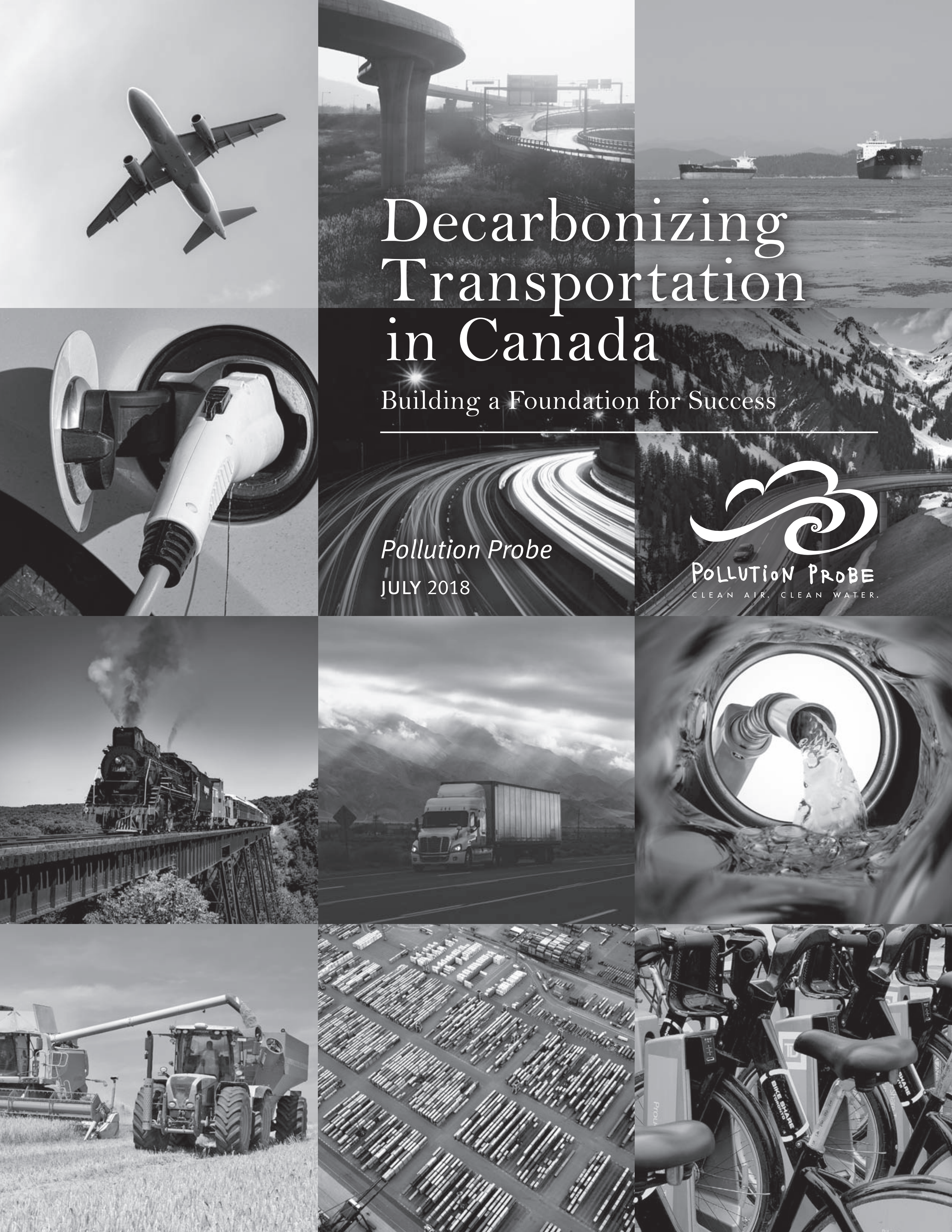

Decarbonizing Transportation in Canada

Building a Foundation for Success

Pollution Probe

JULY 2018

POLLUTION PROBE

CLEAN AIR. CLEAN WATER.

ABOUT POLLUTION PROBE

Pollution Probe is a national, not-for-profit, charitable organization which is improving the health and well-being of Canadians by advancing policy that achieves positive, tangible environmental change. It is a leader in building successful partnerships with industry and government to develop practical solutions for shared environmental challenges. Pollution Probe is leading the delivery of the Electric and Hydrogen Vehicle Advancement Partnership on behalf of the Government of Ontario, to accelerate the adoption of low emission passenger vehicles.

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TOYOTA

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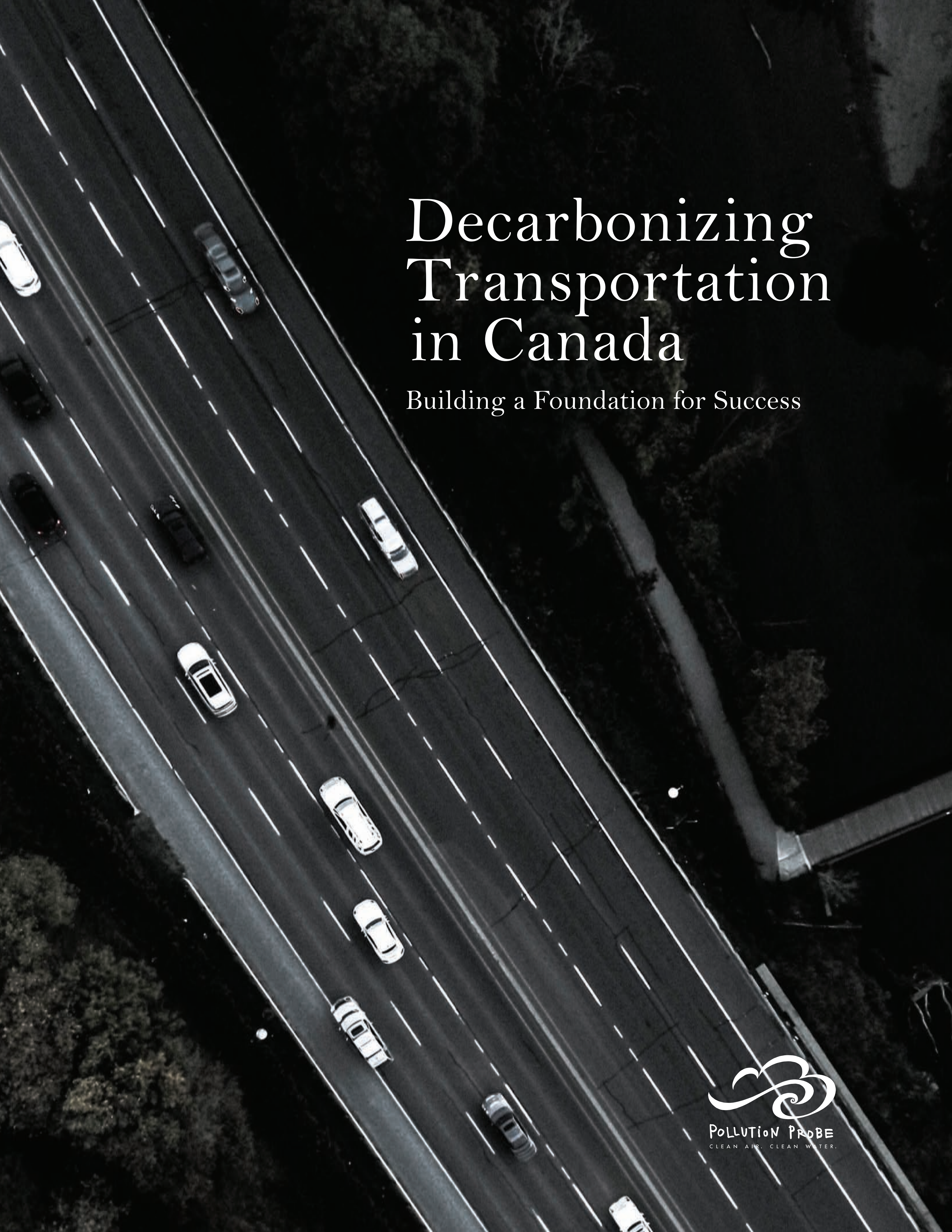

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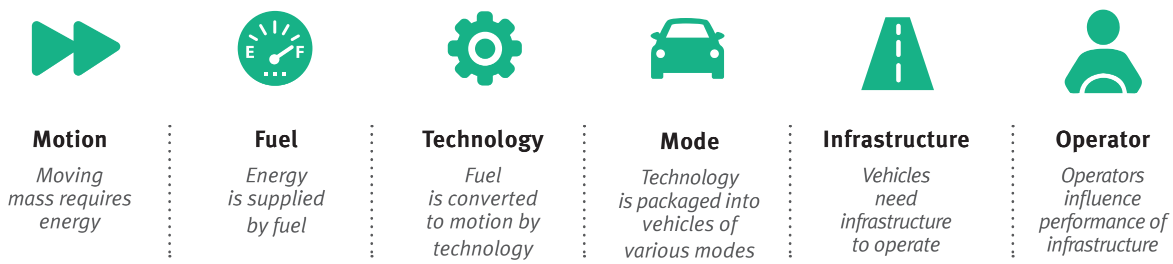
Table of Contents

Executive brief

Pollution Probe is pleased to present this report, which explores a framework approach for developing comprehensive strategies to reduce greenhouse gas (GHG) emissions from transportation energy use in Canada. The intent is to inform and support the current development of decarbonization policies as proposed in the Pan-Canadian Framework on Clean Growth and Climate Change, published by the Government of Canada in 2016.

In this report, key factors that influence overall demand for transportation energy are discussed and grouped into six discrete categories (Section 3). Together, these categories conceptually represent elements of the transportation energy system, depicted as follows:



Intuitively, a change within any *one* of these elements will contribute to *a degree* of overall system change in transportation energy use and in GHG emissions. But an array of actions that target reductions in *all* elements of the system can contribute much more progress towards decarbonization, especially if the actions are complementary or mutually reinforcing. This is the premise that encourages a comprehensive, strategic approach to decarbonizing transportation energy use, and the elements shown above constitute the core of the proposed framework.

To test and demonstrate the utility of the framework in this report, a review of current policies that influence GHG emissions from transportation is conducted (Section 4). These policies are identified and characterized according to the framework elements. Essentially, this is a retrospective exercise that establishes a baseline from which to develop a new, forward-looking strategy.

Next, the framework is populated with a fresh array of policy options for consideration (Section 5). The list of options explored in the report is not exhaustive, but it is sufficient to illustrate how the framework can be used as a tool of strategy development. The intended output is a set of policies and measures that can be further explored to help advance the decarbonization of transportation, holistically (i.e., by levering positive change throughout *all* elements of the system).

To help limit the scope of interventions in the system to a practical level, the following assumptions were observed when developing policy options:

- The market for mass-produced vehicles in Canada is a subset of a global market, and its influence over technology and design is neither hegemonic nor irrelevant. In other words, Canadian policy can stretch global vectors and trends in vehicle design, but not wholly detach from them without forfeiting economic benefits of scale.
- Canada's public-sector capacity for investment is not unlimited, and must serve a wide range of priorities. Therefore, policy options that are relatively low-cost to implement and administer, yet generate persistent pressure toward lower-carbon transportation system outcomes should be in-scope and fully considered. Options that generate multiple environmental and socioeconomic benefits, including public health and safety, should be prioritized.
- Markets are powerful levers of technological and social change, yet are unpredictable. Within markets, innovation produces commercial success when it creates new value for consumers. Therefore, to the extent possible, public policy should reward progress toward desired outcomes but refrain from prescribing specific means and solutions. Thereby, the efficiencies of markets and power of invention will be fully harnessed, while the risk of unintended consequences or unfair distributions of impact will be wisely avoided.

The experience of developing and applying the framework approach in this report yielded the following observations (Section 6):

- A successful decarbonization strategy will likely rely on policies implemented by government as well as a range of measures led by the private sector, or jointly conducted by both.
- There are some areas of technology development where Canada and Canadian organizations can lead from positions of strength and capacity, supporting clean economic growth.
- Some elements of the transportation system (e.g., infrastructure, operator) have not been a focus of decarbonization efforts in the past, and thus suffer from the lack of a well-developed knowledge base on policy options.
- The framework approach supports inclusive and collaborative strategy development and implementation, since it can draw on the interests and capacities of a range of stakeholders in every part of the transportation energy system.
- The framework supports an adaptive strategy for decarbonizing transportation, as it can be updated continually to meet the needs and opportunities of a continually evolving landscape.

Pollution Probe looks forward to using the framework described in this report to engage all sectors of society in developing strategies that support government efforts to decarbonize transportation energy use in Canada. The policies and measures introduced in this report can also be considered as options for further investigation and development. In some instances, qualitative assessment by experts as well as quantitative analysis of potential impacts, through modeling and simulation, are needed to evolve the options to the point where they can be submitted as detailed recommendations.

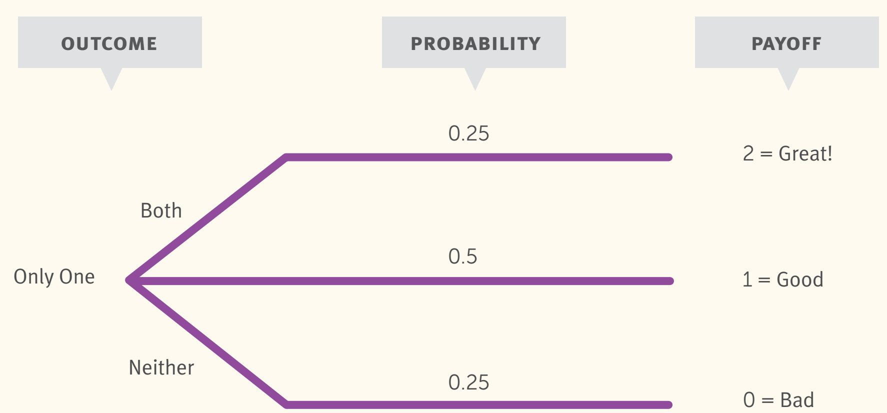
Introduction

The Government of Canada has engaged the Provinces in the collaborative development of a plan to decarbonize transportation system energy use. The Pan-Canadian Framework on Clean Growth and Climate Change sets a target to reduce Canada's greenhouse gas (GHG) emissions by 30% below 2005 levels by 2030. The longer-term vision is for net emissions to fall by 80% by 2050 compared to 2005 levels. This vision is consistent with the Paris Agreement objectives on climate change, which commits nations to work together to reduce GHG emissions by a level that prevents global average temperatures from increasing by more than 1.5°C to 2°C above pre-industrial levels.

Meeting Canada's 2030 target would require a net GHG emissions reduction of approximately 219 Mt from the reference case projection for that year. As emissions from sectors such as electricity generation, buildings, heavy industry, agriculture and waste have decreased or plateaued in recent years, the transportation sector is considered by many experts to constitute "low-hanging fruit" for future emissions reductions. The sector has been undergoing moderate yet steady growth in emissions over the last two decades, primarily driven by the heavy-duty on-road freight sector, which almost doubled its total emissions between 1994 and 2014. Emissions from this sector are forecasted to surpass those of light-duty vehicles by 2030.

GHG emissions reductions at this scale and pace are unprecedented. To improve the probability of success, Canada's framework contemplates a portfolio of progressive measures for the transportation sector. These measures include increasingly stringent emissions standards for light- and heavy-duty vehicles, the development of a zero-emission vehicle (ZEV) strategy to accelerate the rollout and production of low-carbon technologies, increased investments in low-carbon public transit and refuelling infrastructure, and the development of a Clean Fuel Standard (CFS) to reduce emissions from industry, buildings and transportation. Relying too heavily on any one action, or on a limited array of disjointed actions, could greatly increase the risk of failing to meet Canada's targets.

Consider, hypothetically, that decarbonizing transportation were to depend on the commercialization of *either* plug-in electric vehicles *or* fuel cell-electric vehicles, and that each stands a 25% chance of success in the market. Simple decision tree analysis demonstrates that a strategy to support *both* technologies increases the chance of achieving decarbonization through either pathway to 50% as compared to the 25% chance of success through betting on just one option (and this opens the possibility of doubling the benefit if both options succeed).



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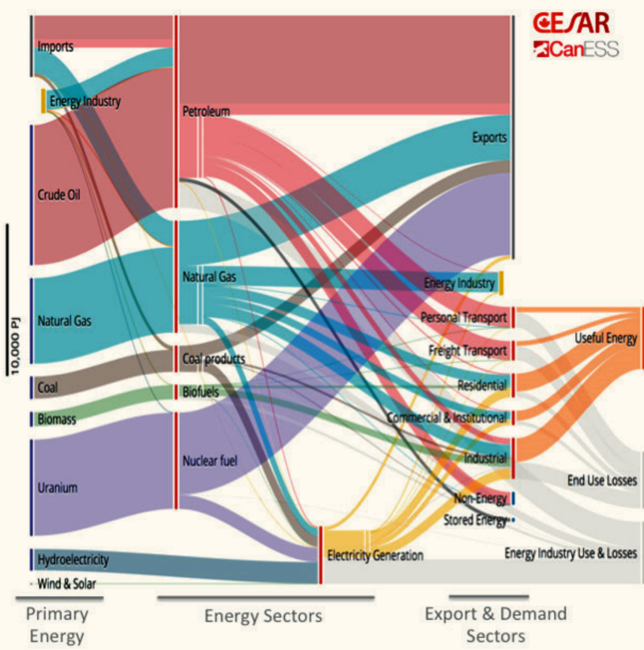
David L. Greene. *Why Hydrogen Fuel Cell Vehicles?* Presentation at The Pathways Initiative Workshop, Toronto, 2016.
http://www.pollutionprobe.org/wp-content/uploads/David-Greene.pdf

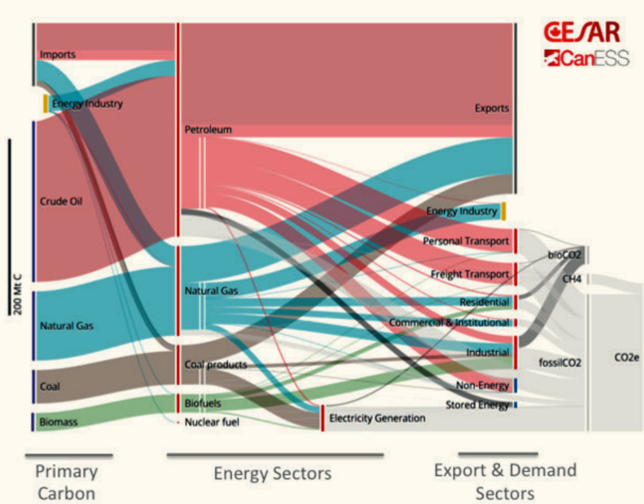
The preceding example is overly simplified, of course, but it illustrates why a comprehensive strategy, composed of complementary and mutually reinforcing actions is necessary. Moreover, since transportation energy use currently constitutes approximately one-quarter of Canada's GHG emissions, no credible plan to achieve the targeted reductions can exclude action in this sector.

Yet for more than a century, transportation systems have been powered almost entirely by the heat generated in the combustion of gasoline, diesel, kerosene and other liquid hydrocarbon fuels in the engines of vehicles running on ground, on water and in the air. Accordingly, a century's worth of socioeconomic and infrastructure development has aligned to this technology platform, and this perpetuates demand for combustible, carbon-intense fuels.

