

Hybrid Electric Vehicles for Sustainable Transportation: A Canadian Perspective

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Abstract

The demand for motor gasoline in Canada, especially by light-duty vehicles, continues to increase with economic growth and development. Fossil fuel driven transportation is not only creating financial strain due to fluctuating gas prices but is also polluting the environment, posing health risks to the community. In an effort to promote public awareness, this paper reviews hybrid vehicle technology as a logical step towards sustainable, efficient and environment friendly transportation and discusses the measures taken by Canadian government to encourage hybrid vehicle sales and minimize fossil fuel dependency of the transport sector.

Keywords: Canada, environment, hybrid electric vehicles, policies

1 Introduction

With increasing awareness of the economic and environmental concerns associated with fuel combustion in automobiles, the world is focusing towards the development of sustainable technology. Transportation is one of the highest consumers of fossil fuels and the largest contributor of greenhouse gas (GHG) emissions in Canada with motor gasoline sales constituting 40% of the country's total domestic petroleum sales [1]. This oil dependency of Canadian transport, particularly light-duty vehicles is responsible for a quarter of the total GHG emissions in the country and has become a source of economic stress with rising oil prices [2]. Hybrid electric vehicles (HEVs) offer a fuel-efficient solution that combines an electric motor based drivetrain with the conventional internal combustion engine (ICE) to reduce fuel consumption and vehicle emissions [3]-[5]. These benefits of HEVs have prompted the automakers to develop hybrid vehicles, most of which are available in Canada today. However consumer acceptance to hybrid vehicles remains low mostly due to public unawareness of the performance and reliability of HEV technology and high initial cost of hybrid cars. This paper attempts to raise public understanding of the grow-

ing need to shift Canada's transport to sustainable, environment-friendly alternatives and review the current hybrid technology as an efficient solution available to Canadian vehicle owners. The policies, programs and incentives taken by federal and provincial governments to promote sustainable transportation and encourage the public to adopt this green technology are also discussed in detail.

2 Economic and Environmental Impact of Fossil Fuel Based Transportation

2.1 Increasing Trends of Global Fuel Prices and CO₂ Emissions

Growth in on-road transportation is closely associated with the development of global economy. Due to the present worldwide trends of population increase, expansion in international trade and economic development, the demand for heavy and light duty vehicles is on the rise. With close to 600 million vehicles on road today, over the next forty years, 800 million more people are expected to own cars around the world. In 2002, light-duty vehicles alone accounted for 23% of the total 77 million barrels per day of oil consumption in the world, and is expected to go as high as 32 million

barrels per day by 2030 [6], making them one of the major users of energy. This absolute dependence of on-road transportation on unsustainable resource of fossil fuels is beginning to raise serious concerns. With the current growth in industrial development and transport demands, especially in the developing countries, the finite fuel reserves are depleting at an alarming rate and will one day run out. Another cause of concern is the soaring gas prices that have increased exponentially over the last few years due to rapid industrialization of growing economies, depletion of fuel reserves, political factors and speculations. This high fuel cost not only influences the direct expense on transport but also has a cascading effect on prices of all other commodities and services, creating stress on the economy.

Another hazard of fossil fuel combustion in vehicles is the expulsion of harmful emissions including carbon dioxide (CO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and unburned hydrocarbons. Emission levels of CO_2 , the principle GHG, have steadily escalated corresponding to the increasing fuel consumption particularly in the transport sector. Figure 1 shows the trend of worldwide CO_2 emissions in the past 3 decades. Although the emission trends of major contributing countries do not show a drastic increase, the steady rise of CO_2 is explained by the industrialization of emerging economies.

