these vehicle technologies. Municipalities and other agencies can continue to support the uptake of these technologies through continued monitoring and demonstration of technologies, deployment of supporting electrical charging infrastructure, and privileged access to dedicated parking spaces or reserved lanes, measures which can be undertaken in the short term.

Reducing fossil fuel consumption, energy use and GHG emissions are not the only benefits to the measures described in this toolbox. Many measures also have co-benefits in terms of increasing the mobility of travellers and increasing accessibility of destinations, improving the livability of urban areas, improving the environment, and enhancing public health and traveller safety. Increasing transportation options and reducing the need for motor vehicles for travel also enhances equity for low-income households.

The choice of measures or bundles of measures that should be adopted by local and regional agencies will ultimately be dependent on a range of factors that go beyond the implementation considerations presented in this report. Notably, the state of existing transportation systems and services, political contexts, budget availability, and time horizons for action will determine the kinds of measures that can be implemented. Opportunities for action, such as funding from upper levels of government; plan, policy or infrastructure renewal cycles; and broader planning processes, will also provide context for the identification and selection of measures. The responsibilities of the implementing agency will also help determine which measures can be implemented, and where collaboration with other levels of government or private enterprise may be required. Each jurisdiction will ultimately need to assess these factors and conditions within their own local context to determine the most appropriate measures to reduce their urban transportation GHG emissions.

## 8.1 Future Work

The evaluation of the GHG reduction potential of measures to reduce transportation GHG emissions presented in this report was qualitative in nature, as it was drawn from a review of previous works. Further research and work is required to provide a quantitative determination of the GHG reduction potential of specific measures in the Canadian context.

Specifically, a more comprehensive evaluation of the GHG reduction potentials could be identified through a close examination of local conditions and opportunities across the country. A determination of which measures would be most suitable in each context and location would need to be completed. Hypotheses as to the geographical extents, timing of application, and intensity of the effort would need to be made. The consideration of these parameters in a specific context or location would provide more information about the economic costs, benefits, cost-effectiveness and implementation considerations of measures. Such an analysis could be carried out for a region, province or across the country.

Finally, this document contains a significant amount of information about the various measures, but is presented largely in the form of text. Further work could employ more graphical presentations to make the document easier to interpret.

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# Appendix A – Energy Generation and GHG Emissions in Canada, Trends and Projections

## Energy Generation Trends

The transportation sector demand for energy will continue to be largely met by fossil fuels in the near term as all modes of transportation in Canada are highly dependent on petroleum-derived fuels. A significant breakthrough in vehicle propulsion technologies will be required to reduce this fossil fuel consumption and dependence as the predominant fuel source (Transport Canada, 2011b). Advancements in hybrid and electric car and battery technologies may provide a means to reducing fossil fuel dependence. However, the contributions to GHG emissions will still depend on the sources of energy used to generate electricity to power hybrid and electric vehicles.

In Canada, the generation of electricity is derived from several sources. In 2012, hydroelectricity supplied the greatest quantity of energy across Canada, followed by nuclear, coal, natural gas and renewables (e.g. wind, solar and tidal power). Energy from heat recovery (e.g. industrial heat recovery processes), petroleum based fuels (e.g. oil, diesel, gasoline) comprise the rest of the fuel sources in Canada. Table A 1 provides a breakdown of energy production by source for 2012 and 1990.

Comparing energy generation in 1990 to 2012, the proportion of energy sources which produce little to no GHG emissions (excluding construction phase emissions) such as hydroelectricity, wind and solar and nuclear, increased as a portion of total energy supply while non-renewables such as GHG intensive coal and petroleum based fuel sources decreased. The one significant exception is the use of natural gas, while less GHG intensive than coal or petroleum fuels, rose significantly between 1990 to 2012 (873%). Generation from solar, wind, tidal, heat recovery and other renewable sources also grew very significantly between 1990 and 2012, although their total energy contribution in 2012 remained small (around 3.5 %).

Due to these trends, total GHG emissions from electricity production in Canada have decreased from 1990 to 2012, from 93,600 to 88,300 kt. $CO_2$ eq., a 26 % decline (see table A1). During the 1990s, the use of coal and petroleum led to an increase in GHG emissions, but the replacement of these fuels in part by natural gas during this period contributed to the emissions decrease post 2001 (Environment Canada, 2014a). The electricity generation sector accounted for only 13 % of Canada's total emissions in 2012.

## Table A 1 – Electricity Generation and GHG emissions in Canada, 2012 and 1990

| Source | Quantity 1990 (GWh) | % change (1990 – 2012) | Quantity 2012 (GWh) | % of total (2012) |
|---|---|---|---|---|
| **Hydroelectricity** | 263,000 | 31% | 345,000 | 61% |
| **Nuclear** | 68,800 | 30% | 89,500 | 16% |
| **Coal** | 82,200 | -29% | 58,500 | 10% |
| **Natural Gas** | 4,140 | 873% | 40,300 | 7.2% |
| **Other Renewable Sources** | 26.2 | 44 175% | 11,600 | 2.1% |
| **Heat Recovery** | 0 | - | 7,530 | 1.3% |
| **Petroleum Products** | 14,800 | -51% | 7,190 | 1.3% |
| **Other** | 0 | - | 2,720 | 0.5% |
| **Total** | **432,966** | | **562,340** | |
| | | | | |
| **GHG emissions** | | | | |
| Coal | 79700 | -21 % | 62700 | 71 % |
| Natural Gas | 2700 | 696 % | 21500 | 24 % |
| Other Fuels | 11200 | -64 % | 4020 | 5 % |
| Other Emissions | - | - | 81 | 0.1 % |
| **Overall Total** | **93,600 kt $CO_2$eq.** | **-6 %** | **88,300 kt $CO_2$eq.** | |
| **GHG Emissions intensity** | 230 g $CO_2$eq./kWh | -26 % | 170 g $CO_2$eq./kWh | |

Source: (Environment Canada, 2014b).

In 2012, GHG emissions from coal fired power plants still contributed to nearly three quarters (71%) of all energy generation emissions. This was followed by natural, contributing nearly a quarter (24%) and other fuel sources (e.g. light fuel oil, heavy fuel oil, diesel, petroleum coke, still gas) making up most of the remaining 5% (Environment Canada, 2014b).

GHG emissions and emissions intensity vary significantly by province due to both energy demand (e.g. population size) as well as energy generation sources (e.g. coal, oil, hydro). In 2012, electricity generation in Alberta, Saskatchewan and Ontario contributed the most to the sector's total GHG emissions, while Prince Edward Island, Manitoba and British Columbia contributed the least. However, from the perspective of energy generation intensity, energy generation in Quebec and Manitoba produced least GHGs / kWh of electricity than the rest of Canada, while energy generation intensity in Alberta, Saskatchewan and Nova Scotia were the highest. Electricity production GHG emissions and emissions intensity are listed by province in the following table (Environment Canada, 2014b).