Energy Flows (PJ/yr) in Canada (2013)



Carbon Flows (MtC/yr) in Canada (2013)



Flows

- Natural gas
- Uranium
- Crude Oil & Petroleum products
- Coal
- Hydroelectricity
- Bioenergy & renewable electricity
- Electricity
- End-use energy
- Energy industry use & losses

Processes

- Primary energy
- Extraction & conversion echnologies
- Imports & exports
- Fuel & electricity for energy industry

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CESAR data visualization: Canadian domestic energy system flows in 2013 shown. http://www.cesarnet.ca/
Note in this illustration that nearly all personal and freight transportation services depend on the combustion of petroleum fuels.

Therefore, progressive decarbonizing of transportation must be grounded in an understanding of the fundamental factors that determine overall transportation energy demand and the associated emissions. A comprehensive plan would involve the deliberate targeting of these factors with the appropriate interventions to motivate transformation.

But how much change can occur over how much time, and at what cost? The climate change imperative calls for swift, disruptive transformation. Yet government strives for order – or at least orderly transitions. And this is wise, because poorly-conceived plans can provoke unintended destruction of valuable capital, provoke opposition among consumers, and create barriers, which may prevent the achievement of economic benefits, potentially creating new problems in the quest to resolve others. Put simply, transitioning to a low-carbon transportation system will be no small task, as it contemplates change at a societal level.

This report aims to identify and characterize the system changes that can drive transformational decarbonization of transportation energy use in Canada, noting the potential risks and opportunities, and thus contribute to developing a comprehensive framework for action.

Structurally, the report begins with an examination of the demand-side factors that drive overall transportation sector energy use. Where appropriate, agents whose actions and decisions within society exert influence over change in each of the identified factors (i.e., individuals, organizations) are also identified. This will lay the groundwork for an informed discussion about the specific mechanisms of change, which may be of a technological nature, an infrastructural nature or a market pricing nature, and be subject to various limitations and opportunities.

From this examination, a framework is then introduced that helps to break down the complex interactions comprising the transportation system into more simplified categories. Within each of these categories, actions can be taken that contribute to decarbonization of the system. Current policies and measures are then organized according to this framework and qualitatively assessed. Finally, to see how the approach can be used to develop new, forward-looking strategies, the framework is freshly populated with an array of policies and measures.

Though the report mainly focuses on the on-road vehicle sector, the framework approach can be conducted for any transportation subsectors (e.g., off-road, rail, marine, aviation), and examples of this are included. It is hoped that the policy options presented in the report will catalyze an inclusive, collaborative effort to fully populate the strategic framework in support of practical and progressive decarbonization of transportation energy use in Canada.

> ***The history of transport is largely one of technological innovation****. Advances in technology have allowed people to travel farther, explore more territory, and expand their influence over larger and larger areas. Even in ancient times, new tools such as foot coverings, skis, and snowshoes lengthened the distances that could be travelled. As new inventions and discoveries were applied to transport problems, travel time decreased while the ability to move more and larger loads increased. Innovation continues as transport researchers are working to find new ways to reduce costs and increase transport efficiency.*

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Pedia Press. *Transport*. 2017. p. 126.
http://pediapress.com/books/show/transport-by-wikipedians/

Deconstructing transportation—

a look at the underlying factors that determine demand for transportation services and energy

Within the context of this report, transportation is considered the movement of people and goods. At the most basic level, the movement of any object having mass requires energy. The total amount of energy needed for transportation – and the associated effects and impacts – is a function of many factors. These can include the amount of people and goods being moved and over what distances, the countervailing forces to overcome, the sources of energy and the technologies involved, as well as the underlying infrastructure.

Choices made within each of these factors can affect overall transportation energy use. Sometimes these choices are made by individuals, reactively from among available options; sometimes they reflect proactive decisions by society, made through governments and planning authorities, based on long-term, strategic objectives.

A current objective of society is to decarbonize transportation energy use, such that the benefits of transportation activity may continue to expand, while GHG emissions are reduced to negligible levels *rapidly*. This is critical to achieving the higher objective of reducing atmospheric concentrations of GHGs, globally, to a level that is consistent with pre-industrial levels on planet earth.

Currently, GHG emissions from the transportation sector are mainly the result of the combustion of hydrocarbon fuels in heat engines to generate motive power. The heat energy released in combustion is at the core of the propulsion systems of almost all the vehicles currently operating in Canada and around the world, including passenger cars, freight trucks, aircraft, locomotives and marine vessels, to name a few. The combustion of common transportation fuels (e.g., gasoline, diesel, kerosene) is a major contributor to the increasing concentrations of GHGs in the atmosphere – principally carbon dioxide – and is thus a significant causal factor in global warming and climate change.

In addition to carbon dioxide, the combustion of hydrocarbon fuels produces nitrous oxide, black carbon and other compounds that contribute to global warming, as well air toxics and smog-forming pollutants, some of which are regulated as Criteria Air Contaminants.

To systematically realize the opportunities to decarbonize transportation energy use, to progressively advance cleaner (i.e., less polluting) technologies and fuels into the sector, and to reduce GHG emissions, a framework that contemplates coordinated and mutually reinforcing actions is recommended. A framework approach helps to identify strategies for decarbonization in which government, industry and consumers all play crucial and complementary roles, thus minimizing sector-specific cost burdens of the effort and capitalizing on the opportunities for value creation and wealth generation.

A conceptual framework for influencing transportation system energy use

A working framework is proposed herein that delineates some of the key factors determining overall transportation energy use and the associated GHG emissions. The goal is to simplify the challenge of decarbonizing the entire system, which is complex, by breaking it down into more intuitive and manageable elements. Tactical actions that target specific, measurable change within each element can 'roll up' into a balanced and comprehensive decarbonization strategy for Canada's transportation sector.

The following factors each contribute to overall transportation energy demand and the associated GHG emissions. We can consider each factor as an element comprising the transportation system. For the most part, these factors are distinct yet interdependent, and the effects of a choice in one factor can cascade into the following factor.

1. **Energy** is needed to transport objects with mass
2. **Fuel** is the source of energy for transportation
3. **Technology** is how fuel energy is converted into motion
4. **Mode of technology** determines the parameters of transportation
5. **Infrastructure** determines what transportation modes are supported
6. **Operators** influence the performance of the infrastructure

In each of these categories, there exist profound options to reduce the contributions made by transportation activity to GHGs (and air pollution). These factors are defined in more detail, as follows:

1. ENERGY – MOVING OBJECTS WITH MASS

Transportation is the movement of people and goods. At a fundamental level, transportation facilitates *access* – access to goods and services, friends and family and work and trade. Transportation services, therefore, greatly influence quality of life and levels of commerce sustained within a society.

But transportation requires energy. People and goods are objects with mass, as are the vehicles in which they are carried. **The energy required for transport is a function of the mass of the objects, the force applied to the objects and the distance traveled**. A less energy-intense transportation system, therefore, begins with ensuring that the essential energy demands are no greater than necessary. In other words, keep the load light and distances short! For example, more compact, mixed-use urban design results in shorter distances to access services, thus curbing transportation energy demand in the first place. Route optimization can reduce movement, as well. Minimizing vehicle mass and friction can also significantly cut the fundamental demand for transportation energy.

Energy: The ability to do work.

Work: The energy transferred to an object through the application of force.

Force: A push or a pull.

Force is required to accelerate a mass. The greater the mass, the more force is required. To move an object the applied force must also overcome friction. The force applied over a distance is considered the work done on the mass. This is also equivalent to the energy transferred to the object. The greater the distance, the more work done and the more energy required.

Therefore, moving less mass, against less friction, over less distance requires less energy.

2. FUEL

Fuel is often referred to as energy. This terminology is casual and inaccurate. It is more appropriate to refer to fuel as an energy commodity. That is, **fuel is the medium in which energy for transportation is supplied**. Petroleum-derived liquid fuels are the most common sources of transportation energy. These include various grades of gasoline, diesel and jet fuel (kerosene). These fuels are energy-dense and are relatively stable liquids at atmospheric temperature and pressure, and are thus a convenient means of storing and distributing large amounts of potential energy throughout the transportation system. However, the useable energy in these fuels is extracted in the form of heat during combustion – an exothermic chemical reaction – the main by-products of which are water and carbon dioxide.

Reducing the carbon intensity of fuels allows the demand for transportation energy to be met with fewer emissions of GHGs, overall. The carbon intensity of such conventional fuels can be reduced marginally, through life-cycle efficiency improvements; that is reducing energy used in the extraction, refining and distribution of fuels. To achieve deeper reductions, the use of lower-carbon alternative fuels, such as natural gas and liquid hydrocarbons synthesized from renewable sources and waste, must increasingly displace conventional fuels. Some fuels can even be virtually *zero*-carbon, such as electrical voltage – a form of energy that can be stored as chemical potential energy in batteries or hydrogen.

Unfortunately, fuels are not all interchangeable. Certain fuels can only power certain technologies, and thus switching to lower-carbon fuels usually means an associated switch in technology platforms and systems of supply.

> *LCA [Life Cycle Analysis] refers to a methodology of tracking and quantifying the GHGs that are emitted at each stage of the product lifecycle of a given unit of fuel. For example, gasoline usually begins its lifecycle as crude oil extracted from certain geologic formations in the earth, whereupon it can be transported, upgraded and refined into gasoline, transported again and finally pumped into a vehicle's fuel tank, where it is eventually combusted in the vehicle's engine, producing heat that is harnessed as mechanical energy to power to the vehicle. Throughout this continuum, energy is added to work the product through the phases of its lifecycle (e.g., mechanical energy for extraction, heat energy for refining and transportation energy for shipping). The GHG emissions associated with the use of energy summed over the entire product lifecycle comprises the CI [Carbon Intensity] of the fuel. To enable useful comparisons of CI between different fuel options, a common measure of energy (e.g., a megajoule, MJ) is used to normalize the CI, and the GHG emissions are represented in carbon dioxide-equivalent masses, usually expressed in grams, or gCO2e. Thus, for the purposes of LCFS [Low Carbon Fuel Standard], the CI of fuels is represented as gCO2e/MJ.*

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Excerpt from *The Workshop on Low-Carbon Fuel Standards* – Pollution Probe, 2013

3. TECHNOLOGY

Technology is how energy in fuel is converted into useful, mechanical motion (i.e., kinetic energy) to transport people and goods. Examples of energy conversion technologies are the internal combustion reciprocating piston-crank engine, the internal combustion rotary turbine engine and electric motors. Even sails on boats are a form of energy conversion technology. Technology also incorporates how energy and power are managed and distributed throughout vehicle systems. The choice of technology and the sophistication of its design influences how much useful energy (work) is extracted from the fuel and how much is wasted. The more work extracted from the fuel (i.e., the more efficiently it is converted and used) the less fuel is required for transportation.

Technologies closely align with fuel type. Internal combustion engines require combustible fuel and oxygen to generate heat, which in turn is converted into motion. Electric motors, by contrast, convert electric energy into motion using the principles of electromagnetism – no combustion occurs and so no combustion emissions are generated. As previously noted, certain technologies and fuels are uniquely interdependent.

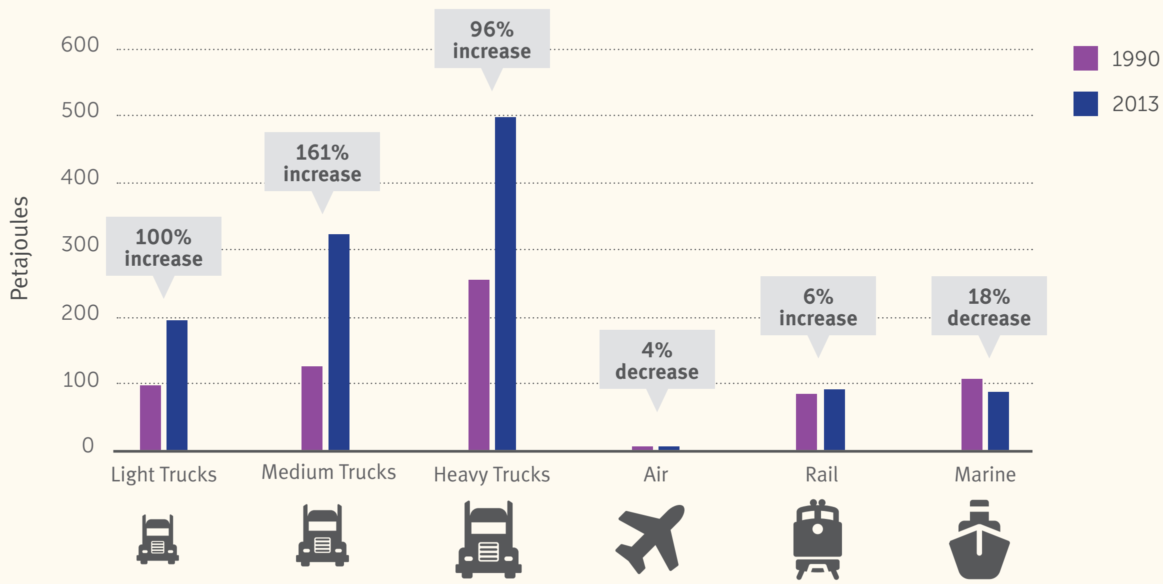
The advancement of transportation systems throughout history owes more to technology innovations than any other factor. Likewise, sustainability in transportation will rely heavily on technological developments – notably, the further development and adoption of electric propulsion.

4. MODE

Distinct modes of transportation have been developed based on function and purpose, utilizing different technologies. Technology modes for transporting people include automobile, bus, light railcar, boat, off-road vehicle, ferry and airplane. Technology modes for transporting goods include heavy truck, freight train, cargo ship and cargo airplane. **The mode of technology utilized determines the parameters of transportation performance (e.g., number of people transported per energy consumed, emissions generated per tonne of goods shipped)**. Importantly, similar technologies may be used in vehicles that are designed for very different applications.

Some of these modes ultimately require less energy and produce fewer emissions in the transportation of people and goods, while others are more energy- and emissions-intense. Modal shift – the migration of transportation services from one mode to another – can have significant impacts on GHG emissions. For example, the modal share of goods transport has shifted during the past half-century from freight rail to over-the-road trucking, which has contributed to an overall increase in CO_2 per tonne-km. This impact is reflected in the excerpt, below.

Freight transportation energy use by mode, 1990 and 2013



"The freight transportation energy use increased by 78 percent, from 673.4 PJ in 1990 to 1,197.6 PJ in 2013. Consequently, there was a 76 percent increase of associated GHG emissions, from 48.3 Mt in 1990 to 85.2 Mt in 2013. Figure 6.12 shows an increase in energy use for all modes of truck freight transportation and rail transportation. Trucks saw the greatest increase, consuming 85 percent of total freight transportation energy use in 2013, compared to 70 percent in 1990. Marine and air transport showed decreased energy use (18 percent and 4 percent, respectively)."

Energy Efficiency Trends in Canada, 1990-2013. Natural Resources Canada

5. INFRASTRUCTURE

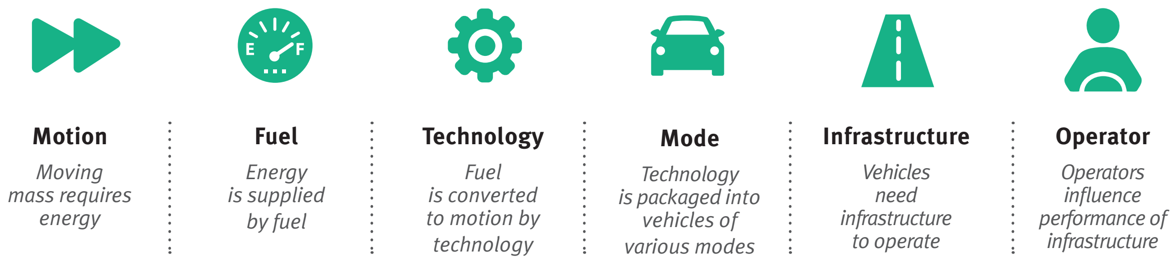
Infrastructure determines the range of modes available within a transportation system, and the extent to which they are supported. Infrastructure encompasses roads and highways for wheeled vehicles, railways for trains, water for marine vessels and air for aircraft. If infrastructure investments are aimed at moving people and goods mostly by road, then the parameters of automobile and truck modes will dominate the performance of transportation, overall. However, if less energy is used and less pollution is generated in moving people by light railcar, for example, then expanding the infrastructure for light rail should be considered as a GHG emission reduction measure.

Infrastructure itself can be also designed to mitigate GHG emissions. Some roads support a steady, efficient flow of vehicles, while some unintentionally induce braking and congestion. Uphill grades slow heavy trucks, and causes lighter vehicle traffic behind to become backed up. Intelligent transportation systems and congestion pricing can help to address some of these issues and maintain efficiency of the infrastructure. Going forward infrastructure should be designed with transportation decarbonization in mind.

6. OPERATOR

The operator controls the vehicle and thus contributes to the performance of transportation infrastructure. Through aggressive or sloppy driving and poor trip planning, operators can negate the benefits of many GHG emissions reductions efforts targeting the other factors listed above. Conversely, conscientious operators can help optimize the efficiency of the transportation system, and lever additional reductions in energy- and emissions-intensity, if appropriately engaged and motivated.

From a systems perspective, it can help to consider the source of transportation emissions as the highway itself. What needs to happen for a section of road to emit less? Among the most cost-effective measures is better drivers and better traffic management. Also, drivers choosing the most fuel efficient, lowest-emitting vehicle that meets their typical needs will also help to reduce the emissions associated with the highways they use – all else held equal.



Moreover, the function of an operator may be increasingly shared with automated driver systems (i.e., autonomous or self-driving vehicles). Such systems, if networked effectively, could substantially increase the capacity of existing transportation infrastructure. On the other hand, automated driver systems could be used in ways that are contrary to efforts to decarbonize transportation (e.g., through drivers opting to live further from where they work due to increased ease of commuting, or delivery companies sending out more vehicles with lighter loads to expedite delivery times). Therefore, the operator is a critical factor in the proposed framework.

The proposed framework presents a way of deconstructing the system of factors that govern transportation energy use and GHG emissions, into a simpler series of interrelated elements. This framework is informed by the research and experience of experts in the field, but there is no absolute correctness in its arrangement. Its arbitrary virtue extends only so far as it helps to make the task of affecting change within a complex system more understandable and manageable.

Within each of the six factors identified, there are targeted policies that can be implemented to address barriers to change, and to leverage opportunities. Some of these policies would naturally be led by government; others by the private sector. Some would obligate specific parties; others would be shared responsibilities. Absent a framework approach to decarbonizing transportation, an imbalance of policy attention may be given to some parts of the system, and insufficient attention to others.

In the next section of this report, many of the prevailing policies in Canada that influence transportation energy use and GHG emissions will be organized according to this framework. Gaps and opportunities will also be identified.