The emissions and pollutants from fuel combustion are not only considered responsible for climate change, but also degrade the air quality that has a far reaching impact on human health. Air pollution is linked to cardiovascular and respiratory diseases and is a major environment-related health threat especially to children. An assessment by World Health Organization more than 2

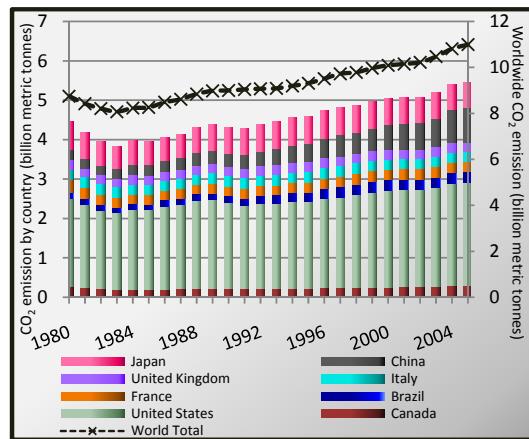
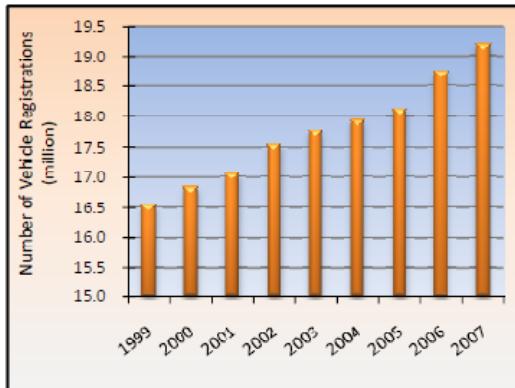


Figure 1: Worldwide CO_2 emission from petroleum consumption.

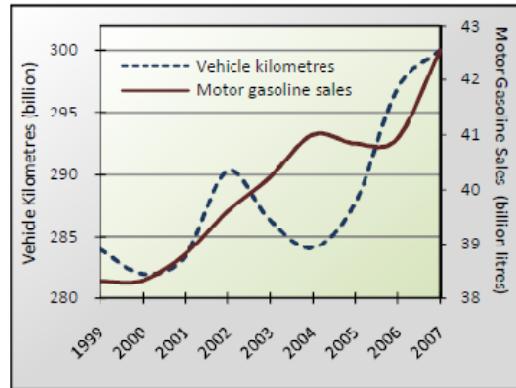
million premature deaths due to air pollution [7]. Owing to its adverse impact on the global economy and environment, and the possibility of complete exhaustion of reserves, use of petroleum based vehicles is raising concern and is driving the research and industry sectors to look for alternative solutions.

2.2 Effect of Growth in Light Duty Vehicle Transportation in Canada

Canada spreads over 9,984,670 km^2 , making it the world's second largest country by total area with a population of 33.5 million. Canada's road network spans more than 1.4 million km over its ten provinces and three territories. It is home to the 7th largest auto industry in the world that employs well over half a million people associated with automotive assembly, component manufacturing, distribution and aftermarket sales and services. The industry produces about 2.7 million vehicles every year and is a major contributor to the Canadian economy with a share of nearly 13% of its current manufacturing GDP of 176 billion dollars. In the midst of its progressive expansion in international trade, economic development and population growth, the country is now facing a sharp rise in the demand for on-road transportation, particularly light-duty vehicles. In 2007, 1.6 million light-duty vehicles were sold in Canada, increasing the total number of light-duty vehicle registrations to more than 19 million from 16.8 million in 2000 as demonstrated in Fig. 2(a) [8]. Although this drastic growth in the transport sector is an indicator of a thriving economy, it has also grown to become the largest consumer of petroleum. The number of vehicles on road today, though higher than ever before, cannot be blamed entirely for high fuel consumption by the country's transport sector. Canada's vast road network compels people to travel longer distances between its widespread cities. According to Canada Vehicle Survey, light-duty vehicles travelled close to 300 billion kilometres in 2007. As a result, motor gasoline sales have reached 42 billion litres [1] that constitutes 41% of the country's total domestic petroleum sales as shown in Fig. 2(b). Weather conditions in Canada also influence the amount of fuel consumption in automobiles. While the coastal regions enjoy milder temperatures, most parts of the country, particularly the interior and Prairie provinces, experience harsh winters forcing vehicle engines to burn more gas. Thus, due to the growth in Canadian transport sector and the vast and diverse geography with long distances and harsh weather, transportation draws the largest share of oil, mak-



(a)



(b)

Figure 2: Growth in transport sector in Canada. (a) Light-duty vehicle registrations. (b) Motor gasoline sales and vehicle kilometres.