### Table A 2 – GHG emissions and Emissions Intensity by Province, 1990, 2012

| Jurisdiction | GHG Emissions (kt $CO_2$ eq.) | | GHG Emissions Intensity (g $CO_2$ eq./kWh) | |
|---|---|---|---|---|
| | 1990 | 2012 | 1990 | 2012 |
| **Canada** | 93,600 | **88,300** | **230** | **170** |
| **British Columbia** | 803 | 494 | 17 | 8.2 |
| **Alberta** | 39,400 | 44,200 | 940 | 820 |
| **Saskatchewan** | 11,100 | 15,800 | 800 | 750 |
| **Manitoba** | 517 | 112 | 26 | 3.4 |
| **Ontario** | 25,500 | 14,500 | 200 | 96 |
| **Quebec** | 1,480 | 520 | 13 | 2.9 |
| **New Brunswick** | 5,970 | 4,050 | 360 | 420 |
| **Prince Edward Island** | 103 | 10.7 | 1,300 | 22 |
| **Nova Scotia** | 6,870 | 7,630 | 720 | 700 |
| **Newfoundland and Labrador** | 1,630 | 843 | 45 | 20 |
| **Yukon** | 93.6 | 18.4 | 190 | 40 |
| **Northwest Territories, Nunavut** | 162 | 142 | 360 | 330 |

## Projections on Energy Generation

A Report on Canada's Energy Future prepared by the National Energy Board (NEB) projects supply and demand for Canada's energy sector to 2035. Projections are based on current macroeconomic perspectives, energy price outlook, existing government programs and regulations, and technology in place. The report makes several observations with respect to energy production in Canada by 2035 (National Energy Board, 2013):

- The price of natural gas will remain competitive for generation due to projected increases in shale and tight gas production across North America. Due to its lower GHG emissions rates compared to coal, shorter construction times, ability to grow incrementally, and lower upfront costs than nuclear or coal plants, natural gas will continue to grow in Canada and double its contribution to the electricity generation mix by 2035 (from 7% to 14%);
- The contributions of nuclear power to electricity generation by 2035 are expected to remain similar to the present day. No new nuclear power plants are expected to be built during this time horizon. Following the decommissioning of Gentilly 2 in Quebec, Ontario and N. B. are the only two remaining provinces to use nuclear power for energy generation.
- The production of electricity from coal will continue its decline, in large part due to government and industry initiatives to reduce GHG emissions. Notably, strict new federal regulations on CO2 emissions rates will put stringent restrictions on the construction of new plants, while existing plants will either have to be equipped with technologies such as carbon capture and storage (CCS) technology to meet the new regulations, or be retired from service. By the end of 2013, all coal-fired plants in Ontario were retired, while further retirements are expected in Alberta, Saskatchewan and

Nova Scotia. Coal's contribution to electricity generation in Canada is expected to be halved by 2035 (from 10% to 5%).
- Electricity from oil-fired (petroleum products) power plants is expected to remain the same through 2035.
- The use of non-hydro renewable energy sources including wind, solar, biomass, tidal and wave power will continue to increase and their share of total generation is expected to double to around 7 % by 2035.
- Hydroelectricity generation will continue to increase due to major projects currently under construction (e.g. La Romaine in Quebec, Muskrat Falls in Labrador) or being planned in B.C., Alberta and Manitoba. However, faster growth in other forms of generation such as non-hydro renewables (wind) and gas-fired generation will mean the share of hydroelectricity generation is projected to go down to around 56% by 2035 (from 61% in 2012).

Therefore, the halving of coal based electricity generation will significantly cut its GHG emissions contributions, while the doubling of natural gas use, a less GHG intensive source of energy, as well as increased growth in hydro and other renewable sources, will result in less overall GHG emissions from the electricity generation sector. The Government of Canada estimates that, based on these trends in energy production in Canada, the electricity generation sector total GHG emission contributions are projected to decline by 33% from 88 Mt in 2012 to 59 Mt in 2030 (Government of Canada, 2014a).

# Appendix B – Evaluating the GHG Reduction Potential of Measures

Specific focus is given in this report to evaluating the relative potential of each of the measures to reduce transportation GHG emissions. However, doing a full quantitative, comparative analysis of the potential GHG reductions is beyond the scope of the current mandate. A qualitative approach to conducting the comparison is proposed instead and described in the following section.

Qualitative scores of 1 – 5 given to each measure included in this toolbox were derived based a review of previous comparative works, a review of Canadian modal share and GHG contributions from each mode of road transportation, as well as a review of literature and documents used to describe measures. Two key studies comparing the GHG reduction potentials of various measures was the Moving Cooler Study, published by the Urban Land Institute in 2009, and the Cost-effectiveness of BART Actions to Reduce GHG Emissions Study, completed by Nelson\Nygaard Consulting Associates in 2008. The findings of these studies are presented first. Then, a table summarizing the GHG reduction potentials of the various measures included in this report is presented. The scale, hypotheses and assumptions behind the GHG reduction values, where available are presented. Next, a brief review of current Canadian GHG emissions by transportation mode is presented (drawn from Chapter 2). Finally, in light of these findings, a discussion of guidelines used to qualitatively rate each measure included in the toolbox is presented. This appendix ends with a presentation of the scores for GHG reduction potential assigned to each measure included in this toolbox.

## Review of Transportation GHG Reduction Strategies in the Moving Cooler Study

The study Moving Cooler, by the Urban Land Institute presents a comprehensive, comparative, national-level (USA) estimate of strategies to reduce GHG emissions from ground based transportation. The study presents approximately 47 different individual strategies seeking to either reduce VKT or improve vehicle/system operations (i.e. enhancing vehicle fuel efficiency when travelling by congestion reduction, speed controls, traffic signal timing, etc.). While many of the measures included in this toolbox are similar to the strategies included in the Moving Cooler Study, direct comparisons or conclusions about GHG reduction potential cannot be drawn due to differences in context, scale, and aggressiveness of application. Nonetheless, a review of the Moving Cooler study's estimates is illustrative of how the measures in this toolbox may perform relative to one another.

In Moving Cooler, cumulative GHG emissions reductions and implementation costs for each strategy are estimated over a 40 year time horizon, 2010 to 2050. They are compared against a baseline which assumes a business as usual practice (BAU) in annual travel rates, fuel prices and gains in vehicle fuel economy. In the BAU case, the 40 year cumulative US on-road emissions would be approximately 67,657 Mt of GHG emissions.

The potential GHG reductions and implementation costs of various strategies depend upon the geography and extent of their implementation, when they are put into place, and how aggressively they are pursued (e.g. price for tolls or taxes, level of transit service offered). In general, the Moving Cooler study evaluated all strategies applied nationally across the United States, applying to urban, rural and intercity transportation. While the Moving Cooler study evaluated three different levels of deployment, it is sufficient for this report to look at only of them to understand the relative performance of strategies. The middle level of deployment, “More Aggressive: Faster, Broader, Stronger Implementation”, is reviewed. At this level of deployment,

*Strategies are implemented sooner, more broadly, and more intensively [than the “Expanded Current Practice” level]. For example, pricing strategies would be implemented in a wide range of metropolitan areas, and requirements would be established for the penetration of pay-as-you-drive insurance in all 50 states* (Cambridge Systematics Inc., 2009, p. 26).

A full description of included strategies and methods of evaluation are not presented in this report. Readers are invited to consult the Moving Cooler study for full details.