Populating the framework

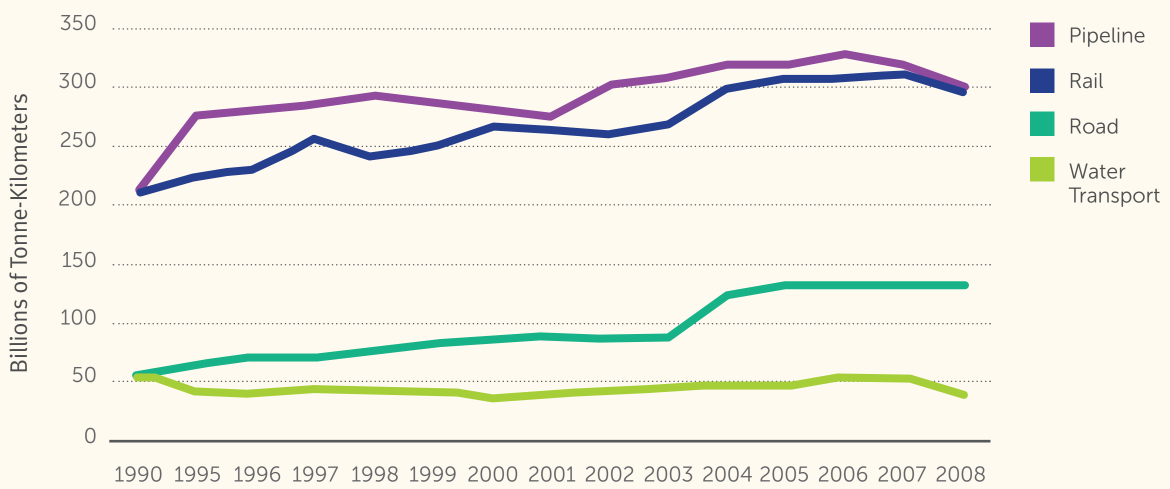
In this section, key policies in Canada that directly (or indirectly) influence transportation energy use and emissions will be organized according to the framework proposed in the previous section. This will be followed by an analysis of the gaps and opportunities for a more comprehensive and balanced approach to progressively decarbonizing the transportation sector in Canada.

Energy (moving objects with mass) –Societal and economic drivers of fundamental transportation energy demand

More people and goods are being moved greater distances today than at any prior point in human history. In Canada, an increasing share of the population lives and works in urban regions, and most families aspire to home ownership. This is not a new trend, and since the mid-20th century, it has driven an approach to community planning that resulted in low-density development. That is, homes built on larger plots of land, spaced further apart. This means that people are generally traveling further to access the services they need, to get to work and to connect with friends and family.

In 2009, Canadians logged more than 300 billion kilometres of travel by personal vehicle alone.[1] Statistical records of passenger-kilometres travelled have been tracked by the U.S. and the OECD since 1950 and 1970, respectively. Both data sets show steady increases, growing annually at 3% in the U.S., on average, with a notable levelling-off over the past decade.[2] It is reasonable to assume that Canadian personal travel has followed a similar track.

Canadian Domestic Freight Activity, by Mode



Source: Commission for Environmental Cooperation. *Destination Sustainability – Reducing Greenhouse Gas Emissions from Freight Transportation in North America*. 2011. p. 19.

1 Transport Canada. Light Vehicle Vehicle-Kilometres by Trip Origin and Destination. 2009. https://www.tc.gc.ca/eng/policy/anre-menu-3042.htm

2 Davis, Williams, Boundy. Transportation Energy Data Book – Edition 35. Oak Ridge National Laboratories, U.S. Department of Energy. 2016.

OECD (2017), Passenger transport (indicator). doi: 10.1787/463da4d1-en (Accessed on 05 June 2017). https://data.oecd.org/transport/passenger-transport.htm

Thinking inside the box

Ports worldwide

	1965	1970
Port labour productivity, tonnes per hour	1.7	30.0
Average ship size, tonnes	8.4	19.7
Number of loading ports in Europe	11	3
Insurance costs†, £ per tonne	0.24	0.04
Value of goods in transit‡, £ per tonne	2	1

Sources: World Trade Organisation; US Bureau of Labour Statistics; Daniel Bernhofen *et al*; *The Economist*

*Deflated by US consumer prices
†Australia to Europe ‡Hamburg to Sydney

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Adapted from: *Estimating the Effects of the Container Revolution on World Trade*, by Daniel Bernhofen, Zouheir El-Sahli and Richard Kneller, Lund University, Working Paper 2013:4, 2013

The nature of goods movement has also undergone significant change in Canada. When Canada was a developing nation, moving valued goods from the interior (e.g., lumber, wheat) to the borders and coastal ports, and hence to international markets, was the priority. Today, much of the movement involves manufactured materials and consumer products – and much of this is imported, bringing offshore goods into the interior. Between 1990 and 2000, total domestic freight activity in Canada increased by more than 50%.

Also, whereas manufacturing was once a centralized process, in which raw materials were worked into finished products, it is now far more distributed. According to the Canadian Manufacturers & Exporters, automotive parts can cross the Canada-U.S. border as often as six times before becoming fully integrated into a finished product. It is, therefore, not surprising that of the land points-of-entry in North America, which handle traffic across the Canada-U.S. and U.S.-Mexico borders, two of the three most active are Detroit-Windsor and Buffalo-Niagara Falls. These crossings, plus the Laredo-Nuevo Laredo crossing, handle half of the total truck and rail traffic in North America.

Contributing to the movement of goods are trade agreements, which have liberalized the flow of goods on a global scale. More of the products Canadian buy are drawn from supply chains that are internationally integrated. This allows more individuals and organizations to participate in the global economy, benefiting from the exchange of goods and services, and contributing to its growth.

POLICIES AND MEASURES

Land use policy.

Efforts to reduce the movement of people and goods, and thus reduce the fundamental need for energy to transport mass, have ranged from social marketing initiatives to hard regulation. At one end of the spectrum, people have been encouraged to choose homes and places of work in close proximity, and to plan their trips to minimize unnecessary travel, and to ‘buy local.’ At the other end, protected lands have been established around urban regions to curb sprawl (e.g., Ontario’s Greenbelt) and municipal zoning by-laws have been enacted to motivate higher-density development. Promoting infill development and mixed-used communities (i.e., neighbourhoods designed to position places of work and critical services nearer to residents) should reduce annual person-kilometres travelled, locally.

Such laws and regulations are implemented by governments, usually at the provincial and municipal level, and the obligated parties consist of developers and community builders. The effects of these policies can take decades to generate substantial reductions in the movement of people, yet they can reduce the intensity of transportation energy use within settled areas, durably, for the long-term.

Lightweight materials R&D.

Often overlooked is the mass of the vehicles that carry the people and goods being transported. Over the years, regulations have required the addition of equipment to vehicles (e.g., restraint systems for passenger safety, emissions control systems for cleaner air). All else held equal, these additions drive vehicle mass upward, thus increasing the amount of energy needed for transportation. The development of lightweight automotive materials can mitigate and reverse this effect.

At times, the Government of Canada has provided grants and loans to researchers working in the auto industry to advance materials science and engineering related to lightweighting. However, these funding programs have often supported a broader a range of R&D initiatives, and have not necessarily focused on specific opportunities for commercial scale-up. Because programs sunset and funding is often not renewed, the deeper impacts associated with long-term, concerted R&D are not realized.

Amory Lovins, founder and chair of The Rocky Mountain Institute, has declared that lightweighting vehicles is the most important first step in making electric vehicles more effective and affordable.[3]

Clean growth advantage!

Canada's automotive parts manufacturers are global leaders in component and materials innovation, as well as high-quality, full-line automotive assembly. For example, Magna International, headquartered in Aurora, Ontario, pioneered hydroforming of metal body parts (through its Cosma unit) which facilitates cost-effective lightweighting of major vehicle components.

Fuel (how energy for transportation is supplied)

The contribution made by fuels to overall demand for transportation energy depends on how efficiently their potential energy can be converted into mechanical energy (to power movement of people and goods). For example, of the heat energy released in the combustion of gasoline or diesel, or even kerosene-based fuels for jet engines, usually less than half can be converted to useful mechanical work at the driveshaft, on average. Under certain conditions, different internal combustion engines will achieve different levels of 'thermal efficiency', but there are practical limits to how much energy can be extracted from the heat.

But the choice of fuel depends on more than just conversion efficiency – other properties of the fuel influence its use. For example, the emissions of air toxics and smog-forming pollutants from gasoline engines can be reduced more easily than from diesel engines. In general, certain fuels are matched to certain engines or motors to produce a certain range of services. Even within a category of fuel, such as gasoline, there can be variants formulated specifically for certain purposes. For example, a higher octane gasoline may be needed for a sports car using a higher compression engine designed to produce power more efficiently under higher loads during acceleration.

Very generally, the more common pairings of fuels to engines and vehicle applications are as follows:

- Gasoline – passenger cars, motorcycles, light trucks and small boats. Aviation gasoline is a variant used in smaller, lower-altitude aircraft (and usually contains tetraethyl lead to facilitate more efficient, higher-compression engine operation).
- Diesel – heavy-duty trucks, off-road vehicles, buses, trains and ships.
- Kerosene – jet airplanes, some types of helicopters.
- Residual fuel oil – ships.
- Biofuels, renewable fuels – can be blended in gasoline and diesel.
- Natural gas – used in a relatively small number of light- and heavy-duty vehicles (mainly cars, buses and heavy trucks) as compressed natural gas or liquefied natural gas. Natural gas is also used as a fuel to power compressors that move product through pipelines.
- Propane – used in a relatively small number of cars, buses and trucks; more often used in forklifts.
- Electricity –public transit buses, light trains and trams, and personal plug-in electric vehicles.
- Hydrogen – fuel cell-electric passenger cars, buses, heavy trucks, passenger trains and forklifts

3 Presentation by Amory Lovins at University of Michigan. *Astonishing Automotive Futures: Disruptive Designs, Analyses, and Strategies*. April 2017. http://energy.umich.edu/news-events/news/2017/05/01/astonishing-automotive-futures-video-and-slides-rocky-mountain

Whereas most of the fuels listed above deliver energy through the heat of combustion, electricity and hydrogen are fuels that rely on electrochemical reactions to generate electric voltage that can power electric motors in vehicles of all types. Electric motors convert electrical energy into mechanical work at efficiencies ranging from 75%-95%, depending on the motor design and its function.

Hypothetically, a shift from internal combustion engines to electric motors could substantially reduce overall demand for transportation energy, since much of the waste heat currently ejected by combustion engines would be eliminated. However, the process of producing the electricity that is supplied to the motor must be considered to determine the net benefit. Coal, oil and natural gas are still burned in Canada to generate electricity at relatively modest conversion efficiencies, and most industrial hydrogen comes from natural gas.

POLICIES AND MEASURES

Vehicle fuel standards.

The most common fuels (e.g, gasoline, diesel) are subject to a range of government regulations that standardize chemical composition.
This standardization delivers several benefits to fuel suppliers, automakers, drivers and the public, including:

- Compatibility with distribution and storage systems, thus avoiding corrosive interactions with the constituent metals and elastomer materials;
- Compatibility with vehicle fuel systems, including `interactions with materials but also with evaporative emissions control systems;
- Engine durability, including lubricant interactions;
- Proper functioning of on-board diagnostic systems, including interactions with oxygen sensors in the exhaust;
- Proper functioning of exhaust after-treatment devices, including catalyst materials, absorbers and traps (too high a sulphur content in the fuel, for example, can temporarily impede the functioning of catalytic converters to reduce harmful hydrocarbons and oxides of nitrogen in engine exhaust); and
- Operability of vehicles in cold weather and hot fuel handling.

At the federal level, these regulations prescribe limits to benzene in gasoline, sulfur in gasoline and in diesel and flowrates from fuel dispensing equipment. These fuel standards are not designed to reduce transportation energy use or carbon dioxide emissions *per se*, but recognizing the role they play in ensuring proper vehicle engine and emissions control system operations is important when considering shifts to alternative fuels.

Alternative vehicle fuels programs.

The federal government has provided financial and strategic support for propane and for natural gas as transportation fuels. In the 1990s and early-2000s, the justification was tied to cleaner air, particularly for heavy-duty vehicles with diesel engines. For example, propane and natural gas were considered solutions for reducing emissions of oxides of nitrogen and particulate matter from buses. Later, CNG and LNG were viewed as having a solid business case in short-haul and long-haul freight transport, as a means of reducing fueling costs and reducing emissions of CO_2. *The Natural Gas Use in the Canadian Transportation Sector Deployment Roadmap*, published by Natural Resources Canada, details this business case.[4]

Natural Resources Canada also provides financial support for companies seeking to establish alternative refueling stations capable of dispensing natural gas, electricity and hydrogen, under the *Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative*. Fast charging stations transfer electric energy to plug-in vehicles' batteries at a high rate (i.e., high power levels), and supports 'convenience charging' away-from-home for EV operators. Hydrogen pumps can pressurize the hydrogen gas tanks in fuel cell-electric vehicles, usually at 350 bar (e.g., for buses) or at 700 bar (e.g., for cars).

While in the U.S., the Department of Energy funds research into other alternative fuels, such as biobutanol, dimethyl ether (DME), methanol and renewable hydrocarbon biofuels (more details below, under *renewable fuels*).

Renewable fuels.

There is a category of liquid fuels that can be combusted in heat engines, but are not derived from non-renewable petroleum sources. Rather, these fuels are derived from a variety of agricultural or otherwise biogenic sources. Familiar examples include ethanol, which can be blended into gasoline or burned "neat," and biodiesel, which can similarly be blended into diesel. Because the feedstocks for these fuels (e.g., sugary and starchy crops like corn and

4 http://www.nrcan.gc.ca/energy/alternative-fuels/resources/3665

wheat for ethanol; soy beans for biodiesel) can be regrown in a short period of time, the fuels are called "renewable" or "biofuels."

Combusted in engines, these fuels generate carbon dioxide and a mix of air pollutants, as is the case with petroleum fuels. However, depending on how the feedstocks are grown and processed into fuels, a significant amount of carbon dioxide can be drawn from the atmosphere through the process of photosynthesis during vegetative growth. Therefore, the *net* release of carbon dioxide into the atmosphere for the combustion of some biofuels *may* be significantly less than for the petroleum fuels they displace.

However, researchers and scientists caution against the assumption that if some biofuel use is good, then more must be better. Policies to promote unrestrained and rapid transition to agricultural-based biofuels could worsen the problem, particularly if lands in which carbon is naturally fixed are appropriated for the cultivation of new feedstocks.

Biodiesel vs. Renewable Diesel

While biodiesel is produced via transesterification, renewable diesel is produced through various processes such as hydrotreating (isomerization), gasification, pyrolysis, and other thermochemical and biochemical means. Moreover, biodiesel is produced exclusively from lipids (such as vegetable oils, animal fats, grease, and algae), whereas renewable diesel is produced from lipids and cellulosic biomass (such as crop residues, woody biomass, and dedicated energy crops).

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US-Dept. of Energy Alternative Fuels Data Centre:
https://www.afdc.energy.gov/fuels/emerging_hydrocarbon.html

If low-carbon, liquid renewable fuels are available in significant volumes, then the optimal use of these fuels may be to displace jet fuel instead of on-road vehicle fuels, since few alternatives to kerosene are apparent. Indeed, more sophisticated process engineering is being used to produce liquids that are virtually equivalent to petroleum fuels like diesel and jet fuel at a chemical level, yet are synthesized from biogenic sources (i.e., plants, algae, waste matter).

Federal renewable fuels regulations require fuel producers and importers to have an average renewable content of at least 5% based on the volume of gasoline that they produce or import into Canada, and at least 2% of the volume of diesel fuel. Provinces also have similar requirements for the blending of renewable fuels in gasoline and diesel, some of which exceed the federal volumetric requirements.

In British Columbia and Ontario, the scope of the regulations also include a focus on reducing the average carbon-intensity (CI) of fuels. Moreover, the Low Carbon Fuels Requirement Regulation in BC sets a progressively decreasing threshold for the average CI of fuels sold in the province over time. This is expected to drive increasing volumes of very low-carbon fuels into the market, such electricity, hydrogen, waste-derived fuels (i.e., landfill methane) and advanced biofuels.

The Sustainable Development Technology Canada (SDTC) Next Generation Biofuels Fund, endowed with $500M of federal funds, provides funding support to help companies take advanced, very low-carbon biofuels (e.g., cellulosic ethanol) from the research and development stage to the pre-commercial stage of product development. SDTC defines next-generation biofuels as those "derived from non-traditional, non-food, renewable sources, like municipal waste; agricultural and forest residues; or perennial crops on marginal land. They are produced through the use of innovative conversion technologies."

Clean growth advantage!

Chatham-based **Greenfield Ethanol** is developing a low-energy, mechanical process for separating sugars from plant cellulose, which can be refined into ethanol, hydrogen and a form of renewable jet fuel. Mississauga-based **Hydrogenics** is a manufacturer of grid-scale electrolyzers, which convert electricity into low-carbon hydrogen. Electolyzers provide grid system operators with a 'dispatchable load' that enhances grid quality and reliability, as well as energy storage for low-carbon renewable and nuclear power. Victoria-based **Blue Fuel Energy** has developed a process to use wind power and waste carbon dioxide from natural gas processing facilities to synthesize low-carbon methanol and gasoline fuels.

Technology (how energy in fuel is converted into useful, mechanical energy – also known as work)

Technologies that convert energy from one form into another, and then distribute energy throughout a vehicle, can profoundly impact overall transportation energy use and emissions. According to the U.S. Environmental Protection Agency, under typical operation a gasoline-powered car uses only about 14-30% of the energy potential in the fuel to move the car down the road. The rest of the energy is lost in the form of hot exhaust gases, transmission losses, accessory loads (e.g., air conditioning, lighting, sensors and computers), heat from braking and so on.

The array of technology innovations that are being used to convert energy more efficiently and to reduce energy lost to friction (both incremental and disruptive) are far too broad to detail in this report. However, a few categories and examples to illustrate the changes underway are listed below.

Engine efficiency.

Atkinson-cycle gasoline engines improve thermal efficiency but sacrifice some power output. This can be achieved through electronically actuated valves that control air intake and exhaust, and this reduces mechanical energy losses. Atkinson engines are often used in hybrid powertrains (discussed further below) in which the electric motor assists the engine in generating torque during periods of heavy load, such as during acceleration.

Another increasingly popular engine design is Gasoline Direct Injection (GDI), in which the fuel-to-air ratio of varied according to the need for power (similar to how a diesel engine operates). When the demand for power is low, the fuel-to-air ratio is lower – also called “lean burn”. This significantly reduces fuel consumption, but it can also increase emissions of smog-forming pollutants, including ultra-fine particulate matter. Special exhaust after-treatment systems are required for GDI engines.

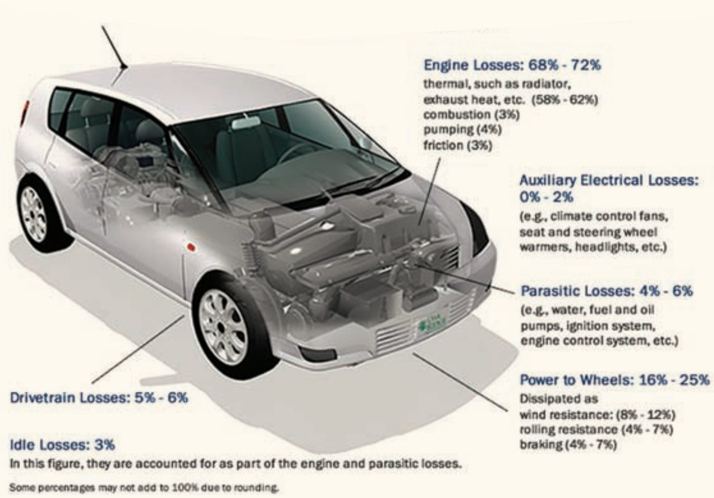
Transmission efficiency.