Table 1: Status of Canada's oil reserve as of 2007.

Country	Reserves (billion bbl)	Production (million bbl/d)
Saudi Arabia	262	10.7
Canada	179	3.3
Iran	136	4.1
Iraq	115	2
Kuwait	102	2.7
UAE	98	2.9
Venezuela	80	2.9
Russia	60	9.7
Libya	42	1.8
Nigeria	36	2.4

ing per capita fuel consumption in Canada higher than most industrialized nations.

2.2.1 Economic impact of fossil fuel based transportation

With the world's second largest oil reserves of 179 billion bbl [9] and a production rate of 3.3 million bbl per day [10] as shown in Table 1, Canada may not have to worry about depletion of fuel reserves for decades, but dependence of its transport sector on fossil fuel is beginning to raise serious concerns as Canadians face the impact of worldwide escalation in oil prices. Rapid industrial development and urbanization of growing economies, depletion of worldwide fuel reserves, political factors and speculations are amongst the many reasons why oil prices in Canada have almost tripled in the last 10 years. In the current scenario of global economy, the price of gasoline saw a sudden decline as far low as 2004 level. This exponential increase or sudden fluctuation in fuel cost not only influences the expenditure on transportation, producing financial strain on vehicle owners, but also has a cascading

effect on the prices of all other commodities and services, creating economic stress and financial uncertainties.

2.2.2 Degradation of air quality due to vehicular emissions

An equally alarming consequence of petroleum combustion in transportation is the emission of CO₂, and toxic pollutants including CO, NO_x, hydrocarbons and particulate matter that are known to produce adverse health effects. Canada is amongst the ten highest CO₂ producing nations in the world with a per capita emission close to 22 tonnes.

In an effort to reduce these emissions, Canada is systematically replacing coal based electricity generation by hydro and nuclear power plants. However, rapidly increasing passenger transportation and consumer trend shifting towards minivans, sport utility vehicles and small trucks have led to an increase in fuel consumption. These heavier vehicles with lower fuel efficiency emit on average 40% more greenhouse gases per kilometre than passenger cars [11], playing a pivotal role in continued deterioration of air quality. Figure 3 and Figure 4 show that transport sector is the single largest source of greenhouse gas in Canada, accounting for about 25% of total emissions within which light-duty vehicles are the highest contributor to air pollution emitting more than 11% of the total CO₂ in Canada. Despite preventive efforts, emissions from transport sector alone rose by about 44 megatonnes, or 32%, in the last fifteen years with a massive 24 megatonne increase in the emissions from light-duty gasoline trucks [12]. In December 1997, Canada and other developed countries negotiated the Kyoto Protocol at the United Nations

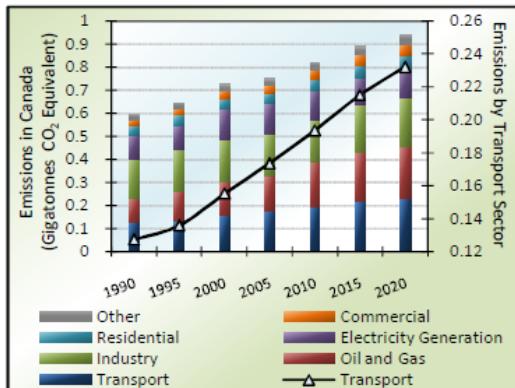


Figure 3: Projected CO₂ emissions by sector in Canada.