The following table presents Moving Cooler’s results on cumulative GHG emissions reductions and implementation costs (in $2008 US) across the 47 strategies over the 40 year time horizon. The second column, percentage of total emissions, indicates relative cumulative reductions as compared to the baseline of 67 657 Mt. Each measure is ranked from 1 (highest) to 47 (lowest) in terms of its overall GHG reduction performance. Estimated cost of implementation at the “More Aggressive” level of deployment is also indicated.

### Table A 3 – Moving Cooler Cumulative GHG Reduction and Implementation Costs, 2010 to 2050, Aggressive Deployment

| Strategy Description | GHG Reduction (Mt) | Rank (GHG) | % of total emissions | Implementation cost ($B 2008) | Cost effectiveness( million $ / Mt)* |
|---|---|---|---|---|---|
| **Pricing Strategies** | | | | | |
| CBD/Activity Center on-street parking | 41 | 28 | 0.06% | 0.05 | 1.22 |
| Tax/higher tax on free private parking | 18 | 33 | 0.03% | 0.05 | 2.78 |
| Residential parking permits | 20 | 32 | 0.03% | 0.05 | 2.50 |
| Cordon Pricing | 76 | 18 | 0.11% | 36.1 | 475.00 |
| Congestion Pricing | 1021 | 6 | 1.51% | 349 | 341.82 |
| Intercity Tolls | 54 | 24 | 0.08% | 44.7 | 827.78 |
| Pay-as-you-drive insurance | 1677 | 3 | 2.48% | 166 | 98.99 |
| VMT fee | 840 | 8 | 1.24% | 166 | 197.62 |
| Carbon Pricing | 3343 | 1 | 4.94% | 0.05 | 0.01 |
| **Land Use and Smart Growth Strategies** | | | | | |
| Combined Land Use | 865 | 7 | 1.28% | 1.5 | 1.73 |
| **Non-motorized Transportation Strategies** | | | | | |

| Strategy Description | GHG Reduction (Mt) | Rank (GHG) | % of total emissions | Implementation cost ($B 2008) | Cost effectiveness( million $ / Mt)* |
|---|---|---|---|---|---|
| Combined Pedestrian | 171 | 12 | 0.25% | 30.4 | 177.78 |
| Combined Bicycle | 117 | 14 | 0.17% | 20.6 | 176.07 |
| **Public Transportation Strategies** | | | | | |
| Transit Fare Measures | 34 | 29 | 0.05% | 0.05 | 1.47 |
| Transit Frequency/LOS/Extent | 72 | 19 | 0.11% | 102.6 | 1 425.00 |
| Urban Transit Expansion | 281 | 10 | 0.42% | 503 | 1 790.04 |
| Intercity Passenger Rail | 47 | 25 | 0.07% | 35.6 | 757.45 |
| High-Speed Passenger Rail | 97 | 15 | 0.14% | 108.2 | 1 115.46 |
| **HOV/Carpool/Vanpool/Commute Strategies** | | | | | |
| HOV Lanes | 64 | 22 | 0.09% | 231.9 | 3 623.44 |
| Car-sharing | 77 | 17 | 0.11% | 0.3 | 3.90 |
| Employer-Based Commute Strategies | 486 | 9 | 0.72% | 120.8 | 248.56 |
| **Regulatory Measures** | | | | | |
| Non-motorized Zones | 4 | 40 | 0.01% | 4.2 | 1 050.00 |
| Urban Parking Restrictions | 189 | 11 | 0.28% | 0.05 | 0.26 |
| Speed Limit Reductions | 2320 | 2 | 3.43% | 6.5 | 2.80 |
| **System Operations and Management Strategies** | | | | | |
| Eco-driving | 1170 | 4 | 1.73% | 0.05 | 0.04 |
| Ramp Metering | 78 | 16 | 0.12% | 3.1 | 39.74 |
| Variable Message Signs | 2 | 41 | 0.00% | 2 | 1 000.00 |
| Active Traffic Management | 46 | 26 | 0.07% | 10.8 | 234.78 |
| Integrated Corridor Management | 46 | 2 | 0.07% | 10.8 | 234.78 |
| Incident Management | 72 | 19 | 0.11% | 5.4 | 75.00 |
| Road Weather Management | 1 | 42 | 0.00% | 4.9 | 4 900.00 |
| Signal Control Management | 18 | 33 | 0.03% | 6.1 | 338.89 |

| Strategy Description | GHG Reduction (Mt) | Rank (GHG) | % of total emissions | Implementation cost ($B 2008) | Cost effectiveness( million $ / Mt)* |
|---|---|---|---|---|---|
| Travel Information | 30 | 30 | 0.04% | 4.9 | 163.33 |
| Vehicle Infrastructure Integration | 16 | 35 | 0.02% | 42.6 | 2 662.50 |
| **Bottleneck Relief and Capacity Expansion Strategies** | | | | | |
| Bottleneck Relief | -5 | 46 | -0.007% | 71.4 | (14 280.00) |
| Capacity Expansion | -7 | 47 | -0.01% | 617 | (88 142.86) |
| **Multimodal Freight Strategies** | | | | | |
| Rail Capacity Improvements | 66 | 21 | 0.10% | 32.6 | 493.94 |
| Marine System Improvements | 8 | 37 | 0.01% | 8 | 1 000.00 |
| Shipping Container Permits | 8 | 37 | 0.01% | 0.05 | 6.25 |
| Long Combination Vehicle Permits | 12 | 36 | 0.02% | 0.05 | 4.17 |
| Weigh-in-motion Screening | 1 | 42 | 0.00% | 0.05 | 50.00 |
| Weight Station Bypass through electronic credentials | 1 | 42 | 0.00% | 0.05 | 50.00 |
| Truck Stop Electrification | 25 | 31 | 0.04% | 1.3 | 52.00 |
| Battery Operated Truck Auxiliary Power Units | 148 | 13 | 0.22% | 0.3 | 2.03 |
| Truck-only Toll Lanes | 59 | 23 | 0.09% | 42.7 | 723.73 |
| Urban Consolidation Centers | 8 | 37 | 0.01% | 0.4 | 50.00 |

*Calculated based on information contained in the Moving Cooler Report

A review of individual strategies in the Moving Cooler study found that (Cambridge Systematics Inc., 2009):

- **Economy-wide pricing strategies** generally performed well among all strategies. Economy-wide measures such as carbon fuel pricing (3,343 Mt reduction), pay-as-you-drive insurance (1,677 Mt), and VMT fee (840 Mt), ranked in the top ten strategies in terms of cumulative GHG emissions. Pricing carbon fuel was found to reduce the most GHG emissions because it discourages travel and spurs improvements in vehicle fuel efficiency. Pricing strategies can also be applied more regionally and locally to influence travel behaviour in specific locations or at specific times of day. Of the regional or local pricing strategies, congestion pricing applied through time-specific tolling along roadways was estimated to reduce the most emissions (1,021 Mt), followed by cordon area pricing (76 Mt), on-street parking fees in central areas (41 Mt), residential parking controls (20 Mt) and higher taxes on free private parking areas (18 Mt). The relative performance of the various pricing strategies in reducing cumulative GHG emissions is tied to the number and extent to which travellers using motor vehicles could be affected. Everyone is affected by carbon taxes and pay-as-you-drive insurance, whereas a decreasing number of travellers would likely be affected by congestion pricing (e.g. congested areas only), cordon pricing (e.g. specific cordon area only), central on-street parking fees, and taxes on free private parking.