Continuously variable, automated-manual shift and dual clutch transmissions can reduce the energy lost between the engine and the wheels by improving the speed of gear shifting and better maintaining gear ratios that optimize engine efficiency. As well, these transmission innovations are increasingly compact, reducing weight.

Higher voltage electric architecture.

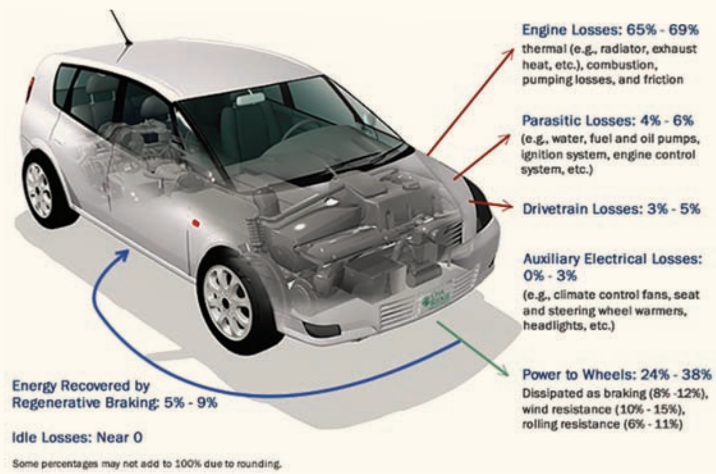
For decades, conventional cars have operated on a 12-volt alternator and battery system. 48-volt systems are expected to replace this standard during the coming decade. This will allow components that are currently mechanically powered through direct linkages to the engine to be offloaded onto a modestly-sized battery. By powering more of a vehicle’s accessory systems electrically, the load on the engine can be lightened. As well, this higher-voltage architecture could support a small electric motor (10-15 kW) to assist the engine during acceleration and to facilitate engine shutdown during idle.

Energy Requirements for Combined City/Highway Driving



Source: U.S. Environmental Protection Agency.
https://www.fueleconomy.gov/feg/atv.shtml

Energy Requirements for Combined City/Highway Driving—Hybrid Vehicles



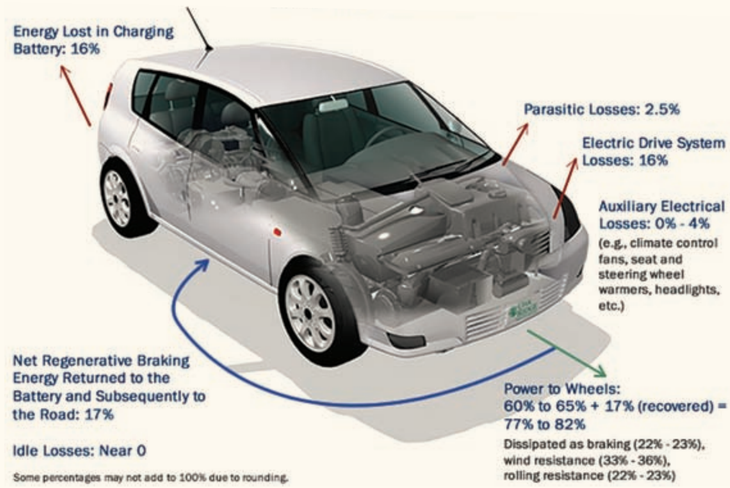
Hybrid powertrain.

By combining the operation of combustion engines and electric motors, hybrids are capable of delivering power to the wheels of a vehicle more efficiently and reducing losses associated with mechanically-powered accessories. Importantly, hybrids can convert some of the energy of braking and deceleration into electrical energy that can be stored in a battery. This stored energy can then be used by the electric motor to assist the engine during acceleration. A light-duty vehicle equipped with a hybrid drivetrain improves energy use substantially. Compared to 14-30% of the fuel energy delivered to the wheels in a conventional vehicle, a hybrid can deliver 25-40% of the available fuel energy. Hybrid vehicles do not plug into a power source to charge their batteries. Instead this is done through a combination of regenerative braking and by using the electric motor(s), powered by the combustion engine, as a generator.

Batteries (and electric motors).

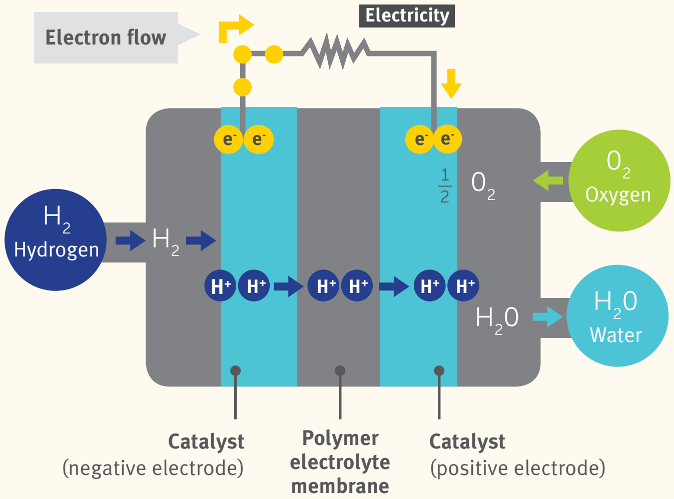
Gasoline- and diesel-powered vehicles carry fuel energy onboard in a tank. This fuel is converted to mechanical energy through combustion in the engine. By contrast, electrically-powered vehicles convert electricity into mechanical energy through an electric motor, and this energy is stored onboard in battery packs. Battery technology is advancing rapidly. Incremental improvements in established battery chemistries are reducing costs and improving performance, while new chemistries are also under development. The more energy that can be stored in a battery pack and the more efficiently it can be discharged to the electric motor, the more all-electric driving range is achieved (all else held equal). As discussed in the next section of this report, some vehicles use *only* the energy stored in a battery to operate. These vehicles are called "plug-in electric vehicles" (PEVs) because they connect to an electrical power source to charge. Within the PEV category there are two broad types of vehicles – those that run strictly on electricity stored in their batteries (battery electric vehicles, or BEVs), and those that have a smaller plug-in battery in addition to having a gas-powered combustion engine for added range (plug-in hybrid electric vehicles, or PHEVs). As with hybrid powertrains, the battery can collect and store a portion of braking energy to improve overall system efficiency. About 74%-90% of the energy supplied to the battery in a modern electric vehicle can be delivered to the wheels. Unlike conventional vehicles, where highway driving tends to use fuel energy more efficiently, PEVs are more efficient during lower-speed, stop-and-go driving typical of city use. This is because there are fewer energy losses to idling and parasitic loads (e.g., power steering, air conditioning, heating, and other accessories that use energy from the battery). The inset figure shows that such losses are estimated at 2.5%, but this does not include losses from heating or cooling, which can be significant in more extreme temperatures. Temperature extremes tend to limit the range of most vehicles, regardless of fuel, but the negative impact is more significant in PEVs – cold temperatures can inhibit electrochemical reactions within batteries, compromising total vehicle range, while under hot temperatures more energy is dedicated to thermal management and air conditioning.

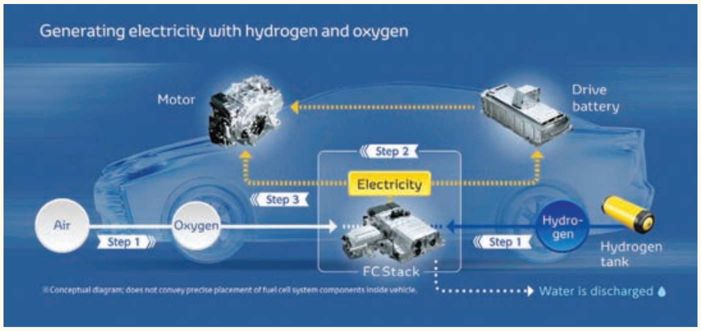
Energy Requirements for Combined City/Highway Driving—Electric Vehicles



Hydrogen fuel cells.

Fuel cells share qualities of both internal combustion engines and batteries. Like engines, they generate power when supplied with oxygen (from the surrounding air) and fuel (in the form of hydrogen gas). Like batteries, the power output is electrical (not mechanical) and no combustion takes place. Thus, there are no emissions of carbon dioxide or air pollutants. The electricity produced by a fuel cell can be used to power an electric motor within a vehicle, as well as its various systems. Such vehicles are called, "fuel cell-electric vehicles" (FCEVs). Often, these vehicles incorporate high-voltage architecture, including batteries to capture and store braking energy and to deliver a power boost to the electric motor during periods of heavy acceleration. FCEVs require special containers to store hydrogen gas under pressure. The higher the pressure, the more hydrogen can be stored and the longer the operating range of the FCEV. The ideal geometry for the containers is cylindrical, and the current standard for personal vehicles is 700 bar. Fuel cell-electric buses often use cylinders rated for 350 bar, since they have space for larger-volume cylinders. Where motive power for heavy loads and long distances are needed, such as in freight locomotives, liquefied hydrogen is being considered as a solution (so is liquefied natural gas). Whereas it is likely that in a PEV the most expensive component is the battery pack, it is likely that the most expensive part of an FCEV is its hydrogen cylinders.





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Credit: Toyota

POLICIES AND MEASURES

Hybrid-electric purchase rebates.

Up until nearly a decade ago, several Canadian provinces paid rebates to buyers of vehicles with hybrid-electric powertrains. The goal was to promote consumer interest in advanced fuel-saving technology and to de-risk the introduction of hybrid systems by automakers. No such rebates currently exist in Canada. In 2016, approximately 20,000 hybrid powertrain vehicles were sold in Canada, or about 1.5 per cent of total light-duty vehicle sales.

Natural gas-powered vehicle rebates.

Organizations that purchased medium- and heavy-duty vehicles with internal combustion engines modified to operate principally on natural gas received rebates in Ontario under the initial rollout of its Green Commercial Vehicle Program in 2008. This program is due to be revamped in 2017, and it is anticipated that natural gas vehicles will continue to be incentivized in the province.

Clean growth advantage!

Magna International, **Linamar Corporation** and **Martinrea International**, all headquartered in Ontario (Aurora, Guelph and Vaughan, respectively) are active worldwide, competing in many parts of the global automotive supply chain, including innovations in engine and engine component design, transmissions and advanced materials, to name just a few, for vehicles of all sizes and applications. Vancouver-based **Ballard** and Mississauga-based **Hydrogenics** are major exporters of hydrogen fuel cell power systems, which enable the electrification of powertrains in their customers' transit bus, passenger train and commercial vehicle platforms. **Westport Innovations**, also based in Vancouver, develops natural gas engines, vehicles and fuel system components, primarily for freight applications, as well as compressed and liquefied natural gas storage technologies.

Mode (the packaging of technologies in different vehicle types)

Mode is somewhat synonymous with *vehicle*, but it more properly encompasses the *use* of the vehicle and thus its contribution to transportation energy use and emissions. To recap, moving people and goods requires an essential amount of **energy**, which is based on the mass to be moved, the distance to be traversed and the forces to be overcome. This energy can be sourced from a wide variety of **fuels**. How efficiently the energy can be extracted from the fuel, and then distributed throughout a vehicle to power the wheels and its other systems, is determined by the **technology** used. This technology is packaged in a range of specific vehicle types that constitute distinct **modes**. These models include:

- Bicycles, low-speed vehicles
- Scooters, motorcycles
- Light-duty vehicles (LDVs)
    - passenger cars
    - light trucks (e.g., minivans, SUVs, pickup trucks)
- Heavy-duty vehicles (HDVs)
    - Class 6-7 trucks (e.g., delivery vans, garbage trucks; often return-to-base vocational purpose)
    - Class 8 tractor (for hauling trailers; staple of the long-haul trucking world)
    - transit buses
- Haul trucks (i.e., heavy-duty off-highway, rigid dump trucks)
- Recreational off-road vehicles (e.g., snowmobiles, pleasure boats)
- Special purpose ground vehicles (i.e., diverse range of materials handling vehicles, including forklifts, mining vehicles, agricultural vehicles)
- Railway vehicles
    - freight locomotives
    - passenger train locomotives
    - light rail transit vehicles
- Aircraft
    - small propeller airplanes
    - turbine-powered airplanes
- Marine
    - cargo freighters
    - vocational vessels (e.g., tugboats, fishing vessels)

Mode governs how transportation energy demands are met, both in terms of the technology comprising the vehicle and the fit of the vehicle to its purpose. For example, a passenger car equipped with the right mix of fuel-saving technologies can move five adults along a highway, safely and comfortably, and more energy efficiently than a transit bus serving only a few riders. This is not to debate superiority among modes; rather, it illustrates the importance of packaging the right technology to the right purpose. In all modes, there are opportunities to improve energy use efficiency and reduce GHG emissions.

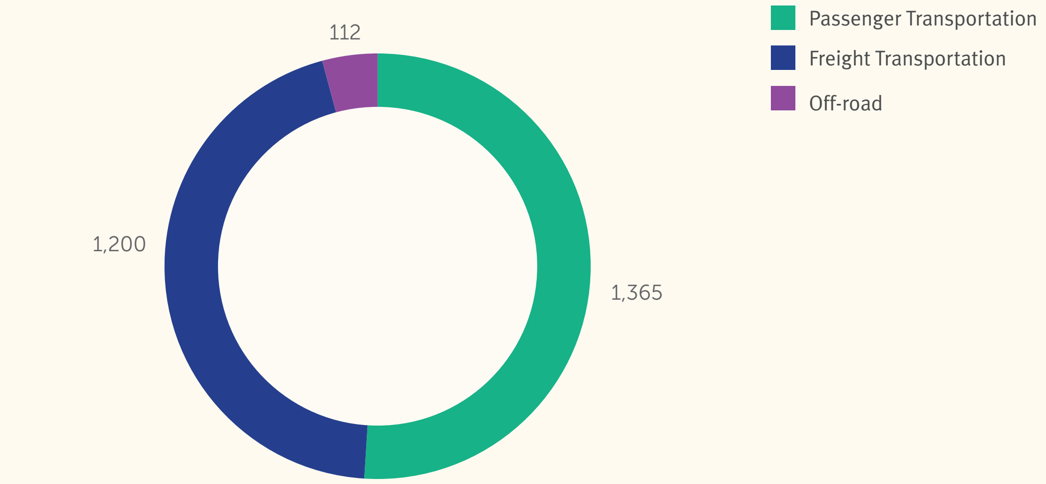
Sometimes, a technology strategy can scale between small to large vehicle formats (e.g., fuel cell-electrified powertrains are being developed for both light- and heavy-duty vehicles); other times, a given technology package is optimal for a specific vehicle mode (e.g., plug-in electric scooters have enjoyed tremendous consumer adoption in recent years).[5]

Total energy use (across all fuel types), as tracked and reported by Natural Resources Canada through its National Energy Use Database, is 2,677 PJ in 2014. The breakdown between people and goods movement, as well as the share by mode, is summarized in the inset charts.

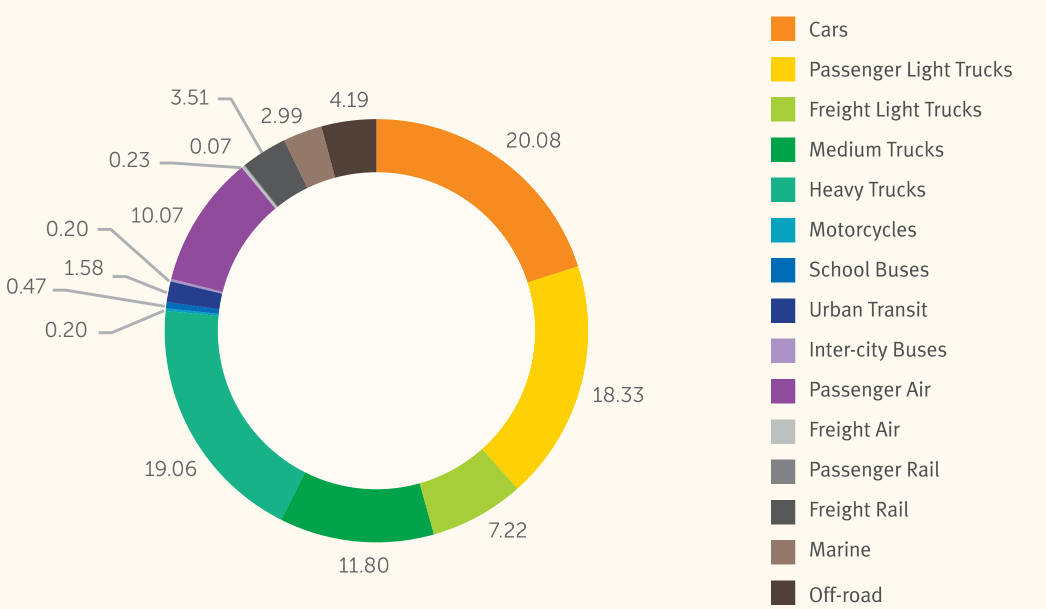
These values are dynamic, changing over time. Leading up to 2014, there are some important trends to note. First, the energy-intensity of passenger transportation is decreasing, about 20% from 2.26 MJ/passenger-km in 1990 to 1.79 in 2014. Over the same period, the energy used per tonne of freight moved increased by about 5%, from 1.17 MJ/tonne-km in 1990 to 1.23 in 2004.

5 Global Market Insights, Inc. *Electric Motorcycles & Scooters Market to hit $55bn by 2024*. 2017. https://globenewswire.com/news-release/2017/04/10/958180/0/en/Electric-Motorcycles-Scooters-Market-to-hit-55bn-by-2024-Global-Market-Insights-Inc.html

Secondary energy use by mode—Canada, 2014 (PJ)



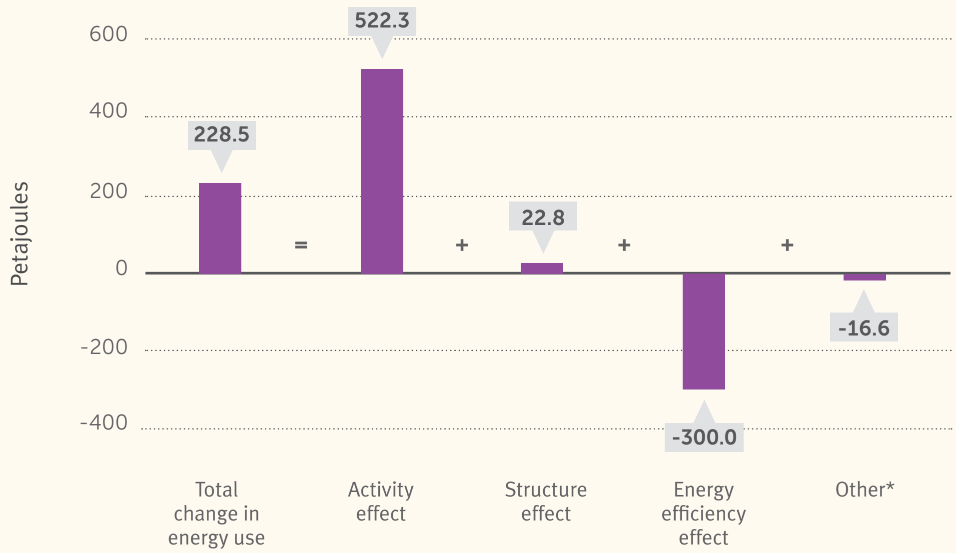
Share of energy use by mode—Canada, 2014 (%)



These trends both owe much to modal shift. For example, the reduction in passenger transportation energy use should have been greater, due to improvements in vehicle fuel efficiency (more on this later, under GHG emissions regulations). However, personal vehicle drivers are increasingly choosing to buy to more light trucks (e.g., SUVs, minivans, pickups) than passenger cars. As a result of driving heavier, less fuel-efficient vehicles, passenger transportation energy use has not improved as much as if the ratio of passenger cars to light trucks had remained constant.