Framework Convention on Climate Change. The protocol commits Canada to reduce its greenhouse gas emissions to 6% below 1990 level, indicated in Fig. 4, during the five-year period from 2008 to 2012. However, if the current emission trend by transportation continues, greenhouse gas emissions in Canada are expected to exceed 1990 level by 38.5% by 2010 and 58.2% by 2020 [13].

2.2.3 Health risks associated with vehicular emissions

Toxic emissions from fossil fuel combustion particularly in vehicles are not only linked to climate change but also have a significant impact on air quality and health, resulting in increased hospital admissions, respiratory illnesses and premature deaths, especially in urban areas. Canadian Medical Association (CMA) has recently released data that predicts the annual death toll caused by air pollution to reach 21,000 in 2008. CMA warns that 710,000 more people will lose their lives by 2031 due to long-term exposure to air pollution and the count for acute short-term effects will reach 90,000 deaths. Children are particularly vulnerable since they breathe faster than adults and inhale more air per pound of body weight. Air pollution is also known to exacerbate the condition of people with respiratory and cardiovascular diseases that are among the leading causes of hospitalization and almost 80,000 deaths every year [14]. Canadians are also suffering the economic impact of air pollution as higher health care expenditures, non-attendance of ill workers and several other factors have cost the country more than \$10 billion this year and according to CMA, the cumulative total between 2008 and 2031 is expected to reach \$300 billion. People are now recognizing the

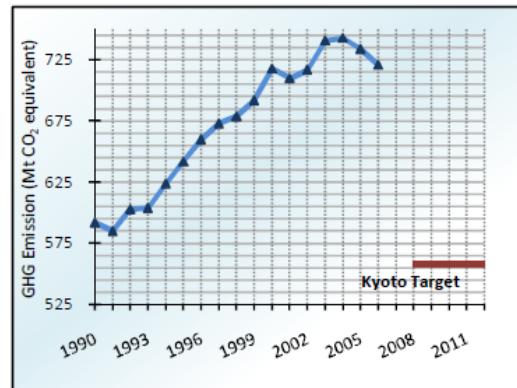


Figure 4: Greenhouse gas emissions in Canada.

economic constraints of fossil fuel-based vehicles and the grave impact of fuel combustion on the Canadian environment and public health.

Attention is, therefore, focused towards the development and promotion of advanced vehicular technology and alternative fuels that can reduce dependency on fossil fuels in order to de-link transportation demand from fuel consumption and emissions. Amongst several possible alternatives, hybrid vehicle technology has proven to be the most commercially viable solution to conventional transportation.

3 Alternative Fuel Vehicles

3.1 Battery Electric Vehicles (BEVs)

Battery powered electric vehicle is one of the first solutions proposed by many to displace ICE based drivetrains in automobiles. In electric vehicles, traction is provided by an electric motor typically powered by a battery that is the only source of energy on-board. The batteries are recharged by plugging into a power source through an on-board or external charger. The electric motor is controlled by an electronic motor controller that signals to a power electronic drive to run the motor [15]. The motor can also act as a generator during braking to regain part of the kinetic energy and store it in the battery as electrical energy. This operation is called regenerative braking. Due to absence of any combustion process BEVs do not require gasoline and have no tailpipe emissions, high efficiency and smooth and quiet operation.

Initial prototypes of battery electric vehicles were developed shortly after the invention of the first DC motor in 1831 and up until the early 1900s, BEVs outnumbered gasoline vehicles. However, with the improvement in the produc-

tion of ICE driven vehicles and the reduction of their cost from \$850 in 1909 to \$260 in 1925, BEVs became a more expensive choice and began to disappear from the market [16]. They started to resurface, however, in the 1960s as environmental concerns began to arise. General Motors (GM) introduced its electric vehicles Electrovaiv with a 115 hp three-phase induction motor powered by a 512 V silver-zinc battery. Around the same time period “The Great Electric Car Race” cross-country competition between an EV from Caltech and an EV from MIT stirred an excitement for electric vehicle technology in USA. However, the BEV technology, especially in terms of energy storage was not mature enough to support commercial production. Energy crisis in the 70s followed by dramatic increase in oil prices made BEVs once again the focus of automotive research. In the coming two decades, development of high frequency semiconductor switching devices and microcontroller technology led to the improvement in power converter devices for efficient control of electric motors in electric vehicles. During the last decade of the 19th century, a number of companies produced battery powered electric vehicles in USA, Britain, and France.