- Among the non-pricing measures, the Moving Cooler Study found that **speed limit reductions** (2,320 Mt reduction) and **eco-driving training** programs (1,170 Mt) ranked in the top 5. Note that speed limit reductions implied reducing current maximum speed limits to 55 mph (~90 km/h). However, since interurban travel is considered in the Moving Cooler Study, the relative performance of reducing speed limits is likely to be lower in the present study, which is focused on local and regional municipalities. The evaluation of eco-driving training, which involves teaching both better driving techniques as well as proper vehicle maintenance, was based on reaching 20 % of the US population and achieving an 8 % net adoption by drivers.

- An integrated set of **land use strategies** also performed well (865 Mt reduction) among all strategies. Land use strategies take many years to implement, require the participation of many different actors, and begin accruing small benefits in the short term before escalating significantly in the long term. However, the benefits of land use strategies can be expected for many years after the 40 year time horizon of the study.

- Among the **transportation supply side initiatives**, urban transit expansion (281 Mt reduction) ranked highest, followed by pedestrian strategies (171 Mt), bicycle strategies (117 Mt), promoting car-sharing (77 Mt), improving transit levels of service (72 Mt), increasing HOV lanes (64 Mt) and decreasing transit fares (34 Mt). It should be noted that employer based commuting strategies (486 Mt) performed well, and comprise both supply side measures (e.g. facilitating carpooling, purchasing transit passes), demand management (e.g. employee parking pricing) and commuting strategies (e.g. encouraging telecommuting and a compressed work week). In terms of cumulative GHG reductions, transportation supply side initiatives are about one to two orders or magnitude less effective than economy-wide pricing and land use strategies.

- **System operation and management strategies** to optimize the fuel efficiency of travelling vehicles generally ranked in the middle of the pack. In descending order, ramp metering scored highest (78 Mt reduction), followed closely by incident management (72 Mt), active traffic management and integrated travel corridor management (46 Mt), providing accurate and timely information about roadway conditions, incidents, closures, special events, alternate routing (30 Mt), and signal control management (18 Mt).

- **Freight improvements** were estimated to achieve generally modest cumulative GHG emissions reductions compared to other strategies from a national perspective. The most effective strategies were the requirement to install battery operated auxiliary power units in truck cabs (148 Mt reduction), followed by enhancing rail capacity (66 Mt), truck-only toll lanes in large urban areas (59 Mt) truck stop electrification (25 Mt), use of urban consolidation centres for deliveries in large urban areas (8 Mt).

- Of all strategies evaluated in the Moving Cooler Study, only two, **highway capacity expansion** (+7 Mt increase) and expansion at specific bottlenecks (+5 Mt increase), generated a net positive contribution to cumulative GHG emissions. The study found that while fuel consumption and congestion improves in the short term after capacity expansion occurs, this is offset by induced VMT over the 40 year study horizon.

The Moving Cooler Study also explores the performance of bundling individual strategies together. Various strategies can be complementary in terms of timing, technical feasibility or behaviour reinforcement, and can be put together to achieve greater reductions in GHG emissions. The Moving Cooler Study proposes and evaluates six different strategy bundles. A description of each strategy bundle, cumulative GHG reduction, % cumulative reduction compared to study baseline (67.7 Gt), as well as net costs per tonne of GHG reduced[45] are presented in the following table.

### Table A 4 – Moving Cooler Strategy Bundles, Cumulative GHG Reductions, Net Cost / Tonne GHG Reduction, 2010 to 2050, Aggressive Deployment Level

| | Bundle Name | GHG Reduction (Gt) | % of total emissions | Net Cost / Tonne Reduction |
|---|---|---|---|---|
| 1 | **Near-Term/Early Results** | **7.1** | **10.5%** | **-356** |
| | Strategies that can be implemented relatively quickly to obtain GHG reductions in near term. Assuming political or financial barriers overcome, strategies can be put in place quickly compared to others requiring intensive construction or fundamental changes in land use policies and patterns. | | | |
| 2 | **Long-Term/Maximum Results** | **7.6** | **11.2%** | **-293** |
| | All-out effort to achieve maximum GHG reductions by pursuing all non-duplicative strategies. Presumes all cost, technical feasibility issues are resolved, including shifts in national attitudes and political will. Almost every single strategy is included in this bundle. | | | |
| 3 | **Land Use/Transit/Non-motorized Transportation** | **3.8** | **5.6%** | **-484** |
| | Focus on shift towards transportation-efficient land use changes to promote more transit, active transportation, and alternative trips. Land use changes would result in shorter trips overall, and fewer trips by SOV. Expansion of alternative transportation supply. | | | |
| 4 | **System and Driver Efficiency** | **5** | **7.4%** | **-69** |
| | Strategies focus on enhancing efficiency of transportation system by making the most of existing road, rail and transit infrastructure while targeting capacity expansions at specific highly congested areas. Strategies use infrastructure optimizations and traffic management to improve travel speeds, reduce start/stops and congestion. | | | |
| 5 | **Facility Pricing** | **1.4** | **2.1%** | **891** |
| | Strategies to expand transit and highway infrastructure combined with local and regional pricing mechanisms to shape travel choice. | | | |
| 6 | **Low Cost** | **7.5** | **11.1%** | **-387** |
| | All lowest cost strategies packaged together without consideration of whether strategies may or may not actually work together. | | | |

45 *Net costs / tonne of GHG was calculated based on implementation costs minus vehicle cost savings (ownership and operating costs), divided by the amount of cumulative GHG emissions reduced. Oher co-benefits such as travel time savings, safety, public health, environmental quality were not included. The net cost / tonne GHG reduction illustrates the overall benefit to society. The Moving Cooler study recognizes that vehicle cost savings may not accrue to the same agencies who were responsible for implementing and paying for strategies.*

The evaluation of bundling strategies suggests that implementing the long-term/maximum strategy bundle can reduce cumulative GHG emissions the most (11.2 % reduction of US cumulative transportation GHGs over baseline), followed by the low cost bundle (11.1%), near-term/early results bundle (10.5%), system and driver efficiency bundle (7.4%), land use/transit/non-motorized transportation bundle (5.6%) and facility pricing bundle (2.1 %).

In terms of net costs per tonne of GHG reduced, the land use/transit/non-motorized transportation bundle was estimated to be the most beneficial for society, or a net cost of -$484/tonne of GHG reduced (i.e. net gain for society). This result is in large part due to the significant savings that can be achieved in reducing the need and costs of vehicle ownership and operations due to combined land use/transit/active transportation measures, which handily outweigh the costs of implementation.

The near-term/early results bundle, and the low cost bundle performed almost as well (-$356 and -$387 / tonne GHG reduced respectively). These results suggest that choosing strategy bundles via a near-term/early results or lowest cost approaches could yield interesting results, although the applicability of such approaches to individual jurisdictions will need to be evaluated.