As for freight transportation energy use, a greater share of the goods being moved throughout Canada are carried by over-the-road transport trucks. This contrasts with goods movement many decades ago, which were predominantly raw materials and agricultural products moved by rail. Truck transport offers the versatility of door-to-door delivery of goods, which has contributed to economic growth and competitiveness. But it has come at the cost of increasing energy demand and GHG emissions.

Impact of activity, structure, and energy efficiency on the change in passenger transportation energy use, 1990–2013



* "Other" refers to non-commercial airline aviation, which is included in the Total change in energy use value depicted above, but is excluded from the factoriztion analysis.

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"Figure 6.11 indicates the impact of various factors on the change in energy consumption of the passenger transportation subsector between 1990 and 2013."
– *Energy Efficiency Trends in Canada, 1990-2013*. Natural Resources Canada.

These factors (or "effects") are:

- Activity – Changes in total passenger-km traveled
- Structure – Changes in the combination of modes used (e.g., aircraft, train, car), which vary in terms of energy use.
- Energy efficiency – Changes in the rate of energy use among different modes.

Since transportation energy has been mainly provided through the combustion of fossil fuels, GHGs tend to track with overall energy use. Energy efficiency has thus mitigated growth in GHGs.

From the preceding discussion, two inferences can be made:

1. Energy efficiency within key modes (e.g., passenger cars, heavy-duty trucks) has delivered substantial reductions in GHG emissions relative to consistently increasing levels of transportation activity. Moreover, the beneficial effects of improved energy efficiency have been realized over relatively short periods of time.
2. Switching between modes (e.g., from car to bus) doesn't necessarily reduce GHG emissions – it depends on the circumstances. Also, to achieve a major modal shift across society (e.g., from predominantly private car use to public transit, or from transit to a cycling society) requires an associated building or repurposing of infrastructure. Modal shifts thus require longer-term planning and investment.

Of the policies and measures detailed below, most are focused on the deployment of technologies to improve the fuel efficiency and reduce the GHG emissions-intensity of the mode. The section thereafter, which focuses on infrastructure, addresses measures to expand access and attractiveness of alternative modes, such as public transit.

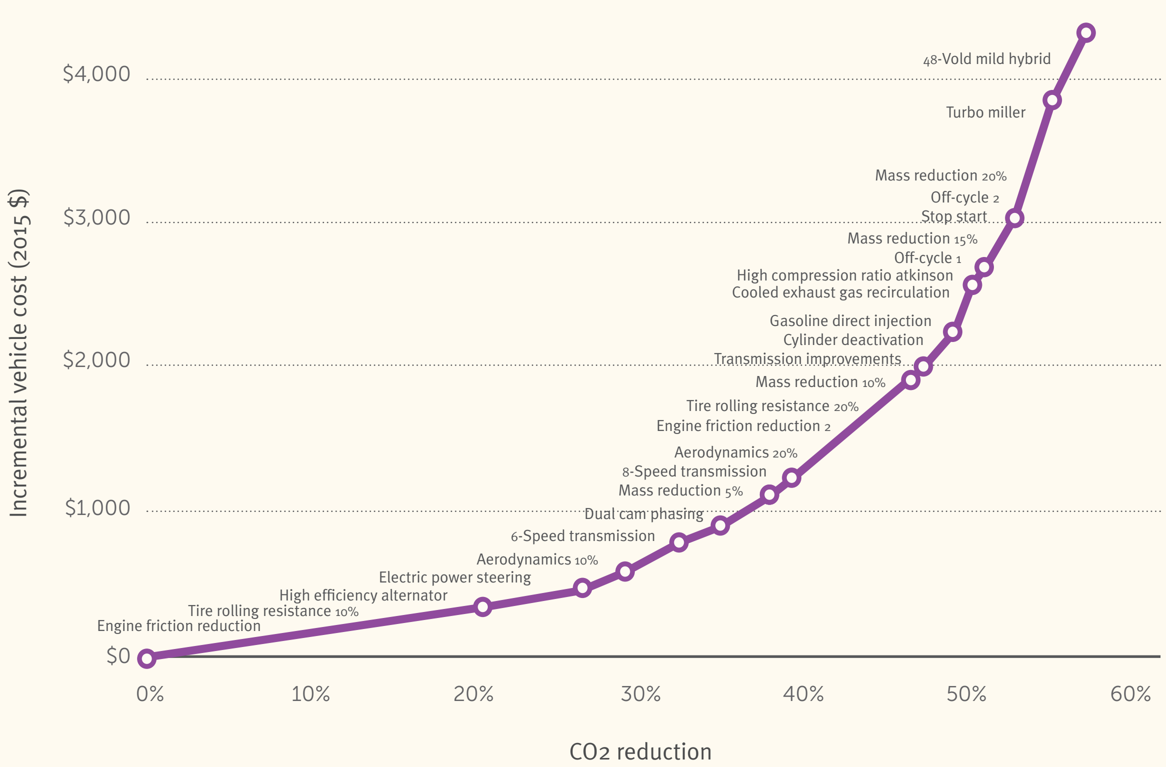
POLICIES AND MEASURES

Light-Duty Vehicle Greenhouse Gas Emissions Regulations.

The first regulatory action to directly reduce greenhouse gas emissions from a major source, nationally in the U.S. and in Canada, were the GHG emissions regulations on light-duty vehicles. These regulations obligate each automaker to comply with a standard for new vehicle GHG emissions. The standard applies to the *fleet* of all new vehicles sold by an automaker. Each vehicle sold in the U.S. and Canada is assigned a GHG emissions rating, determined by federal test protocol (i.e., FTP-75, not to be confused with the fuel efficiency and GHG emissions ratings posted on a car in retail showrooms, or on government websites). The *average* emissions ratings of all new vehicles sold must comply with the standard (i.e., the "fleet-average" standard). Furthermore, there are two fleet-average standards for light-duty vehicles: one for passenger cars, and one for light trucks (i.e., cargo vans, minivans, pick up trucks up to a certain size and SUVs). Hence, the regulations comprise a two-fleet standard (often called the “two-fleet rule”).

The regulations were jointly developed by the U.S. Environmental Protection Agency (EPA) and Environment and Climate Change Canada, and announced in 2010. Model years 2011 onward are subject to the regulated standards. Each year the standard for fleet-average emissions is reduced, thus becoming more stringent over time. Currently, the standards are generally set to lower (i.e., tighten) each year by approximately 5% to 2025 for passenger cars. For light trucks, the annual reduction rate is approximately 3.5% until 2021, and 5% thereafter to 2025. No standards have yet been proposed for beyond 2025.

The regulations are guided by principles of *technological feasibility* and *economic practicability*. To support its rulemaking, the EPA conducts forecasts of fuel-saving, GHG emissions-reducing technologies that automakers could apply to reference case vehicle platforms, and then estimates the associated reductions in fuel consumption and GHG emissions (i.e., CO_2 generated in fuel combustion, mainly, though N_2O and CH_4 are also covered under the regulations). The incremental costs of these technologies is estimated, and the monetary value of the avoided fuel expense and GHG emissions (a modest price for GHGs is applied, reflecting social costs of climate change) is also calculated. These data establish “cost curves” – plots of the increasing cost to achieve increasing fuel savings against the avoided GHG emissions. From this, a level of improvement can be targeted to optimize socioeconomic benefits. In other words, vehicles subject to the regulation may be priced higher, due to the inclusion of more fuel-saving technology, but only so far as the incremental cost is offset by the value of fuel savings (and avoided emissions) over the useful life of the vehicle. This ensures that the regulations remain cost-beneficial to society and to individual vehicle owners. It also explains why certain advanced technologies, like hybrid- or fully-electric powertrains, are not yet explicitly driven into the market by the standards, since their incremental costs are still judged to be too high at this stage of development.



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Source: Lutsey, Meszler, Isenstadt, German, Miller. *Efficiency Technology and Cost Assessment for U.S. 2025-2030 Light-Duty Vehicles*. ICCT, 2017. Lowest cost efficiency technology progression for CO2 reduction in passenger cars and crossover vehicles (Based on U.S. EPA, 2016c).

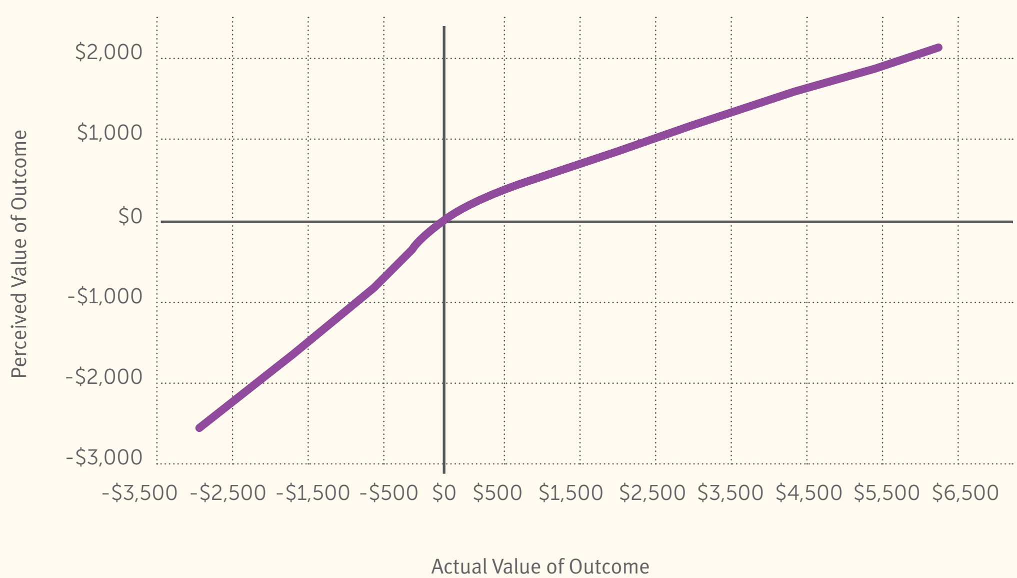
A question that often arises is why the regulations are necessary if the value of the fuel savings is greater than the incremental cost of the technologies? Shouldn't the market be capable of more efficiently realizing the value potential of advanced, fuel-saving technology? This question has been studied in depth and the answer forms the essential justification for the regulations. Essentially, new vehicle consumers tend to underestimate the full value of the future savings resulting from an investment in efficiency-enhancing technology today. The proposition can be thought of as a "bet": if (hypothetically) you put down an extra $300 today for marginally better fuel economy in a new vehicle, you may earn back $1,000 in avoided fuel expenses over the next 10 years … or you may not. The consumer must consider whether they expect fuel prices to go up or down in the future, or whether they will drive more or drive less, or whether they will sell the car after only a few years, or whether the fuel consumption label on the car will prove to be an accurate estimate of the fuel consumption that they, personally, will experience. Many factors may cause them to rationally discount the expected value of the payback on the fuel economy bet.

Perhaps more accurately, Amos Tversky and Daniel Kahneman first detailed the phenomenon of "consumer loss-aversion", for which the Nobel Prize in Economics was awarded in 2004. Put simply, while people tend to estimate the downside of a bet accurately, they persistently undervalue the upside. They tend to be far more motivated, psychologically, to avoid losses than to acquire gains. It is also worth noting that while most vehicle performance attributes can be directly perceived during a test drive (e.g., acceleration), accumulated fuel savings due to technology is not immediately visible – it is a benefit that takes time to be revealed.

Even when consumers are willing to pay more for fuel efficiency, they usually need to see a simple payback within three years. Anything longer is often wholly discounted. And, while taxing fuel would reduce GHG emissions over time, it would not necessarily optimize the use of fuel-saving technologies in new vehicles to generate maximum benefits at a societal scale. The regulations are specifically designed to address this market behaviour.

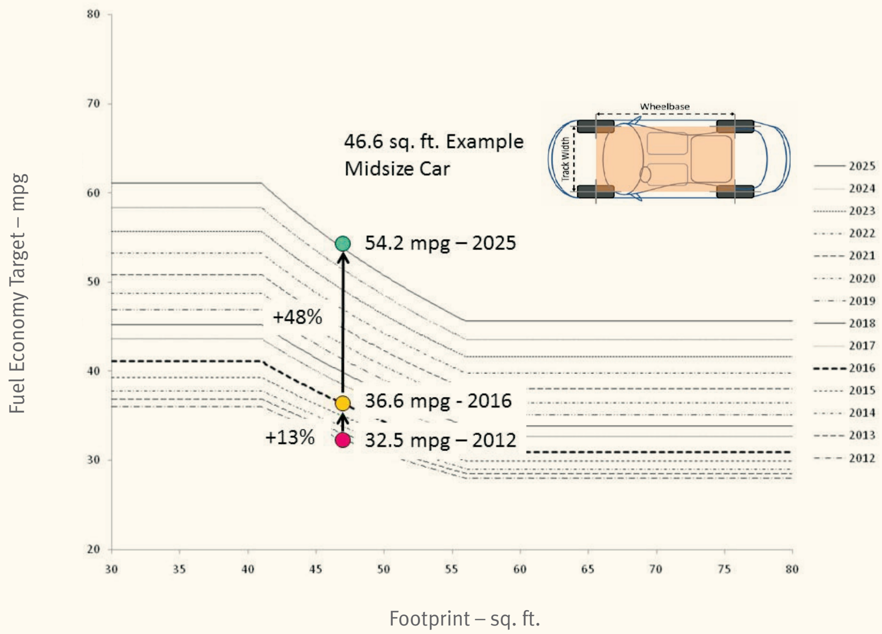
Pollution Probe contends that these vehicle GHG emissions regulations, along with the regulations on emissions of criteria air contaminants, represent some of the most sophisticated environmental rulemaking ever implemented in any jurisdiction. Not only must credible estimates of vehicle technologies and costs be made by the regulator, but of their potential market penetration, too. These considerations are important, as some bundles of available technologies are more sensibly applied to certain vehicle types, but not to others.

Consumer Loss Aversion Function



Kahneman and Tversky's loss aversion function.
Greene, David (2010): Why the market for new passenger cars generally undervalues fuel economy, OECD/ITF Joint Transport Research Centre Discussion Paper, No. 2010-6, http://dx.doi.org/10.1787/5kmjp68qtm6f-enGreene

CAFE MPG target curves for passenger cars nearly 50% increase—2016 **to** 2025



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Wade. Asilomar Presentation: *What the National Academies Report Says About Technology*. 2015.

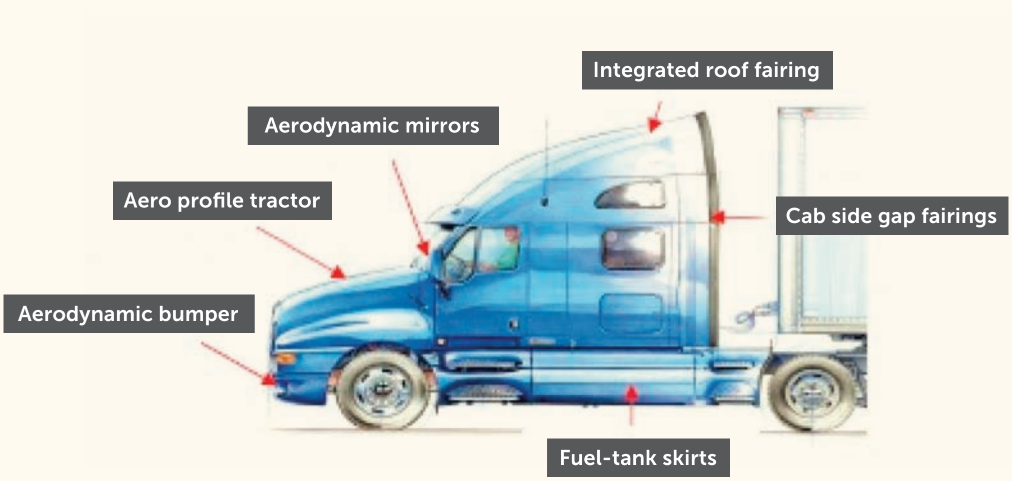
Moreover, while vehicle lightweighting is encouraged by the standards, vehicle downsizing is not. The standard to which each automaker must comply is attenuated to the average size of the vehicles it sells in a given model year. That is, each vehicle is assigned a GHG emissions level that is a function of its "footprint" (i.e., the area under a vehicle, defined as wheelbase times track width). Smaller vehicles are assigned lower emissions limits; larger vehicles are assigned higher limits. This ensures that *all* vehicles – big and small – sold by an automaker incorporate a more consistent array of fuel saving technologies. Once an automaker closes its vehicle sales for a model year and submits its report to the U.S.-EPA and/or Environment and Climate Change Canada, the average of the emissions limits ascribed to each vehicle in the fleet is calculated to determine the overall fleet-average GHG emissions limit for that automaker in that model year. The larger the vehicles sold, on average, the higher the GHG emissions threshold the automaker must remain below to comply; the smaller the vehicles sold, the lower the threshold under the regulation.

It may seem that the size-based standard unfairly advantages automakers that sell larger vehicles. But the objective of the policy is not to force automakers to sell smaller, more fuel efficient vehicles. Rather, the policy is intended to force technology into the market such that *all* vehicles are more fuel efficient and emit fewer GHGs, regardless of size. In this sense, the regulation is less an emissions standard, and more a technology standard. Moreover, there is compelling evidence that reducing vehicle mass, while maintaining vehicle size (i.e., footprint) reduces highway fatalities. Therefore, government rightly seeks to embrace a regulation that encourages vehicle lightweighting but not vehicle downsizing. As well, the size-based approach to rulemaking promotes a fair distribution of impacts among automakers whose product lines, for reasons of market competitiveness, may be weighted towards vehicles of particular sizes.

However, some industry analysts believe that the two-fleet rule is unfair, as it requires a less aggressive pace of improvement for light trucks, at 3.5% annual emissions reductions until 2021, compared to passenger cars at 5%, beyond which there is no need for a separate standard for the two classes of vehicle.[6]

6 The ICCT, 13-Feb-2012. "Separate footprint curves for cars and light trucks distort the requirements by making it easier for vehicles classified as light trucks to comply. Unlike the 2012-2016 requirements, the 2017-2025 rule increased the gap between cars and light trucks, providing stronger incentives for manufacturers to reclassify cars and light trucks and potentially undermining the benefits of the rule. A single footprint function would still give larger trucks a less stringent target to meet, while avoiding vehicle classification games." http://www.theicct.org/sites/default/files/ICCT%20comments%20on%202017-25%20GHG%20NPRM_FINAL.pdf. p.4.

Class 8 tractor aerodynamic treatments to reduce energy losses at high speeds.



Source: California Air Resources Board

Heavy-Duty Vehicle Greenhouse Gas Emissions Regulations.