BEVs however have a crucial limitation of short driving range due to the limited capacity of batteries and the absence of any on-board charging source. They have a high initial cost, long charging time and smaller capacity. This is why BEVs today are mainly used for small vehicles and short distance applications. Nickel-metal hydride batteries, most commonly used in automotive applications at present, do not have sufficient storage capacity and energy density to allow wide-scale mass production of BEVs. However, lithium-ion batteries are under research that is expected to provide specific energy and storage capacity higher than any other commercially available battery to provide a much more extended range for battery dependent automobiles.

3.2 Fuel Cell Vehicles (FCVs)

Since the specific energy and energy density of batteries are much lower than that of gasoline, the development of fuel cells to generate power for electric vehicles has accelerated in recent years. FCVs are similar to BEVs in their electric propulsion as shown in Figure 5 except, in addition to a chemical battery for energy storage, they use fuel cells to generate electricity by an electrochemical reaction between electrodes in the presence of an electrolyte. Unlike batteries,

fuel cells consume their reactants and do not store energy but only generate it as long as the fuel supply is maintained [17]. This fuel can be hydrocarbons or alcohol but hydrogen is most typically used that can either be stored in pure form on-board or produced from on-board hydrogen carriers that feed directly to the fuel cells. A fuel cell system in an FCV serves as the primary energy source to generate electricity which is then either used to propel the vehicle or stored in a battery that does not need any external charging. Battery serves as a storage device for energy generated by fuel cells and also improves the low power density of fuel cell systems that, when serving alone, would require a more bulky construction [18]. Furthermore, fuel cells have a slow response that increases the start-up time of the vehicle. Fuel cell vehicles offer a much longer driving range than BEVs and almost zero emissions.

The concept of fuel cell was discovered in by Sir William Grove in 1839, the design of which was first engineered in 1889. The first successful fuel cell was produced in 1932. It consisted of a hydrogen-oxygen cell using alkaline electrolytes and nickel electrodes. In 1959, a practical 5 kW fuel cell system was produced followed by the first ever 20 hp, fuel cell-powered tractor. More recently, several leading auto makers have initiated research on fuel cells for use in automotive applications with the aim to displace conventional power sources. Honda developed FCX which became the first fuel cell vehicle to be approved by US Environmental Protection Agency (EPA) and California Air Resources Board (CARB) for commercial use and has been certified as a zero emission vehicle by EPA and CARB. 2008 Honda FCX offers a fuel economy of 124 km/kg and 108 km/kg for city and highway driving respectively. Although fuel cell is an emerging technology with immense potential to significantly reduce petroleum combustion and harmful emissions, however high cost and life-cycle of the fuel cell, and storage, production and transportation of hydrogen are huge challenges that need to be addressed before FCVs can become feasible for commercial production [19].

3.3 Hybrid Electric Vehicles

Hybrid electric vehicles (HEVs) were designed to overcome the disadvantages of gasoline powered and battery electric vehicles. HEVs combine the conventional ICE driven mechanical drivetrain with a motor propelled electric drivetrain. Electric power to the motor in a