The system and driver efficiency bundle is rated second last in terms of cost-effectiveness (-$69/tonne of GHG reduced). However, it was estimated to achieve more GHG emissions savings than land use/transit/non-motorized transportation bundle. The performance of this strategy bundle can be attributed to the fact that the majority of on-road transportation in the USA still occurs in private vehicles. Thus, making the transportation system more efficient targets a larger portion of GHG emission sources (i.e. vehicle travel). Significant investments are required in this strategy bundle for improving the operations and management of the transportation system; alleviating bottlenecks and congestion through targeted capacity expansion; and implementing advanced intelligent technology systems (ITS) to track, monitor, adjust and optimize transportation flows. In short, this strategy bundle aims to make the existing transportation system and vehicle operation more efficient, but does not necessarily aim to reduce VKT, reduce trip length, or change the way people travel in the way that the land use/transit/non-motorized transportation strategy bundle does (e.g. reduce vehicle dependence and ownership). Thus, the system and driver efficiency bundle may achieve higher GHG emissions because it targets vehicle use, but significant investments are still required to implement this strategy bundle, motor vehicle use is still favoured, and significant vehicle cost savings are not realized.

Finally, the facility pricing bundle once again was estimated to be the least beneficial at a net cost of $1693 B/Gt, and is the only one which direct implementation costs do not outweigh vehicle cost savings. This latter bundle is most costly because it focuses largely on highway and transit infrastructure capacity and service expansion, and less attention dedicated to optimization of existing systems.

## Review of the Cost-effectiveness of BART Actions to Reduce GHG Emissions

A recent study for the San Francisco Bay Area Rapid Transit system (BART) compares the cost-effectiveness of various actions on a more regional scale (Nelson/Nygaard Consulting Associates, 2008). Actions evaluated comprised those fully within the control of BART (e.g. transit service) as well as those requiring the coordination of regional partners for broader land use and transportation changes. Assessed costs only covered public sector costs, not those to individuals or businesses (Nelson/Nygaard Consulting Associates, 2008).

The figure below presents the cost-effectiveness evaluation of various BART actions.

## Table A 5 – Cost Effectiveness of BART Actions (Cost / tonne of GHG emissions)

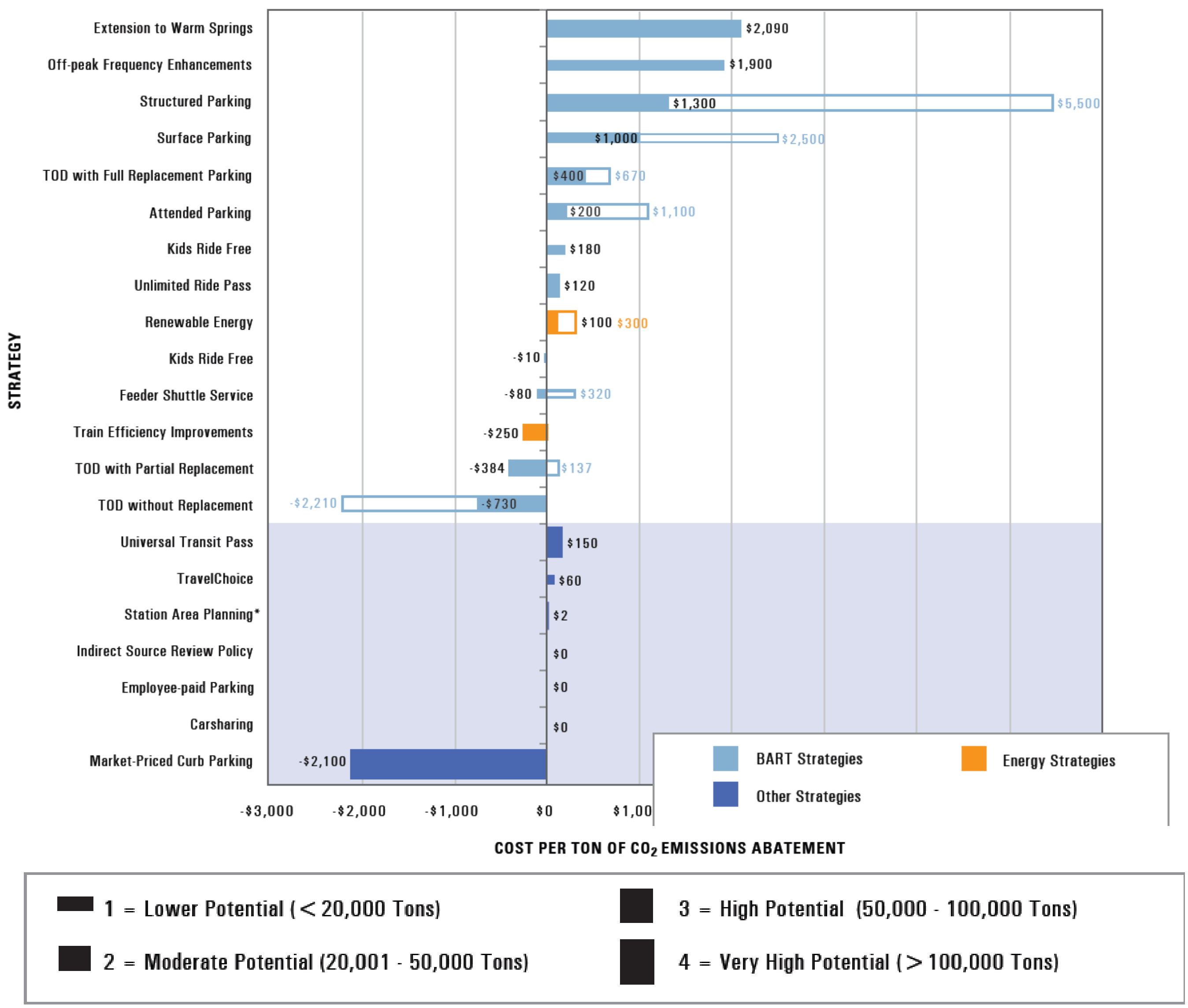


Figure source: (Nelson/Nygaard Consulting Associates, 2008, p. 3)

According to this study, the least cost-effective actions in terms of GHG reduced per expenditure were those requiring new capital or operational expenditure, including BART system expansion, construction of new parking areas and increasing service frequency. More cost-effective actions with low to high potential for GHG reduction were fare incentive measures, marketing, and adding feeder shuttle services. These relatively low cost actions performed well from a cost-effectiveness perspective because they increased ridership on existing services. Train efficiency improvements, as well as land use development on BART property turned out to be net revenue generators which have a moderate GHG reduction potential. Finally, paid public parking strategies were significant revenue generators for BART with a very high potential to reduce GHG emissions.