Unlike light-duty vehicles, which are primarily used to carry passengers and light cargo, heavy-duty vehicles (HDVs) are used in a diverse array of applications. This makes regulating all trucks according to a common metric inappropriate and ineffective. Instead, the U.S.-EPA and Environment and Climate Change Canada have developed a GHG emissions rule that is composed of four distinct rules that govern (1) the efficiency of engines, (2) the use of particular fuel-saving technologies and aerodynamic features on tractors, (3) the fuel efficiency of commercial pick-up trucks and vans, and (4) a host of vocational vehicle prescriptions. These rules covered model years 2014-2018 (phase 1). In the U.S., the regulations have been tightened and extended to included model years, 2018-2027 (phase 2), which add a fifth rule governing trailers (towed by tractors). In March 2017, the Government of Canada published its phase 2 standards in the Canada Gazette Part 1. Pronouncement of the final rule is expected in the coming months.

Tractor engine efficiency is expected to improve marginally under the regulations, due to the application of technology enhancements including variable value timing, turbocharged exhaust gas recirculation, reduced friction and accessory loads – similar to efficiency-enhancing technologies on gasoline engines in light-duty vehicles. Once certified ascompliant, these engines are then incorporated into tractors and vocational vehicles. Class 8 tractors – the workhorse of over-the-road freight transport – must comply by incorporating a range of fuel-saving technologies and designs, such as aerodynamic drag reducers, low-rolling resistance tires, advanced automated transmissions and anti-idling devices. Vocational vehicles, which include delivery trucks, garbage trucks, bucket trucks and so on, are separately regulated in 18 different categories, reflecting the predominant functions for which the vehicles are designed. Finally, commercial pick-up trucks and large vans are subject to standards based on work factor, which encompasses design factors such as payload and towing capacity, and whether the vehicles are equipped with four-wheel drive.

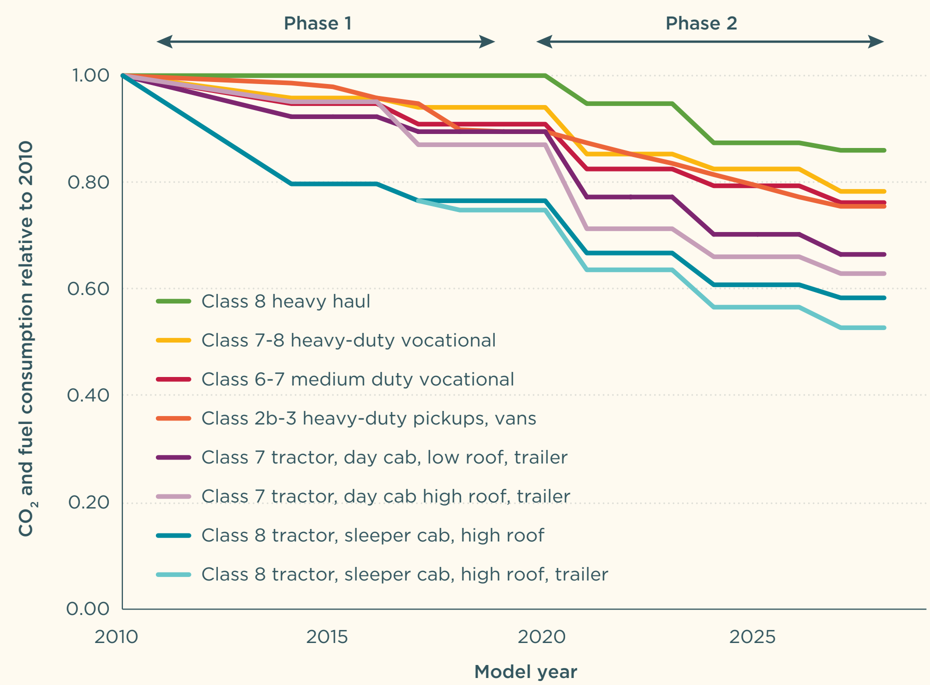
The chart below summarizes the many elements of the HDV engine and GHG emissions regulations (i.e., phase 2 rules in the U.S.), along with the expected changes to fuel efficiency and GHG emissions.

Table 1. Phase 2 requirements* for engines, tractors, trailers, and vocational vehicles

Class	Type	Baseline: Phase 1 2017		Final rule 2027		Final rule: percent change 2017–2027	
		g CO_2 / bhp-hr		g CO_2 / bhp-hr			
Compression ignition engine	TRACTOR (MD)	481		457		-5%	
	TRACTOR (HD)	455		432		-5%	
	VOCATIONAL (LD)	576		552		-4%	
	VOCATIONAL (MD)	558		535		-4%	
	VOCATIONAL (HD)	525		503		-4%	
Spark ignition engine		627		627		0%	
		g CO_2 / ton-mile	mpg	g CO_2 / ton-mile	mpg	CO_2	Fuel economy
Class 7 tractor	LOW ROOF	119.1	6.8	96.2	8.5	-19%	24%
	MID ROOF	127.2	6.4	103.4	7.9	-19%	23%
	HIGH ROOF	129.7	6.3	100.0	8.1	-23%	30%
Class 8 tractor (day)	LOW ROOF	91.3	5.9	73.4	7.3	-20%	24%
	MID ROOF	96.6	5.5	78.0	6.9	-19%	24%
	HIGH ROOF	98.2	5.5	75.7	7.1	-23%	30%
Class 8 tractor (sleeper)	LOW ROOF	84.0	6.4	64.1	8.4	-24%	31%
	MID ROOF	90.2	5.9	69.6	7.7	-23%	30%
	HIGH ROOF	87.8	6.1	64.3	8.3	-27%	37%
Heavy haul tractor		57	4.2	48.3	4.6	-15%	12%
Long box trailers	DRY VAN	83.2	6.4	75.7	7.1	-9%	10%
	REFRIGERATED VAN	84.9	6.3	77.4	6.9	-9%	10%
Short box trailers	DRY VAN	126.5	8.0	119.3	8.5	-6%	6%
	REFRIGERATED VAN	130.3	7.8	123.1	8.3	-6%	6%
Non-aero box trailers		-	-	-	-	-3 to -4%	3 to 4%
Non-box trailers		-	-	-	-	-3 to -4%	3 to 4%
		g CO_2 / ton-mile		g CO_2 / ton-mile		g CO_2 / ton-mile	
		Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline
Light heavy-duty	URBAN	482	502	367	413	-24%	-18%
	MULTI-PURPOSE	420	441	330	372	-21%	-16%
	REGIONAL	334	357	291	319	-13%	-11%
Medium heavy-duty	URBAN	332	354	258	297	-22%	-16%
	MULTI-PURPOSE	294	314	235	268	-20%	-15%
	REGIONAL	249	275	218	247	-12%	-10%
Heavy heavy-duty	URBAN	338	354	269	297	-20%	-16%
	MULTI-PURPOSE	287	314	230	268	-20%	-15%
	REGIONAL	220	275	189	247	-14%	-10%

* Equivalent NHTSA fuel consumption standards in gallon/1,000 ton-mile are based on 10,180 gram CO2 per gallon diesel

POPULATING THE FRAMEWORK



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Source: The ICCT. *U.S. Efficiency & Greenhouse Gas Emission Regulations for Model Year 2018-2017, Heavy-Duty Vehicles, Engines and Trailers*. 2016.

As with the LDV GHG emissions regulations, the stringency of the standards are intended to optimize economic and social benefits. The addition of advanced, fuel-saving technologies are expected to increase the price of vehicles, marginally, which is offset by lifetime fuel savings. The projected reductions in fuel consumption and GHG emissions is estimated by The ICCT in the inset chart.

Pollution Probe supports a regulatory approach and believes that Canada should harmonize its HDV GHG emissions standards with the U.S. rule.

Electric Vehicle Purchase Incentives.

Rebates are paid by provincial governments to buyers and leasers of PEVs and FCEVs in the provinces of British Columbia, Quebec and Ontario. In general, the rebates are meant to mitigate the cost increment associated with advanced technology content, such as battery packs capable of storing sufficient energy for longer-range operation, thereby reducing the price apparent to consumers.

The Governments of British Columbia, Quebec and Ontario also provide financial assistance to consumers who purchase and install high-power charging stations for their PEVs. In Quebec, up to $4,000 in rebates is available for buyers of *used* PEVs (but only 1,000 such rebates are currently available as part of a pilot project).

In addition to rebates, the BC Clean Energy Vehicle program also includes PEV charging and FCEV hydrogen refueling infrastructure investments, incentives for fleet adoption and support for research, training and public outreach. The program vision is that by 2020, 5% of new LDV sales in BC are "clean energy vehicles."

These programs face horizons in terms of time and available funding. The programs help catalyze and sustain consumer interest in electrified powertrain vehicles, such that market demand drives adoption. Furthermore, as volumes increase, it is assumed that prices will drop to more affordable levels, thus reducing the need for ongoing incentives.

ZEV Standard (Quebec).

The Government of Quebec has proposed a regulation obligating automakers to ensure a minimum number of vehicles sold within the province conform to a definition of zero-emission vehicle (ZEV). This policy is part of a broader strategy to position Quebec as a global centre of excellence on electrified transportation technology, thus growing its industrial capacities in the sector, and to decarbonize transportation energy use. The foundational documents are the Transportation Electrification Action Plan and the 2013-2020 Climate Change Plan, for which the ZEV standard is a supporting measure. One of the objectives under the plan is to have 100,000 PEVs registered in the province by 2020.

The stated goal of the ZEV standard is "to incentivize automobile manufacturers to build more models and use increasingly efficient low-carbon technology."[7]

At the time of drafting this content, it was unknown whether the proposed regulation would be accepted under an act of the National Assembly.

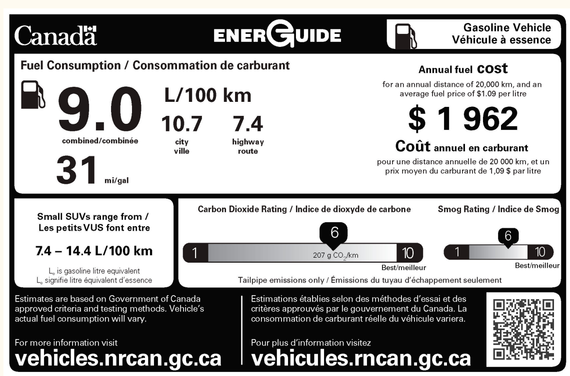
Ontario Electric and Hydrogen Vehicle Advancement Partnership (EHVAP)

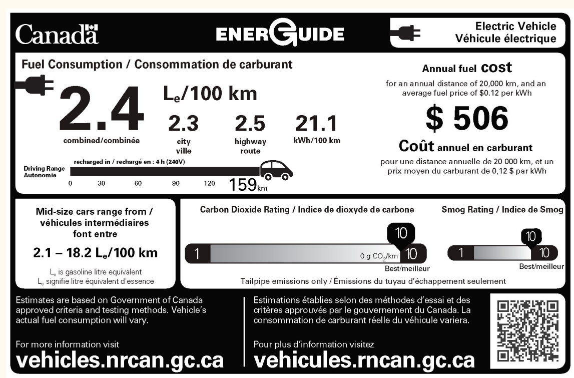
The Electric and Hydrogen Vehicle Advancement Partnership (EHVAP) brings together the automotive sector, environmental advocacy organizations and academic leaders to work alongside government to advance electric and hydrogen-powered vehicle technology and help reduce greenhouse gas emissions. This voluntary partnership will help the province reach its goal — that five per cent of new passenger vehicles sold or leased in Ontario be electric or hydrogen-powered in 2020.

EnerGuide Label for Vehicles.

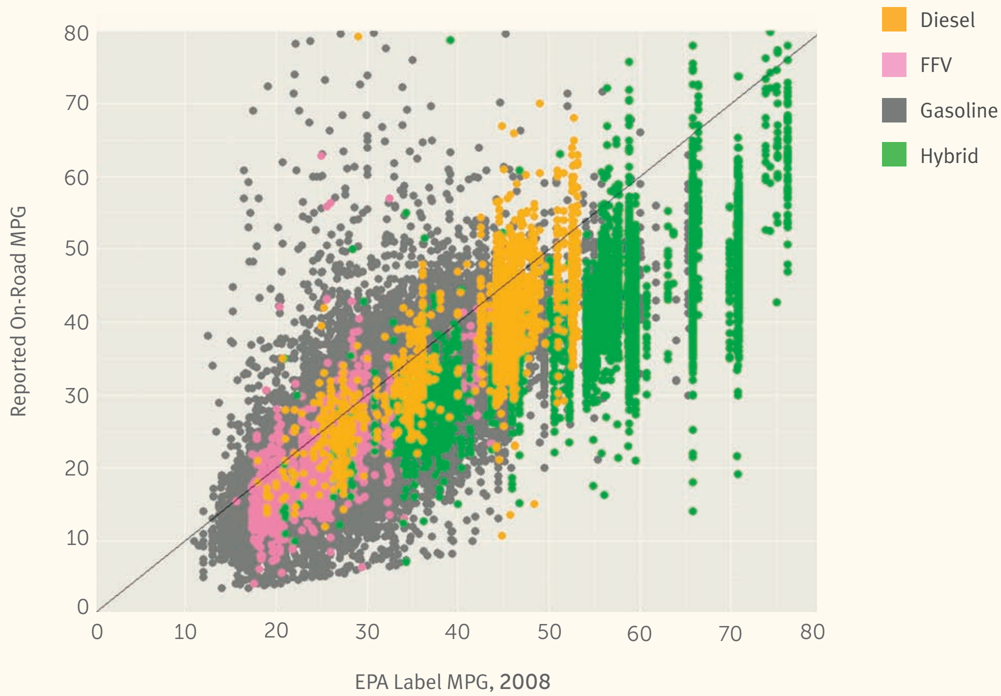
The Office of Energy Efficiency at Natural Resources Canada publishes the annual Fuel Consumption Guide, which reflects the model-specific fuel consumption information shown on the EnerGuide label for vehicles that manufacturers affix to their new light-duty vehicles. Both information tools are intended as inputs to the decision-making process of a consumer who is considering which vehicle to purchase from among available options. Both provide an estimate of the fueling expenses associated with a prospective vehicle option, as well as its relative emissions performance. Consumers are encouraged to use these tools to choose the most fuel–efficient vehicle that meets their needs, and thus save money and reduce emissions. As such, these tools are considered critical for comparative analysis among models.

Automobile dealers are encouraged to display the EnerGuide label on new vehicles at dealerships to assist consumers in their decision-making. The sample labels shown are for a gasoline-powered vehicle and a PEV, respectively. Other labels provide similar information for diesel-powered vehicles, PHEVs, ethanol blended fuel vehicles, natural gas-powered vehicles, FCEVs, and so on.





7 http://www.mddelcc.gouv.qc.ca/changementsclimatiques/vze/index-en.htm#objectif



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Greene et al. The Howard H. Baker Jr. Center for Public Policy. *How do Motorists' Own Fuel Economy Estimates Compare with Official Government Ratings?* 2015.

But is the information presented on the label a reliable predictor of the fuel efficiency an individual driver will experience during use? Researchers at the University of Tennessee plotted the fuel economy of vehicles reported by approximately 75,000 actual drivers against the U.S. EPA's fuel economy label to determine accuracy and bias. They found that while the label was considered inaccurate as a predictor, there did not appear to be a strong bias towards underestimating or overestimating "real world" fuel economy. In other words, the label was deemed a reasonable predictor of the average of drivers studied, but any individual driver's experience "could vary widely from the average. However, it is expected that as powertrain technologies diversify in the future (e.g., turbocharged engines, diesel, hybrid-electrics, all-electric drive), biases could emerge and a more personalized, accurate predictor of fuel consumption and emissions performance may be needed to motivate vehicle buyers.

Figures presented on the EnerGuide labels differ somewhat from those on U.S. fuel economy labels, but both source the same vehicle test data.

Clean growth advantage!

Waterloo-based **FleetCarma** designs advanced telematics systems for the automotive aftermarket throughout North America, enabling the more efficient and productive use of PEVs, particularly among fleets. In particular, FleetCarma can predict the optimal electric vehicle option for procurement, based on fleet vehicle duty-cycle datalogging. Information technology-based service providers are one of the fastest-growing and most disruptive segments of the automotive industry in Canada and the U.S., capable of rapid innovation.

Infrastructure (determines what modes are supported)

As described in the previous section, infrastructure represents the underlying technology and systems of support that make possible the use of certain modes of vehicle technology. From a historical perspective, technology *precedes* infrastructure. Put simply, highways came *after* the automobile. Airports came *after* airplanes. In North America, the post-war era of transcontinental highway development was intended to expand private and commercial on-road vehicle use, and thus fully realize the social and economic benefits that enhanced mobility would bring. But the cars and trucks were already there.

Today, the challenge is more complex. While we strive to preserve the benefits of mobility, we also strive to decarbonize it. How then should our approach to infrastructure planning and development change? In the Netherlands, 36% of people rely on cycling as their most frequent mode of transport on most days. This is largely because the nation has dedicated infrastructure to make the mode as easy as possible to use. In Europe, railways are principally designed to carry passenger trains, while railways in North America are principally built to carry freight trains. As a result, little freight moves by rail in Europe, while few passengers move by train in North America.

To move more people and more goods by modes that are inherently less energy-intensive, or can be powered more easily with less carbon-intense fuels, there must be sufficient infrastructure to accommodate the shift.

POLICIES AND MEASURES

Dedication of fuel tax revenue to public transit.

The Government of Canada levies a tax of 10 cents per litre of gasoline, or 4 cents per litre of diesel, on fuel used for all modes of transportation. A Goods and Services Tax (GST) of 5% is also charged, but this is allocated for the government's general pool of tax revenue. Revenues from federal fuel taxes are placed into the Federal Gas Tax Fund, which provides funding twice a year to provinces and territories, who in turn pass that funding on to municipalities to support local infrastructure and transportation priorities. This Fund provides over $2 billion per year to support local projects such as public transit, airport, marine vessel and rail infrastructure, waste and wastewater management, drinking water, and recreational amenities.

In addition to the federal fuel tax, each province and territory sets its own fuel tax rate, which range from 33 cents per litre in Newfoundland and Labrador to 6.2 cents per litre in Yukon. Funding priorities for provincial fuel taxes vary across the country, with portions of some revenues earmarked for public transit support or road maintenance and construction, and other portions flowing into general government revenues or being passed on to municipalities.

Municipalities in Canada are also free to charge fuel taxes within their jurisdictions, and three currently do: Montreal (3 cents per litre of gasoline), Vancouver (11 cents per litre of gasoline and diesel), and Victoria (3.5 cents per litre of gasoline or diesel). Metro Vancouver allocates its entire municipal fuel tax, plus a portion of its share of the provincial fuel tax to TransLink, its local public transportation authority, to fund mass transit maintenance and enhancement. Throughout British Columbia drivers are also charged roughly 7 cents per litre of fuel as part of the provincial carbon tax.

Investments in expanding light rail public transit service, subways, commuter regional rail.

Both the federal and provincial governments in recent years have been making substantial new commitments of funding to enable the construction of new and expanded public transit infrastructure. This includes subway expansions, new busways and surface rail. For example, Metrolinx is undertaking at $13.5B expansion of it GO rail system. Known as "Regional Express Rail", it envisions a transformation form its current core service of morning and evening commuter service between downtown Toronto and the surrounding suburbs, into more frequent, all-day service throughout the GTHA. Daily trips are expected to increase from roughly 1,500 to more than 6,000.