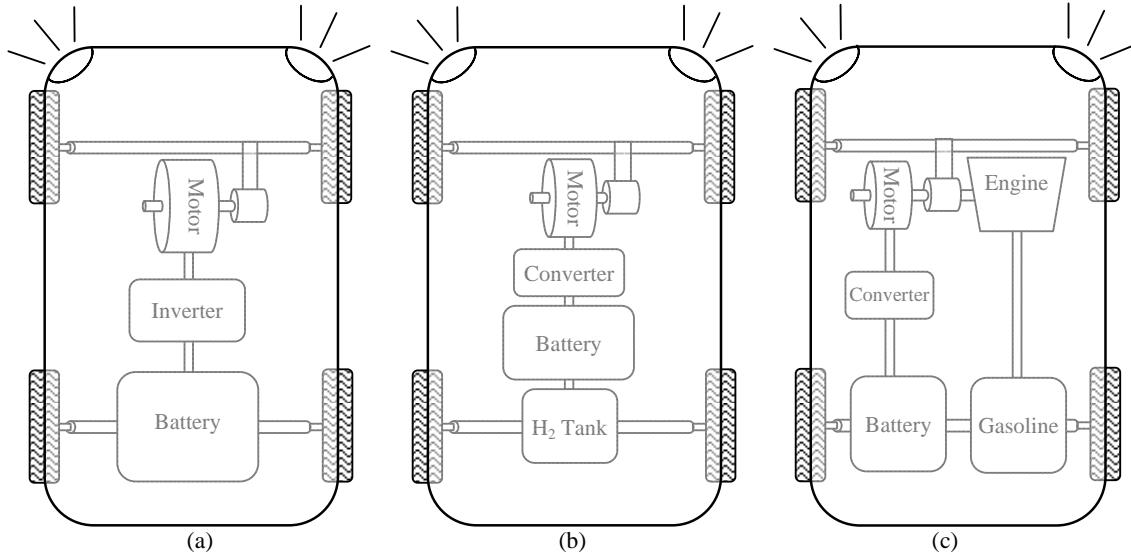


Figure 5: Vehicles partly or fully driven by electric power. (a) Battery electric. (b) Fuel cell. (c) Hybrid electric.

hybrid vehicle is usually provided by a chemical battery. The presence of an on-board electric motor allows optimized operation of the engine in its maximum efficiency region, thus giving higher fuel efficiency than ICEVs while the use of ICE to charge the battery allows a much more extended driving range than BEVs. The electric motor also enables regenerative braking and shutting down the engine during idling further increasing the efficiency of the vehicle [20].

3.3.1 HEV technology

The two drivetrains in an HEV can be integrated in various configurations that give varied operational and performance characteristics. In a series HEV, the ICE propels an electric generator to produce electrical energy either to charge the battery or to propel the vehicle by an electric motor [21]. In parallel HEVs, both the ICE and the motor are coupled to the drive shaft of the wheels, allowing the power to be delivered in dual, ICE alone or motor alone mode [22]. Series-parallel is a more complex design in hybrids that combines the advantages of both series and parallel configurations. Due to the optimized operation of the ICE and regenerative braking, maintenance requirements for oil changes, exhaust repairs, and brake replacement are significantly reduced. Hybrids can also be classified as series, parallel, series-parallel and complex based on the combination of electrical and mechanical drivetrains, or as mini, mild, and full based on the degree of hybridization. Honda Civic Hybrid, for example, is a mild hybrid with a 12kW motor, Toyota Prius is a full hybrid of series-parallel design with a

50kW permanent magnet synchronous motor and GM's upcoming Chevy Volt is a full hybrid with a series configuration and 112 kW motor.

The first hybrid car design is reported as early as 1899 by Pieper establishment of Liège, Belgium. It was a parallel hybrid with lead acid batteries that were charged by the engine during coasting or idling. The electric motor, in addition to regenerative braking, assisted the motor in high power demands. The same year Vendovelli and Priestly Electric Carriage Company of France presented a series hybrid with a tri-wheel design with electric motors on the two rear wheels and a fractional horsepower gasoline engine that did not propel the vehicle but was only coupled to a 1.1 kW electric generator. Dr. Ferdinand Porsche's second car was also a hybrid that used an ICE to propel a generator which in turn powered electric motors located in the wheel hubs.