## Summary of GHG Reduction Potential in the Toolbox of Measures

The following section provides a summary of GHG reduction potentials drawn from the document and literature review completed as part of this mandate[46]. GHG impacts from the various toolbox measures are summarized in the table below. Unfortunately, it is difficult to make a comparison based on this data because of differing geographic contexts, scales of application, application intensities, differing methodologies for measurement, and different base units for comparison (per VKT, per year, per household, per capita).

| Measures and Examples | GHG Reduction Potential | Geography/Scale of Implementation | Study Time Horizon |
|---|---|---|---|
| **Reduce Vehicle Kilometres Travelled** | | | |
| Land Use | | | |
| TOD | 2.5 - 3.7 t GHG / household / year | California | |
| TOD | 20 - 40 % GHG reduction compared to baseline | Uptown District in San Diego, and Mountain View, CA | |
| TOD/Urban Areas | 3 – 8 t GHG / household / year | Chicago, Toronto | |
| Transportation Supply-Side Alternatives | | | |
| Public Transit Measures | | | |
| 12 m diesel bus fully loaded vs. SOV | 0.36 kg GHG / VMT | USA | |
| 40 km round trip to work by bus transit vs. SOV | 2.2 t GHG / year | Laval Transit, QC | |
| People living close to Frequent Transit Network | 33% less VKT per capita | Metro Vancouver Region | |
| Taxibus Transit | Low impact due to low ridership | Low density areas | |
| Active Transportation | | | |
| Bicycle transportation | 40 x more energy efficient than travel by car | | |
| Car Sharing | | | |
| All car sharing services | 0.84 t GHG / year / household, or<br>158 – 224 kt GHG / year | North America | |

[46] *Excluding the results from the Moving Cooler Study.*

| Measures and Examples | GHG Reduction Potential | Geography/Scale of Implementation | Study Time Horizon |
|---|---|---|---|
| Communauto Network | 10.1 kt GHG / year | Quebec | |
| Carpooling | | | |
| 4 person carpool vs. SOV | 0.33 kg GHG / VMT | USA | |
| Carpooling network | 1.5 t / commuter / year | General commute to work in North America | |
| Telecommuting | Unknown | | |
| Pricing Mechanisms | | | |
| Toll roads | 2 – 10 % reduction in VMT | USA | |
| Cordon Area Pricing | 24 % decrease in GHG emissions | London, UK | |
| | 2.7 % GHG / year, or 41 kt GHG / year | Stockholm, Sweden | |
| Distance Based Pricing | 60 % reduction GHG / year | Leeds region, UK | 10 years |
| HOV Lanes | 7 % reduction in GHG emissions during AM peak | San Francisco Metro Area | |
| Distance based insurance costs | 5 – 10% decrease in VKT | Minnesota and Texas | |
| | 8 % reduction in VMT and 2 % reduction in GHG emissions | USA | |
| Gas and Carbon Taxes | Average 2.5 % reduction / year of total province's GHG emissions | British Columbia | 2008 - 2012 |
| Increase Parking Costs | | | |
| Modal shift from cars to transit, 20 km commute | 17 kt GHG / year | Central Perth, Australia | 1999 - 2001 |
| Parking Mechanisms | | | |
| Parking Management | No data found | | |
| Cash in lieu of parking | | | |
| Mandatory parking cash-out | 1.1 % reduction in VMT | USA | |
| Parking cash-out | 12 % reduction in GHG | Eight employers, Downtown LA, USA | |
| Trucking | | | |
| Optimizing Logistics Management | 8 % reduction in GHG emissions | Global | |
| Consolidated freight delivery | 1.5 t GHG / year | City of La Rochelle, France | |

| Measures and Examples | GHG Reduction Potential | Geography/Scale of Implementation | Study Time Horizon |
|---|---|---|---|
| centre | | | |
| Encouraging freight modal shift | | | |
| Marine vs. truck freight transport | 0.7 – 1.4 kg GHG / tonne-km | | |
| Enhanced inspection and maintenance programs | No data found | | |
| **Improve Transportation System and Driver Efficiency** | | | |
| Infrastructure Capacity Expansion | GHG emissions increase from induced traffic | | |
| Speed Change Policies | | | |
| Reducing max speed from 120 to 105 km/h | 20 % reduction in fuel consumption | | |
| Limiting truck speeds to 105 km/h | 0.64 Mt GHG reductions / year | Ontario and Quebec | |
| Traffic Signal Optimization | | | |
| Corridor Signal optimization | 17 % reduction in fuel consumption | Quebec | |
| Corridor Signal optimization | 1 – 7 % GHG reduction | Toronto | |
| Ramp Metering | No data found | | |
| Incident Management | Incidents responsible for 25 – 60 % of all urban highway congestion | USA | |
| Transit Priority Measures | 4 kT GHG reduction / year | Montreal Transit Corporation, 56 urban routes | |
| Eco-driving training | No data found | | |
| **Encourage Alternative Vehicle and Fuel Technologies** | | | |
| Improved LD vehicle fuel economy | 8 – 30 % GHG reduction / year over baseline | USA | By 2030 |
| Canadian Fuel Economy Regulations for LD Vehicles | 17 Mt GHG / year | Canada | By 2020 |
| Transit Vehicle Technologies | | | |
| Cost-effectiveness of various bus technologies | \$0.13 – 0.65/ kg GHG - diesel-electric<br>\$0.26 –1.30 / kg GHG – battery electric | European survey of transit operators | By 2030 |

| Measures and Examples | GHG Reduction Potential | Geography/Scale of Implementation | Study Time Horizon |
|---|---|---|---|
| | $0.65 – 0.91/ kg GHG – fuel cell<br><br>$0.78/ kg GHG – CNG<br><br>$0.91/ kg GHG – trolley electric | | |
| Hybrid-electric bus | 12 % reduction, or 15 t GHG / bus / year compared to conventional diesel bus | 70,000 km / year, Gatineau Quebec | |
| Hybrid-electric bus | 36 % reduction, 36 t GHG / bus / year compared to conventional diesel bus | 70,000 km/ year, Montreal, Quebec | |
| Heavy-duty Truck Technologies | | | |
| Engine and powertrain technologies | 5 – 50 % reduction in fuel consumption | | |
| Aerodynamics and low rolling resistance tires | 0 – 15 % reduction in fuel consumption | | |
| Implement ICT in all HD trucks | 10 % GHG reductions / year | USA | |
| Low Carbon Fuel Requirements | | | |
| Low Carbon Fuel Requirement of 4.5 % blended in transportation fuels | 3.5 % reduction, 0.91 Mt GHG /year | British Columbia | |

## Canadian Transportation GHG Emissions by Transportation Mode

As seen in chapter 2 of this report (table 2-1), road and rail based passenger and freight transportation accounted for approximately 88 % (~150 Mt / year) of all transportation sector emissions in Canada in 2011. Passenger car, light truck and motorcycles accounted for 52 % (88 Mt / year) of that total, while urban bus and urban rail passenger transportation (e.g. transit service) accounted for less than 4 % (< 7 Mt / year)[47]. Freight by heavy-duty trucks and rail modes accounted for 32 % of emissions (54 Mt / year) in 2011.

[47] *The category, Passenger Transportation by Bus, Rail and Aviation comprises emissions from domestic aviation, and urban and interurban passenger bus and rail service totalling 5 % of transportation emissions (8 Mt) in 2011. The contributions of domestic aviation can be estimated based on Environment Canada's 2014 National Inventory Report. It reported that domestic aviation accounted for nearly 1 % of transportation GHG emissions in Canada in 2011 (Environment Canada, 2014b).However, a specific breakdown of the contribution between the interurban and urban passenger transportation was not available. Nonetheless, it is reasonable to hypothesize that urban bus and rail passenger transportation, or transit service, is likely to have contributed to less than 4 % of GHG (< 7 Mt) emissions in 2011.*

This would suggest that measures to improve the efficiency of passenger transportation by cars and light trucks would be targeting more than half of transportation GHG emissions, while measures targeting on-road freight transportation would be targeting close to one-third of transportation GHG emissions. Measures to improve the fuel efficiency of urban transit would tackle no more than 4 % of total transportation emissions. However, improving transit systems, as well as offering other transportation supply measures are clearly key to reducing passenger transportation by cars and light trucks.