Moreover, new light rail transit systems in Brampton, Mississauga, Hamilton and within Toronto (i.e., Eglinton Crosstown) are planned to connect the GO rail system, thus providing travelers with new options for moving throughout the region, mainly on tracks. This is expected to provide people with alternatives to bus and private car use, and form the backbone of a more effective, integrated mass transit system in Canada's most populous urban region.

New and expanded commuter rail systems are also being built in Montreal, Ottawa, Calgary and Vancouver over the next decade.

Infrastructure bank (federal, under development).

Through the federal government's Investing in Canada plan, the Canada Infrastructure Bank was created to provide funding for community-based projects that reduce GHG emissions, spur economic development and help to build more inclusive communities. The Bank will provide a minimum of $5 billion from federal tax revenues to enhance public transit systems across the country. It will become operational in late 2017, at which time provinces and municipalities can begin applying for mass transit funding. The Minister of Infrastructure and Communities, Amarjeet Sohi, has hinted that funding from the Bank may be used to support the establishment of high-speed rail corridors linking major cities in regions such as Alberta and Southern Ontario. For such projects, it is envisioned that funding from the Bank will be used to leverage further funding and attract interest from the private sector.

Congestion pricing (Ontario HOT lanes pilot).

Ontario has been running a congestion pricing pilot in recent years. The pilot is designed to test the effectiveness of road pricing as a means of improving traffic flow on major highways in the GTHA. The mechanism being tested is a High Occupancy Toll (HOT) lane. A vehicle may use the lane if occupied by two or more passengers, or if the user pays a toll. It is a fineable offensive to use the lane otherwise. Progress reports show that traffic congestion has indeed eased and flows have improved. The pilot continues to inform policy development relating to congestion pricing, and substantiate the hypotheses that the measure can enable more drivers to reach their destinations sooner. In other words, pricing the road infrastructure improves the efficiency of its use.

Operator

The performance of the infrastructure depends on operators of the vehicles. Policies and measures in this part of the transportation decarbonization framework are traditionally 'soft', focusing on driver education and training. However, information technology is increasingly assisting the operator. Simulated and artificial intelligence systems could become the primary operators in the future (i.e., self-driving, autonomous vehicles).

POLICIES AND MEASURES

SmartDriver program.

The Office of Energy Efficiency at Natural Resources Canada has developed comprehensive educational and training materials for commercial drivers in highway trucking, in forestry trucks, transit buses, urban fleets and school buses. Tips for private vehicle drivers are also available.

Speed limiters on trucks in Ontario and Quebec.

By law, most large trucks driven in Ontario and Quebec are required to use electronically controlled governors that limit the speed of the vehicle to 105 km/h. Relative to operating at higher speeds, this reduces fuel consumption. It should also improve highway safety, and remove any incentive among some trucking companies to encourage speeding to gain competitive advantage over those that do not.

Ontario's permitting of autonomous vehicles testing on provincial roads and highways.

The Province of Ontario launched a 10-year pilot in 2016 to facilitate and encourage testing of automated vehicles on Ontario's roads. The pilot is to support technology innovation towards realizing the potential benefits of self-driving vehicles, and help make Ontario a centre of research in the field.

Clean growth advantage!

The BlackBerry **QNX** Autonomous Vehicle Innovation Centre (AVIC)[8] was created to advance technology innovation for connected and autonomous vehicles, independently as well as in collaboration with private and public sector organizations and research institutes. Building on the company's experience in the automotive industry, the centre will germinate new ideas and transform innovative concepts into reality through advanced engineering projects and demonstration vehicles tested on real roads.

8 http://www.qnx.com/content/qnx/en/blackberry-qnx-autonomous-vehicle-innovation-centre.html

Framework summary

The following chart is a representation of the policies and measures mentioned and described in the previous section, organized according to the proposed framework for decarbonizing transportation.

Motion	Fuel	Technology	Mode	Infrastructure	Operator
Land-use policies	Vehicle fuel standards	Government funding for various technology R&D (via NRC, NSERC, SDTC, etc.)	LDV GHG Emissions Regulations	Dedication of fuel tax revenue to public transit	Smartway Driver Training
Lightweight materials R&D programs	Alternative vehicle fuels programs		HDV GHG Emissions Regulations	Investments in expanding light rail public transit service, subways, commuter regional rail	Ontario – commercial truck speed limiter regulation
	Alternative Fuel Infrastructure Deployment Initiative		BC Clean Energy Vehicle Program (CEVforBC™) – ZEV rebates	Infrastructure bank (federal, under development)	Ontario – autonomous vehicles permitted for testing
	Renewable fuels requirements		Quebec Transportation Electrification Action Plan – ZEV rebates for passenger cars	Congestion pricing (Ontario HOT lanes pilot)	
	BC Low-carbon fuels requirement		Quebec Transportation Electrification Action Plan - ZEV rebates for e-bikes, scooters motorcycles		
	SDTC Next Generation Biofuels Fund		Ontario Electric Vehicle Incentive Program (rebate)		
	Ontario – EVSE rebate		EnerGuide Label for Vehicles		
	Quebec – EVSE rebate				
	BC – EVSE rebate				

The policies listed within the framework are a fraction of the activities currently underway, and only reflect policies and programs that are government-led. The content can be further evolved by incorporating private sector-led initiatives, as well. Furthermore, activities that are interdependent or otherwise focused on common objectives could be linked across the rows, revealing gaps in a strategy. This can help to continually coordinate actions among federal, provincial, municipal and private sector organizations over the long-term, as they drive towards a shared decarbonization goal. The framework should thus be viewed as an adaptive tool of strategy development.

A quick glance at the framework above suggests that current policies that play a role in decarbonizing transportation energy use are mainly focused on fuels and vehicles (i.e., *modes* of technology). By contrast, it appears that less priority is being placed on the advancement of core technologies. For example, while there are several activities to promotion PEVs in the market, there are no identified programs focused on the development of battery technology. This may be appropriate, since there is already substantial R&D investments being made by governments and the private sector elsewhere in the world. Yet, it warrants consideration in the development of a going-forward strategy to decarbonize transportation in Canada.

It is important to recognize that the framework *informs* the strategy. It should be used as an adaptive, qualitative tool. It is *not* a strategy in and of itself. In the next section, this framework approach will be demonstrated.

Applying the framework to building a transportation decarbonization strategy: Options

In this section, the proposed framework is populated with an array of fresh, forward-looking policy options and measures. This exercise is intended to demonstrate the framework's value as a tool for guiding the development of a comprehensive strategy for decarbonizing transportation energy use in Canada.

Mapping the options

The proposed framework identifies six interconnected elements that determine overall transportation energy use and emission. Changes within any of these elements will result in change to the overall demand for transportation energy, as well as the associated GHG emissions. To optimally and progressively reduce energy and emissions, actions within each element of the framework should be considered. The presumption is that integrated and coherent set of actions will lever synergies and opportunities within the transportation system that drive emissions downward more rapidly and at least cost.

This is a qualitative exercise that can consider policy options and measures at a high level or at a detailed level. In either case, the specifics of implementation must still be developed based on careful analysis, evidence and sound judgement.

Furthermore, a set of assumptions or principles can help contain the scope of options to a manageable degree, and set boundaries for what is considered practical and possible. To guide this exercise, the following assumptions are observed:

- The market for mass-produced vehicles in Canada is a subset of a global market, and its influence over technology and design is neither hegemonic nor irrelevant. In other words, Canadian policy can stretch global vectors and trends in vehicle design, but not wholly detach from them without forfeiting economic benefits of scale.
- Canada's public-sector capacity for investment is not unlimited, and must serve a wide range of priorities. Therefore, policy options that are relatively low-cost to implement and administer, yet generate persistent pressure toward lower-carbon transportation system outcomes should be in-scope and fully considered. Options that generate environmental as well as multiple socioeconomic benefits, especially public health and safety, should be prioritized.
- Markets are powerful levers of technological and social change, yet are unpredictable. Within markets, innovation produces commercial success when it creates new value for consumers. Therefore, to the extent possible, public policy should reward progress toward desired outcomes but refrain from prescribing specific means and solutions. Thereby, the efficiencies of markets and power of invention will be fully harnessed, while the risk of unintended consequences or unfair distributions of impact will be wisely avoided.

Above all, Canada's framework for decarbonizing transportation must be *adaptive*, updated continually to meet the needs of an ever-changing landscape.

In the chart below, a range of policy options and potential measures for further consideration are presented according to the elements of the framework, and consistent with the principles listed above. The underlying reasoning for each of these actions, as well as the cautions and considerations, are presented in the discussion sections that follow. In addition to the on-road transportation sector, this exercise also begins to consider off-road, marine, rail and aviation.

	Motion	Fuel	Technology	Mode	Infrastructure	Operator
	Reduce essential demand for transportation energy by minimizing mass in motion and distances to be traversed	*Ensure market access to fuels for efficiency-enhancing, emissions-reducing technologies, and that are inherently less carbon-intense*	*Support and incentivize advanced vehicle technology development and commercialization*	*Progressively and persistently migrate the active vehicle stock to the more fuel efficient, lower-emitting end of the product spectrum*	*Establish clear policy bias for investment in infrastructure that supports less energy- and emissions-intense vehicle modes*	*Realize efficiency potential of infrastructure though enhanced vehicle operation and control*
On-road vehicles	Promote community energy planning that includes transport energy demand, supporting shift to transit and active modes	Maintain/enhance existing regulations on fuel quality (i.e., gasoline, diesel)	Develop govt-industry joint R&D program focused on innovation priorities among Canadian automotive parts manufacturers	Maintain and enhance GHG emissions standards for light- and heavy-duty vehicles	Identify investment opportunities in enabling infrastructure that would achieve major mode shifts	Expand eco-driver training programs for private and commercial operators, with rewards and incentives
	Establish interprovincial working group to develop harmonized long combination tractor-trailer standards	Expand access to PEV charging infrastructure and services (but develop LDC load management strategy)	Identify mineral resource development opportunities in Canada to meet global demand for advanced vehicle electric architecture	Incent early retirement of vehicles with disproportionately high service life and/or high GHG emissions levels	Establish long-term financing mechanisms for expansion of rail transit systems, providing effective, urban alternatives to private vehicle use	To minimize idling emissions, develop congestion pricing strategy for optimal traffic flow throughout urban regions
	Maintain and enhance dedication of fuel tax revenues to urban transit system operations	Support development of a network of hydrogen refueling stations in key markets	Establish a global centre of expertise in fuel cell system development and commercialization for vehicles	Light-duty vehicle feebate system (revenue-neutral) to de-risk introduction of disruptive innovations	Engage road construction sector in investigation of "low-carbon road & highway design" principles	Regulate use of speed limiters in commercial traffic, nationally
	Increase fuel or VKT tax to reduce activity and demand for transportation energy	Initiate science program to identify most sustainable renewable fuels production options	Assess preparedness of fuel supply chain and engine systems for more biofuel blending in gasoline and diesel	Support demonstrations of zero-emission vehicle systems in heavy-duty applications (e.g., truck, bus) with commercial intent		Establish world-class research, development and testing capacities for autonomous vehicle control
	Focus R&D support on development of lightweight materials for vehicle applications	Joint initiative among academic institutions to advance artificial photosynthesis technology and other low-carbon fuels	Study and support Canada's evolving automotive after-market technologies and IT services sector	Revise tax code provision for standby charge to reflect vehicle GHG emissions instead of capital cost		
				Comprehensive social marketing & consumer awareness campaign to promote the value of highly fuel efficient, low-emissions vehicles		
Off-road vehicles		Assess technical potential for renewable diesel in compression-ignition engine systems for heavy off-road applications	Investigate industry need and commercial applications for electric, ZEV technologies in mining, agriculture, construction			
Marine vehicles		Maintain and enhance regulations on use of ultra-low sulphur marine fuels				
		Investigate low-carbon intensity fuel alternatives for marine applications (e.g., natural gas)				
Railway vehicles		Assess technical potential for renewable diesel locomotive engine systems	Establish a railway technology innovation and development centre, linking with US based R&D centres	Support commercial development of next-generation zero-emission commuter rail systems	Investigate if/where intercity passenger rail service could compete with regional air travel	
				Support development of commercially viable alternative fuel-powered freight locomotives		
Aircraft		Investigate renewable kerosene drop-in aviation fuels	Assess potential of electric, zero-emission power systems for aircraft taxiing	Assess potential of small aircraft electric propulsion systems	Investigate the role of regional airports in reducing int'l airport congestion and overall aviation fuel use	

The following subsection present additional details about the options presented in the above framework. These descriptions are brief and preliminary in nature. Evolving these options into fully-developed recommendations will require further investigations and analyses, which are beyond the scope of this report.

Energy (for Motion) – reducing the movement of mass

The following measures aim to reduce the essential demand for transportation energy by minimizing mass in motion and distances to be traversed. While movement of people and goods is a necessity within our society, often more mass is being moved over longer distances that necessary.

1. *Promote community energy planning that includes transport energy demand, supporting shift to transit and active modes*

CONCEPT: Recognizing that urban design can either foster excessive vehicle use, or mitigate it, tools to support less private automobile-reliant urban development are needed by municipalities and provinces. This recommendation advocates for lower transportation energy use as an objective in community planning. Mixed-use development, in which places to live, work and play are co-located, is an example of planning efforts that cut demand for transportation energy at its core.

LEAD: Provincial and local governments

TIMEFRAME: Long-term impact

CO-BENEFITS: Many believe that denser, mixed-use development can result in safer, healthier populations with enhanced quality of life and social cohesion.

2. *Establish interprovincial working group to develop harmonized long combination tractor-trailer standards*

CONCEPT: This is to revamp the patchwork of misaligned highway standards across the country to achieve a harmonized system of permitted weights and dimensions that would facilitate the most efficient transport of goods by tractor-trailer. This could also facilitate greater use of multiple trailer configurations.

LEAD: Federal and provincial governments

TIMEFRAME: Long-term impact, due to time needed to negotiate new standards. Otherwise the impact could be near-term.

CO-BENEFITS: Cross-country shipping costs would be reduced, making companies that are reliant on long-distance, over-the-road shipping more competitive. Strong economic benefits would make the policy popular among large distributors, retailers and manufacturers, and mitigate consumer price increases.

3. *Maintain and enhance dedication of fuel tax revenues to urban transit system operations*

CONCEPT: A portion of federal fuel tax revenue is currently dedicated to support public transit operations across Canada. This is an important source of operating revenue for transit authorities. It should be maintained and enhanced, as it supports modal choice that could reduce overall transportation energy demand.

LEAD: Federal government

TIMEFRAME: Near-term impact

CO-BENEFITS: More effective public transit can improve the efficiency with which major urban regions create value and generate wealth, the benefits of which are shared nationally. Better performing transit also supports labour mobility and is a hallmark of world-class cities.

4. Increase fuel or VKT tax to reduce activity and demand for transportation energy

CONCEPT: Increased fuel prices correlate to short-term and long-term trends in driver and consumer behaviour, leading to reduced transportation energy demand and purchase of smaller, more fuel-efficient vehicle models.

LEAD: Federal and provincial governments

TIMEFRAME: Near-term impact

CO-BENEFITS: As gasoline and diesel consumption decouples from transportation activity and economic growth, due to vehicle fuel efficiency improvements and shifts to alternative transportation energy commodities, such as electricity, federal and provincial fuel tax revenues will decline. By increasing these fuel taxes, or by replacing them with road-use taxes (i.e., taxes paid according to distance traveled – vehicle kilometers travelled, VKT), which are independent of fuel type or efficiency, critical government revenues can be restored to maintain transportation infrastructure. Such taxes are partly avoidable by individuals and companies who minimize travel and transport.

5. Support development of lightweight materials for vehicle applications

CONCEPT: R&D programs that support technologies and processes for cost-effective, scalable lightweight materials solutions for automotive applications. Support could be directed towards Canada's tier 1 & 2 auto sector suppliers.

LEAD: Federal and/or provincial government

TIMEFRAME: Long-term impact

CO-BENEFITS: Build on the existing capacity of Canada's Tier 1 automotive components suppliers in materials and process innovation, thereby enhancing the global competitiveness of Canada's auto sector and supporting manufacturing exports.

Fuel – developing cleaner, less carbon-intense fuels

The following measures aim to ensure robust market access to fuels for efficiency-enhancing, emissions-reducing technologies, and fuels that are inherently less carbon-intense.

1. Maintain/enhance existing regulations on fuel quality (i.e., gasoline, diesel)

CONCEPT: The current array of fuel regulations serves to standardize the composition of major fuels, such as gasoline and diesel, such that vehicle engines and emissions control systems operate as intended. For example, current regulations require minimal sulphur levels in gasoline and diesel, which in turn allows emissions control systems on new vehicles to operate in compliance with Tier III emissions levels – the tightest limits on smog-forming air pollutants anywhere in the world. These regulations produce important public health benefits that should not be compromised (unintentionally) by aggressive alternative fuel switching and renewable fuel blending initiatives. Care must be taken to consider such impacts when developing renewable fuel policies.

LEAD: Federal government

TIMEFRAME: Near-term impact

CO-BENEFITS: The public benefits associated with clean air are well-established.

2. Expand access to PEV charging infrastructure and services (but develop LDC load management strategy)

CONCEPT: To support consumer adoption of PEVs across Canada, access to battery recharging services is critical – at home and away from home. Government support of PEV charging infrastructure is advised, but there is a risk of local electricity system assets overloading as PEV charging becomes more commonplace and prevalent. Local Distribution Companies (LDCs) need to develop capacity for active load management – not only to protect the grid, but to enhance the value of the utility to all rate-payers. By using PEVs as a "dispatchable load," LDCs can help to optimize asset utilization (e.g., transformers, generators), ultimately mitigating electricity price increases.

LEAD: Federal and provincial governments and electricity distribution companies

TIMEFRAME: Near-term impact

CO-BENEFITS: Developing a sophisticated approach to PEV charging builds upon Canadian leadership in the field. Indeed, companies from Ontario and Quebec are assisting power utilities in the U.S. to develop active PEV load management capacities. This can be part of a shift among Canadian utilities towards developing valued service offerings in an era of declining demand for centrally-supplied electricity.

3. Support development of a network of hydrogen refueling stations in key markets

CONCEPT: FCEVs are ready for introduction to markets in Canada. Some 1,500 are already on the roads in California, where 30 hydrogen refueling stations have been commissioned. California aspires to at least 40,000 FCEVs by the middle of next decade, supported by at least 100 H_2 stations. Scale is key for hydrogen fueling to achieve commercial self-sufficiency. To achieve this goal and realize the social benefits of zero-emissions vehicle use, $100M in financing has been dedicated to by the state government to station builders and operators for capital and operating expenses. Similarly, to attract FCEVs to Canada in support of its decarbonization efforts, a commitment to build an initial network of H_2 stations is needed.

LEAD: Federal government (and provinces where initial fueling networks are established)

TIMEFRAME: Near-term impact

CO-BENEFITS: Canada's supply of low-carbon electricity is ideal for hydrogen production, via water electrolysis. Under-utilized generating capacity can power grid-scale electrolyzers to produce hydrogen, which can then be distributed throughout a network fueling stations. This would support Canada's renewable power and energy storage agenda.

4. Initiate science program to identify most sustainable renewable fuels production options

CONCEPT: Much of the debate over whether biofuels and renewably-sourced fuels are less carbon-intense than their fossil counterparts stems from a lack of conclusive and comprehensive data on region-specific carbon balances and global socioeconomic impacts on commodity supply and demand. The carbon-intensity of biofuel products depends significantly on land use effects associated with feedstock production. To understand which practices and processes should be promoted, and to build confidence in renewable fuels policies, a world-class science program should be established.