## Evaluating the GHG Reduction Potential of Toolbox Measures to Reduce Urban Transportation Emissions

Based on the review of existing comparative studies on GHG reduction measures for transportation, as well as on current Canadian GHG contributions by transportation mode, the guidelines below were used to assign a qualitative score for GHG reduction potential to each of the measures included in this toolbox. Guidelines are presented in order of those potentially resulting in the greatest emissions reduction to those which may contribute the least.

- Applied provincially or nationally, economy wide pricing mechanisms such as carbon pricing, VKT fees, and distance-based insurance costs have the ability to significantly reduce GHG emissions. In the Moving Cooler Study, these measures applied individually could reduce up to 5 % of cumulative emissions over that study's baseline. In Canada, such measures would target vehicle modes currently contributing to around 150 Mt / year (>80%) of transportation GHG emissions. However, the implementation of these mechanisms largely fall outside the purview of regional and local authorities;
- More regional and local pricing mechanisms can also have a significant effect on transportation GHG emissions. Where high travel demand exists to central or major employment areas, or where there is road congestion along major routes or in certain areas, tolls, congestion pricing and parking pricing can serve as an incentive for other forms of transportation. The Moving Cooler and BART studies found that these pricing measures performed relatively well in reducing GHG emissions, though not to the same extent as economy-wide pricing measures. In Canada, these measures would also target the vehicle modes contributing to around 150 Mt / year (>80%) of transportation GHG emissions. These measures are largely within the purview of regional and local authorities, with the exception or highways which are largely a provincial responsibility;
- More efficient light-duty and heavy-duty vehicle technologies have a significant potential to reduce transportation GHG emissions. Alternative powertrains for light-duty vehicles like plug-in hybrids and fully electric vehicles can significantly reduce or eliminate fossil fuel dependence for most urban transportation purposes in jurisdictions with less GHG intensive energy generation. Similarly, alternative fuels and hybrid systems have the potential to significantly reduce urban truck GHG emissions. Truck aerodynamic improvements and low rolling resistance tires will have a more limited impact for urban transportation as compared to interurban travel due to generally lower vehicle speeds;
- Eco-driving strategies applied nationally could have a relatively important impact on transportation GHG emissions. The Moving Cooler Study found that this measure alone could result in close to 2 % reductions in GHG emissions. Once again in Canada, wide scale eco-driving training could target both truck and passenger vehicle drivers who currently contribute to approximately 150 Mt / year (>80 %) of transportation GHG emissions.
- Comprehensive transportation-efficient land use developments can play a major role in reducing VKT, trip length and vehicle transportation GHG emissions. In the Moving Cooler study, individually,

land use and smart growth strategies could result in a 1.3 % reduction in cumulative GHG emissions. When combined with alternative transportation supply measures such as transit and active transportation, they could result in up to 5 % cumulative reductions. In Canada, land use, transit, and active transportation measures would be aimed at passenger vehicle transportation, which currently contributes just over 88 Mt / year (>50%) of transportation sector GHG emissions.

- The Moving Cooler Study ranked individual transportation supply side initiatives in decrease order of impact in terms of being able to reduce overall transportation GHG emissions: transit expansion, pedestrian strategies, bicycle strategies, car sharing, improving transit levels of service. Individually, emission reductions ranged between 0.1 to 0.4% below study baseline.
- The Moving Cooler Study ranked individual measures to improve the transportation system's efficiency (through reducing congestion and enhancing traffic flow), in decreasing order of impact: ramp metering, incident management, travel corridor management, and signal control management. Individually, cumulative emissions reductions ranged between 0.03 to 0.12% below study baseline. However, bundled together to improve system and driver efficiency, the Moving Cooler Study found that these transportation system efficiency measures could result in approximately 7% reduction in cumulative GHG emissions. In Canada, these system efficiency measures would be targeted at all vehicle modes currently contributing around 150 Mt / year (>80%) of transportation GHG emissions.
- The Moving Cooler study found that employer-based commute strategies, which include encouraging carpooling, parking demand management and pricing, and compensating employees for choosing alternative modes of transport can have a cumulative impact on transportation GHG emissions in the order of 0.7%. It was also included in five of the six strategy bundles evaluated by the Moving Cooler study, highlighting its importance as part of any strategy going forward to reduce transportation GHG emissions.
- The Moving Cooler Study found that all infrastructure capacity expansions, including targeted bottleneck relief, would eventually contribute to a net increase in cumulative GHG emissions. Emissions reductions and smoother traffic flow may result immediately after construction, but induced traffic in the longer term ultimately erases initial reductions in GHG emissions.
- Measures to reduce freight VKT through intermodal transportation were found to reduce cumulative GHG emissions by 0.01 to 0.1%. Truck engine and aerodynamic measures were not considered in the Moving Cooler study, although this study's own review of literature revealed that engine and powertrain technologies could result between 5- 50 % reduction in fuel consumption per truck, while aerodynamic improvements and low-rolling resistance tires could achieve anywhere between 0 – 15 % fuel consumption reduction per truck. Natural gas for truck propulsion was also found to reduce life-cycle GHG emissions by 20 – 30 % as compared with diesel fuels. How these may be generalized to the entire freight sector would require further analysis. However, they would be acting on freight transportation, which currently accounts for over 50 Mt / year (>30%) of Canadian transportation GHG emissions.

Based on these guidelines, a qualitative score of 1 (lowest) to 5 (highest) was assigned to the measures in the toolbox. The scoring summary as well as qualitative reasoning is provided in the following table.

*Land Use*
*Transportation Supply-Side Alternatives*
*Pricing Mechanisms*
*Parking Mechanisms*
*Trucking*
*Transportation System and Driver Efficiency*
*Alternative Fuel and Vehicle Technologies*

## Table A 6 Qualitative Evaluation of Measures Included in the Toolbox

| | Measure | GHG Reduction Potential | Description |
|---|---|---|---|
| | **Reduce VKT** | | |
| 1 | Land Use Planning and Smart Growth | 4 | Sustained, long term planning and smart growth can have a significant impact on GHG emissions by reducing VKT, making trips shorter, and support transit and active modes of transportation |
| 2a | Expand Transit Service | 3 - 4 | Can have significant impact on reducing car based travel while current transit vehicle fleets contribute marginally to GHG emissions |
| 2b | Enhance Existing Transit Services | 3 | |
| 3 | Provide Taxibus Transit Service | 1 | Taxibus transit service is generally limited to small, low density communities or on the peripheral areas around municipalities where regular transit service is not viable |
| 4 | Encourage Active Transportation | 3 | Long term effectiveness is extremely high through encouraging development of zero-emission travel mode, but has little impact for medium to longer travel distances |
| 5 | Provide Carsharing Services | 2 – 3 | Encourages more considered and moderate use for some users, but continued use of fossil fuels for vehicle travel (regular and hybrid vehicles), car travel may continue to contribute to congestion. |
| 6 | Encourage Carpooling | 2 - 3 | Carpoolers depend on passenger/driver matches, flexibility of riders, which has limited widespread effectiveness, but widespread employer programs may be more effective. |
| 7 | Encourage Telecommuting | 2 | Depends on uptake of program by employees |
| 8 | Implement Toll Roads and Cordon/Area Pricing | 3 | Effective in area or segment that is tolled, but some travel may shift to un-tolled routes. Will also depends on whether alternatives (e.g. transit) are attractive |
| 9 | Implement Distance Travelled Fees | 5 | Impact directly proportional to VKT, provides strong incentive to changing travel behaviour |
| 10 | Charge Distance-based Insurance Costs | 3 - 5 | Impact directly proportional to VKT, but non-mandatory implementation may see only some drivers adhere to the program. |

| | Measure | GHG Reduction Potential | Description |
|---|---|---|---|
| | | | Mandatory, nation-wide application will be more successful. |
| 11 | Implement a Fuel Sales or Carbon Tax | 5 | Comprehensive, multi-sectoral impacts, directly proportional to VKT, reductions depends on tax rate. |
| 12 | Increase Parking Costs | 2 – 3 | Provides strong incentive to changing travel behaviour, but only to (central) areas which are priced. Changes in zoning requirements apply only to new developments and not to existing zones |
| 13 | Offer Fees in Lieu of Travel, Cash in Lieu of Parking | 2 – 3 | Depends on uptake of program by employees, but can be part of a comprehensive employer program alter commuting habits |
| 14 | Optimize the Use of Existing Parking Spaces | 1 – 2 | Reducing parking availability is a strong mechanism for encouraging a change in travel behaviour. Furthermore, it supports densification of urban environment, which may in the long term contribute to more active transportation and transit use. Dynamic parking guidance systems helps drivers find parking spaces more quickly, but does not discourage vehicle use |
| 15 | Reduce Minimum Parking Requirements | 1 – 2 | Short term effectiveness limited to new developments, but supports denser urban development by reducing parking needs, contributes to active transportation and transit use in the long term |
| 16 | Enhance Logistics Management | 2 - 3 | Depends on the extent to which truck loads can be maximized while minimizing VKT. |
| 17 | Encourage Modal Shift for Freight | 1 | Freight by train and boat have significantly lower GHG emissions per tonne/km than trucks, although opportunities for intermodal deliveries in urban areas will be limited. |
| 18 | Enhance Truck Inspection and Maintenance | 1 - 2 | Inspection programs tend to have a greater impact on air pollution emissions from inefficient or older combustion engines, but impacts to GHG emissions are small |
| | **Improve Transportation System and Driver Efficiency** | | |
| 19 | Increase Infrastructure Capacity | 1 | Benefit of added capacity reduces congestion in the short term, but does not encourage modal shift. In the medium to longer term induced vehicle traffic will lead to congestion in the future, erasing net gains. |
| 20 | Manage Roadway Capacity Dynamically | 1 – 2 | Benefits to added capacity reduces congestion in the short term, but vehicles are still being used. In the medium to longer term induced vehicle traffic will lead to congestion in the future, erasing gains. |
| 21 | Implement Speed Change Policies | 3 – 4 | May reduce traffic congestion, but does not encourage modal shift |
| 22 | Optimize Traffic Signal Operation and Timing | 2 – 3 | Can improve traffic flow, but does not stimulate modal shift. |
| 23 | Implement Ramp Metering | 3 – 4 | Reduced congestion on highways allowing more free flow of traffic |
| 24 | Improve Traffic Incident Management | 3 – 4 | Removes bottlenecks and congestion more rapidly |
| 25 | Provide Transit Priority Measures | 2 | Decreases fuel consumption by transit vehicle fleet, but they contribute very little to GHG emissions. |

| | Measure | GHG Reduction Potential | Description |
|---|---|---|---|
| 26 | Encourage Eco-driving | 3 - 4 | Individual fuel savings are small, but large scale training can lead to significant reductions. Long term effectiveness depends on continued practice by drivers |
| | **Encourage Alternative Vehicle and Fuel Technologies** | | |
| 27 | Encourage Adoption of Efficient Vehicle Technologies | 4 – 5 | Vehicle technologies have the potential to significantly reduce GHG emissions. PHEV and EV in particular have significant potential in jurisdictions where grid electricity is less reliant on fossil fuels |
| 28 | Implement New Transit Vehicle Technologies | 1 | Transit vehicle GHG emissions are a very small % of overall transportation GHG emissions in Canada. Reductions in transit vehicle GHG emissions will therefore make a small contribution to overall GHG emission reduction |
| 29 | Encourage New Heavy-Duty Vehicle Technologies | 4 - 5 | Widespread adoption of efficient heavy-duty vehicle technologies may contribute to significant GHG emissions reductions |
| 30 | Use Low Carbon Fuels | 2 | Small percentages of biofuels are already blended into conventional fuels in many jurisdictions in North America, but the ability of biofuels to replace a significant portion of conventional fuels is unlikely due to fuel feedstock requirements. |

Finally, it is interesting to note that the Moving Cooler Study found that even the long-term/maximum results strategy bundle at the middle, "Aggressive" level of deployment only resulted in a cumulative **reduction of 11.2%** of GHG emissions over the 40 year study time horizon. Even at the study's highest deployment level, "Maximum Effort", this strategy bundle resulted in a **16% cumulative reduction** of US road-based transportation sector GHG emissions[48]. These values may provide an indication of the current upper-bounds of an all-out, economy wide effort to reduce transportation sector GHG emissions in North America.

It should be noted that the estimates of GHG reduction potentials discussed above are in reference to the Moving Cooler study baseline, which estimated that approximately 67.7 Gt of GHGs would be emitted between 2010 and 2050 (40 years) based on current policies in place in the USA.

This report does not provide a quantitative estimate of the potential GHG emissions reductions that are achievable by the toolbox of measures. The effort to do so is out of scope of the current mandate, and would require a full evaluation of the geography, timeframe, feasibility and intensity of implementation of the various measures within the context Canadian. However, a similar methodology to the Moving Cooler study can be used to estimate the upper limits of potential GHG emissions reductions. This can be done by applying the maximum reductions (as a %) estimated by the Moving Cooler study to Canadian transportation sector emissions.

[48] *In order to implement this strategy bundle's all-out effort to reduce GHG emissions, the study assumed that significant changes to political will and travel behaviour have occurred, and the significant financial and technical barriers were overcome.*

To do so, an estimate of cumulative baseline emissions for Canadian road and rail passenger and freight transportation between 2015 and 2030 is made. This estimate was developed based on assuming a linear growth rate in annual emissions between 2011 and annual values projected by the Government of Canada for 2020 and 2030 for these modes. The estimated cumulative emissions are approximately 2,415 Mt. The table below presents what a 5%, 10%, and 16% cumulative reduction in GHG emissions over 15 years might represent in terms of the Canadian road and rail passenger and freight transportation sector.

### Table A 7 Potential Reductions in GHG Emissions in Canada Applying Moving Cooler Study Results

| Level of Reduction | GHG Reduction in Canada (Mt) | Equivalent Annual Emission Reductions (Mt) |
|---|---|---|
| 16 % (Maximum Effort and Deployment according to Moving Cooler Study) | **386** | **25** |
| 10 % (Similar to Moving Cooler Low Cost Bundle, Aggressive Implementation) | **241** | **16** |
| 5 % (Similar to Moving Cooler Land Use/Transit/Non-motorized transportation strategy bundle, Aggressive Deployment) | **120** | **8** |