LEAD: Federal government

TIMEFRAME: Long-term impact

CO-BENEFITS: The outputs of this program could also position Canada as a leader in science that supports sustainable societies.

5. Joint initiative among academic institutions to advance artificial photosynthesis technology and other low-carbon fuels

CONCEPT: A handful of universities around the world are advancing the technology of highly efficient, low-cost hydrogen production, using techniques that are broadly labeled as "artificial photosynthesis." Similar to typical solar panels, artificial photosynthesis uses solar radiation (i.e., sunlight) to catalyze the separation of hydrogen and oxygen in water. By combing hydrogen with carbon dioxide, liquid transportation fuels can also be synthesized. Many leading scientists consider this a potential breakthrough in energy technology that would render fossil fuels obsolete. The University of Toronto is a leader in the field, along with Harvard and universities in Australia and South Korea. To accelerate progress, Canada could establish and resource a selection of global academic institutions to act as a coordinated research team, similar in spirit to the Human Genome Project. In California, there is the Joint Centre for Artificial Photosynthesis, established in 2010 with funding from the U.S. Department of Energy, but its membership is only California-based institutes – this recommendation is to establish a global network, building upon domestic expertise and leadership already in place.

LEAD: Federal government

TIMEFRAME: Long-term impact

CO-BENEFITS: This type of initiative is aligned with *Mission Innovation*, of which Canada is a member, representing tangible action in a critical area of clean energy R&D focus (see http://mission-innovation.net/).

Mission Innovation Clean Energy R&D Focus Areas

	Australia	Brazil	Canada	Chile	China	Denmark	European Union	Finland	France	Germany	India	Indonesia	Italy	Japan	Kingdom of Saudi Arabia	Mexico	Netherlands	Norway	Republic of Korea	Sweden	United Arab Emirates	United Kingdom	United States
Industry & Buildings	o	o	o	o	o	o	o		o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Vehicles & Other Transportation	o	o	o	o	o	o	o	o	o	o	o	o		o	o	o		o	o	o	o		o
Bio-based Fuels & Energy	o	o	o			o	o	o	o	o	o	o	o			o	o	o	o	o	o	o	o
Solar, Wind & Other Renewables	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Nuclear Energy	o	o	o		o											o			o		o	o	o
Hydrogen & Fuel Cells	o	o	o		o	o	o	o	o	o	o			o	o	o	o	o	o			o	o
Cleaner Fossil Energy		o	o		o	o		o		o	o	o			o		o		o				o
Co, Capture, Utilization & Storage	o	o	o		o	o	o		o	o	o	o		o	o	o	o	o	o		o	o	o
Electricty Grid	o	o	o	o	o	o	o	o	o	o	o	o	o	o		o	o	o	o	o	o	o	o
Electricty Storage	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Basic Energy Research	o		o			o	o		o	o	o	o	o	o	o		o	o		o	o		o

Technology – putting energy from fuel to best use

The following measures aim to support and incentivize advanced vehicle technology development and commercialization.

1. *Develop government-industry joint R&D program focused on innovation priorities among Canadian automotive parts manufacturers*

CONCEPT: Canada seeks to secure its positioning and comparative advantages within the global automotive supply chain. Tier 1 suppliers often innovate technology solutions for the major, global automakers. A joint R&D program, focused on the parts manufacturing sector could help Canada's Tier 1 suppliers, such as Magna, Linamar and Martinrea, to enhance their competitiveness in global market that increasingly tilts towards more fuel-efficient, lower-emitting products.

LEAD: Federal government and industry

TIMEFRAME: Long-term impact

CO-BENEFITS: This action does not directly result in reduced GHG emissions, but it represents a commitment to maintain Canada's position as a key player in the global automotive supply chain, even as it undergoes radical change.

2. *Identify mineral resource development opportunities in Canada to meet demand for advanced vehicle electric architecture*

CONCEPT: The array of metals and materials in modern vehicles is becoming increasingly diverse and exotic. The mix of materials in today's cars is beginning to resemble that of consumer electronics, more so than the cast iron, steel and aluminum comprising cars of generations past. Canada is rich in mineral resources, some of which could play a significant role in the transition of advanced and electrified vehicle systems.

LEAD: Federal government and industry

TIMEFRAME: Long-term impact

CO-BENEFITS: This action can represent a proactive, industry-led and government supported economic development initiative, ultimately contributing to new mining developments and employment – particularly in Northern regions and communities.

3. *Establish a global centre of expertise in fuel cell system development and commercialization for vehicles*

CONCEPT: Canada is currently one of the leading suppliers of fuel cell technologies, globally. For example, Canadian fuel cells are the core technology within zero-emission buses, trains and delivery trucks currently operating in Asia, Europe and the U.S. A centre of activity that is focused on the development of new, commercial applications of fuel cell technology in transportation would not only support decarbonization of the sector, worldwide; it would also promote clean economic growth through increased technology exports. This could integrate with the Province of Ontario's vision for a centre for low-carbon mobility.

LEAD: Federal government, key provinces (BC, ON, QC) and industry

TIMEFRAME: Long-term impact

CO-BENEFITS: Economic development and clean tech employment

4. *Assess preparedness of fuel supply chain and engine systems for more biofuel blending in gasoline and diesel*

CONCEPT: As blends of biofuels and renewable fuels increase, a comprehensive compatibility assessment with automotive fuel, engine and exhaust systems should be conducted jointly by government and industry. This will enable any issues to be proactively addressed before they become problems.

LEAD: Federal government and industry

TIMEFRAME: Long-term impact

CO-BENEFITS: Helps to identify and address potential barriers to biofuel and renewable fuel use.

5. Study and support Canada's evolving automotive aftermarket technologies and IT services sector

CONCEPT: Small- and medium-sized enterprises in Canada are currently driving significant levels of consumer-focused innovation in the automotive aftermarket (i.e., vehicle enhancements made *after* a vehicle has left the dealership). Many of the services offered are IT-based (e.g., telematics, navigation, entertainment), some of which can support reduced fuel consumption and emissions, as well as optimal PEV charging. Whereas vehicle platforms can remain fundamentally unchanged for years, aftermarket products can be refreshed on a scale of months or even weeks – much like software updates for personal computers. This is a potential that government should investigate and assess to determine if targeted support is warranted.

LEAD: Federal government

TIMEFRAME: Short-term impact

CO-BENEFITS: By supporting new integrations between Canada's information technology and automotive sectors, new value creation opportunities can be realized.

Mode – packaging technology into highly efficient, low-emissions vehicles

The following measures aim to progressively and persistently migrate the active vehicle stock towards the more fuel efficient, lower-emitting and less carbon-intense end of the product spectrum.

1. Maintain and enhance GHG emissions standards for light- and heavy-duty vehicles

CONCEPT: Canada's GHG emissions regulations are the foundation of any transportation decarbonization strategy, and are the primary driver of technology change in the vehicle market. No transition to zero-emission vehicles can be successful if it undermines or compromises the function of the regulations. The regulations progressively reduce fuel consumption and GHG emissions in new vehicles by forcing the development and application of fuel-saving technologies. In time, as zero-emissions vehicle technology decreases in cost, and as the regulations become increasingly stringent, ZEVs will become necessary for compliance. If, on the other hand, the regulations were removed, it is highly unlikely that ZEVs would be able to compete on cost with conventional vehicles. This principle has been established by the most credible and comprehensive studies on the subject.

LEAD: Federal government

TIMEFRAME: Near-term impact

CO-BENEFITS: The design of the regulations also ensures national economic benefits and public health benefits owing to reduced fuel use. Furthermore, although the regulation applies to new vehicles sold, it ultimately introduces fuel-saving technologies into the used vehicle market, where fuel efficiency is even more valued than in the new vehicle market. The regulation is thus considered to enhance social equity, too.

2. *Incent early retirement of vehicles with disproportionately high service life and/or high GHG emissions levels*

CONCEPT: The contribution that new vehicles make to reducing GHG emissions can be more rapidly realized if older, less fuel-efficient vehicles are retired from service earlier. Numerous mechanisms already exist that can be modified to dissuade individuals and businesses from continuing to operate very old, more polluting vehicles. For example, a schedule of increasing licensing fees for vehicles that have logged, say, more than 200,000 km of service, would dissuade users from continued operation of older technology vehicles, and promote the use of newer vehicles that are subject to more stringent efficiency and emissions standards, in general. Similarly, fees can escalate according to a vehicle's rated GHG emissions levels. Administratively speaking, this can be implemented relatively easily, by working through existing license and registration programs at a provincial level.

LEAD: Provincial governments

TIMEFRAME: Long-term impact

CO-BENEFITS: As new vehicles are subject to increasingly stringent limits on emissions of criteria air contaminants, accelerated vehicle retirement should contribute to improved air quality.

3. *Light-duty vehicle feebate system (revenue-neutral) to de-risk introduction of disruptive innovations*

CONCEPT: Feebate systems have been studied, simulated and promoted by economists for many years.[9] While it is considered by leading experts to be one of the most promising measures to reduce fleetwide vehicle emissions, it is also among the least understood. Feebates encourage automakers to go beyond regulatory compliance (if they are able) by paying for risks taken in the introduction of more advanced vehicle technologies.

LEAD: Federal government or provinces (i.e., provincial feebates systems can be integrated into existing fuel efficient vehicle models)

TIMEFRAME: Near-term impact

CO-BENEFITS: Properly designed feebates are administratively simple and cost efficient, enabling a smaller jurisdiction (like Canada) to implement them even if larger neighbouring jurisdictions (like the U.S.) does not.

4. *Support demonstrations of zero-emission vehicle systems in heavy-duty applications (e.g., truck, bus) with commercial intent*

CONCEPT: Heavy-duty vehicle use is the fastest growing source of energy use and emissions within the on-road vehicle sector. Governments in Canada should therefore support development and demonstrations of zero-emissions technologies that are applicable to larger vehicle applications, such as trucks, transit buses and trains and special-purpose off-road and industrial vehicles.

LEAD: Federal government

TIMEFRAME: Long-term impact

CO-BENEFITS: A development and demonstration program for zero-emission heavy-duty vehicles can position Canada as a supplier-of-choice in niche segments of the market, building on existing strengths and contributing to export growth, economic development and employment. For example, Canadian fuel cell providers are already supplying powertrain technologies to transit buses, passenger trains and delivery vehicles elsewhere around the world. This represents valuable strategic positioning that Canada stands to lose if it does not act to bolster and expand its leadership in the field. In the public transit sector, the Canadian Urban Transit Research & Innovation Consortium is striving to achieve a similar set of goals.

9 The International Council on Clean Transportation. *Best Practices for Feebate Program Design and Implementation*. German, Meszler. 2010.

5. Revise tax code provision for standby charge to reflect vehicle GHG emissions instead of capital cost

CONCEPT: The use of a company-supplied vehicle is considered a taxable benefit for an employee. To determine the value of this benefit, a "standby charge" is calculated per the Canadian Income Tax Act [i.e., Part I, Division B, Section 6(2)]. The Act currently evaluates the standby charge as a function of the original *cost* of the vehicle to the company. Hence, the value of the benefit increases with vehicle price. By linking the standby charge to GHG emissions *instead*, an incentive can be embedded within the tax code that enhances the attractiveness of cleaner vehicles to companies.

LEAD: Federal government

TIMEFRAME: Short-term impact

CO-BENEFITS: This tax code change would contribute to a sustained increase in market demand for more fuel efficient, lower-emitting vehicles (notably, in fleets), resulting in positive social benefits as well as corporate benefits.

6. Comprehensive social marketing campaign to promote the value of highly fuel efficient, low-emissions vehicles

CONCEPT: Despite the demonstrated effectiveness of social marketing campaigns to engage citizens and consumers in driving behaviour change towards positive, social outcomes, policies to promote cleaner vehicles have never been fully embedded within such a strategy. Sophisticated social marketing campaigns lever multiple channels to connect with consumers, and provide contextual information when, where and how it's needed to inform and influence decisions. The intent is *not* to force consumers to behave against their nature; rather, it is to reveal how their interests and motivations are best served by an investment in fuel-saving, emissions reducing technologies represented in a wide range of highly efficient automobiles. Essentially, this is about packaging information in ways that are relevant and meaningful to targeted segments of the consumer market, and proactively mobilizing it. Moreover, social marketing complements regulatory tools, making them less disruptive and more efficient by better aligning market demand with the aims of regulation.

LEAD: Federal government and/or civil society groups

TIMEFRAME: Long-term impact

CO-BENEFITS: Social marketing campaigns are often best implemented through cross-sectoral partnerships, making them opportunities for government, industry and civil society to collaborate on positive, tangible change. Private sector partnerships with the insurance and finance sectors, as well as with loyalty program providers and lifestyle retailers are also promising options.

Infrastructure – ensuring lower-carbon modes of transportation are fully supported

The following measures aim to establish clear policy bias for investment in infrastructure that supports less energy- and emissions-intense vehicle modes.

1. Identify investment opportunities in enabling infrastructure that would achieve major mode shifts

CONCEPT: This is about understanding where an investment in specialized infrastructure (e.g., a bus transit way, a light rail system, an effective network of bike paths) in Canada has the potential to propagate a substantial modal shift within a population (likely urban) because it provides a more effective transportation solution. This also applies to intercity travel, in which passenger rail might conceivably compete with air travel.

LEAD: Provincial and municipal government

TIMEFRAME: Long-term impact

CO-BENEFITS: Synergistic with urban densification and community energy planning.

2. Establish long-term financing mechanisms for expansion of rail transit systems, providing effective, urban alternatives to private vehicle use

CONCEPT: Consistent with the motivations for institutions like Canada's proposed Infrastructure Bank, predictable and ongoing financing is needed to expand rail transit systems, including light surface rail and subways.

LEAD: Federal government and key provinces

TIMEFRAME: Long-term impact

CO-BENEFITS: Canada's large cities (often referred to as Canada's "economic engines") will create value and generate wealth more efficiently with the mass mobility that an expanding rail transit system can provide. Effective rail service is a hallmark of world-class urban regions.

3. Engage road construction sector in investigation of "low-carbon road & highway design" principles

CONCEPT: The ways in which roads and highways are designed can often support efficient vehicle operation, or inhibit it. This proposal is to collaboratively scope the potential for new road and highway design principles, including surface materials, that contribute to reduced transportation energy demand and emissions. These principles can subsequently be integrated in construction codes and standards, as appropriate.

LEAD: Provincial governments, industry

TIMEFRAME: Long-term impact

CO-BENEFITS: Roads and highways that support energy efficient driving can also improve safety and reduce highway fatalities, and mitigate traffic congestion.

Operator – getting the best performance out of the infrastructure

The following measures aim to realize the efficiency potential of infrastructure though enhanced vehicle operation and control.

1. *Expand eco-driver training programs for private and commercial operators, with rewards and incentives*

CONCEPT: This is to build upon the successful experiences in driver training programs and institutionalize incentive and reward systems for ongoing improvement (the availability of simple telematics systems for individual drivers could facilitate).

LEAD: Industry

TIMEFRAME: Long-term impact

CO-BENEFITS: More eco-driving results in safer roads and cleaner air.

2. *To minimize idling emissions, develop congestion pricing strategy for optimal traffic flow throughout urban regions*

CONCEPT: ongestion pricing is a means of keeping the flow of traffic smooth, steady and efficient, and ensures that highway infrastructure is operating at optimal capacity.

LEAD: Provincial and municipal government

TIMEFRAME: Near-term impact

CO-BENEFITS: Contributes to the economic efficiency of the region served.

3. *Regulate use of speed limiters in commercial traffic, nationally*

CONCEPT: Ontario requires commercial vehicles to set speed governors to 105 km/h, which saves fuel and reduces emissions relative to highway velocities that exceed this level. A variation of this policy could be nationally established.

LEAD: Federal government and provinces

TIMEFRAME: Near-term impact

CO-BENEFITS: This measure should improve the safety of highways shared by trucks and passenger vehicles.

4. *Establish world-class research, development and testing capacities for autonomous vehicle control*

CONCEPT: Building on Canada's strengths in the IT and software sectors, as well as its academic capacities in artificial intelligence, a centre of excellence in driver-assist and self-driving vehicle systems could be established, with a focus on potential decarbonization benefits.

LEAD: Federal government and provinces

TIMEFRAME: Long-term impact

CO-BENEFITS: The centre could augment Canada's role in the global automotive supply chain.

Off-road, marine, rail and aviation

Comprehensive decarbonization of the transportation sector should address all modes of transportation. Thus, while the framework in this section is mainly populated with options relating to the on-road sector, some preliminary ideas were also added for off-road, marine, rail and air. Pollution Probe would be pleased to conduct a more thorough examination of options in these important sectors. Below is a list of the concepts proposed.

Off-road vehicles

- Assess technical potential for renewable diesel in compression-ignition engine systems for heavy off-road applications.
- Investigate industry need and commercial applications for electric, ZEV technologies in mining, agriculture, construction

Marine vehicles

- Maintain and enhance regulations on use of ultra-low sulphur marine fuels
- Investigate low-carbon intensity fuel alternatives for marine applications (e.g., natural gas)

Railway vehicles

- Assess technical potential for renewable diesel locomotive engine systems
- Establish a railway technology innovation and development centre, linking with US based R&D centres
- Support commercial development of next-generation zero-emission, zero-carbon commuter rail systems
- Support development of commercially viable alternative fuel-powered freight locomotives
- Investigate if/where intercity passenger rail service could compete with regional air travel

Aircraft

- Investigate renewable kerosene drop-in aviation fuels
- Assess potential of electric, zero-emission power systems for aircraft taxiing
- Assess potential of small aircraft electric propulsion systems
- Investigate the role of regional airports in reducing int'l airport congestion and overall aviation fuel use

Concluding remarks

The experience of developing and applying the framework approach in this report yielded several observations. First, a successful decarbonization strategy will likely rely on policies implemented not only by the federal government, but by provincial and municipal governments, too. Also, a range of critical measures are best-led by the private sector, or jointly conducted by both industry and government.

Furthermore, there are some areas of technology development where Canada has established commercial capacities. A transportation system decarbonization strategy can, therefore, promote clean growth opportunities for Canada by building its current strengths in the global supply chain for transportation technologies.

Some elements of the transportation system have not been prime targets for decarbonization policies in the past. For example, highway design and driver training programs are generally driven by safety concerns. Therefore, the literature is less well-developed on policy options pertaining to these elements of the system. Pollution Probe believes that this represents an opportunity for fresh research into infrastructure- and operator-oriented measures, especially in the context of autonomous vehicle use.

Importantly, the framework approach supports inclusive and collaborative strategy development and implementation, since it can draw on the interests and capacities of a range of stakeholders in every part of the transportation energy system. Co-creation of a strategy can build support among key partners, and yield a more sophisticated array of tactics to achieve a shared goal.

As well, the framework supports the development of an *adaptive* strategy for decarbonizing transportation. Not only can the strategy be updated continually, *it should*, thereby addressing the needs and opportunities of a continually evolving landscape.

In conclusion, Pollution Probe looks forward to using the framework described in this report to engage all sectors of society in developing strategies that support government efforts to decarbonize transportation energy use in Canada.




SCHOOL BUS