The aim of these early HEVs was to assist the rather weak gasoline engines. But as Henry Ford overcame many of the challenges in ICEs including noise and vibration, and mass production of self-starting gasoline engines gained pace in 1920s, like all other alternative fuel vehicles, HEVs saw a sharp decline. The control of electric machines in the absence of advanced power switching devices was also a hurdle that discourages the use of electric motors in cars. This is why HEVs did not attract attention until the 1970s as the converter technology began to evolve and Arab oil embargo and consequent energy crisis triggered the development of alternate fuel vehicles including HEVs.

The status of hybrid vehicles took a drastic turn

with the commercial launch of Toyota Prius in 1997 which has sold over a million units since then. Two years later, Honda Insight was introduced in North America soon followed by Honda Civic Hybrid. There are several hybrid vehicles offered by some of the prominent automakers around the world that have together raised annual sales of hybrid units from over 62,000 in 2002 to almost 400,000 in 2006. These sales have proven that hybrid cars not only offer a much better fuel efficiency than ICEVs but are commercially the most viable technology at present despite their comparatively higher purchase cost. Most of these mass produced hybrid models are available in Canada but despite their well recognized environmental benefits and fuel savings, and government incentives to promote their sales, consumer acceptance to HEVs remains low throughout the country. With growing awareness of deteriorating air quality and the economic burden of fluctuating gas prices, it has become essential to determine the inhibitors that are retarding market diffusion of hybrid electric vehicles in order to devise systematic strategies to produce hybrid vehicles that satisfy consumer demands and help encourage buyers to consider HEVs in their choice of vehicles.

3.3.2 Lifetime emission savings

To examine the emission levels of HEVs, a comparative assessment of hybrid cars was conducted with their corresponding standard counterparts. The aim of this study is to determine the amount of emissions that vehicle owners can save by driving a hybrid car. In order to determine the emission savings that can be achieved in a lifetime of seven years with annual mileage of 24,000 km by replacing conventional vehicles with hybrids, emissions from hybrids and gas powered vehicles were calculated for 55 percent city and 45 percent highway driving based on their respective fuel economies. Since combustion of one litre of gasoline emits 2.4 kilograms of carbon dioxide (CO_2) [23], the consequent emissions from vehicles in their lifetime were evaluated and are summarized in Table 2.

The emission calculations show that high fuel efficiency of hybrids not only means less spending on gas but also translates into reduced CO_2 emission. The analysis indicates that at the end of seven years, all hybrids exhibit much lower emissions. Honda Civic Hybrid, for instance, emits 1,421 kg, or 31%, less CO_2 than standard Civic. This means that displacement of gas driven cars by hybrid vehicles can have a signifi-

cant impact on the air quality in Canada. In 2006, close to 870,000 passenger cars were sold country wide. Amongst these, Honda Civic alone sold 70,028 units. If these Civic models were to be replaced by their hybrid version, Canada could save 100 kilotonnes of CO_2 every year. Hybrid vehicles can thus have a huge impact in controlling vehicle emissions countrywide to improve the air quality that can ensure a safer environment to safeguard public health.

Despite this significant benefit of HEV technology, sales of hybrid units in Canada continue to remain low. Close to 900,000 passenger cars were sold countrywide in 2007 out of which HEVs could penetrate the market with a share of merely 1.6%. There are several reasons associated with the slow market diffusion of hybrid technology. High initial cost, presumably poor acceleration, limited cargo and passenger space, availability of spare parts and technicians and long waiting periods for vehicle delivery are some of the causes of consumer hesitation in adapting HEVs. Overcoming these barriers is a challenging task that calls for a two pronged approach that not only requires the formulation, regulation and implementation of policies, incentive strategies and promotional campaigns to support and encourage hybrid vehicles but also requires strenuous efforts towards the technological development of hybrid drivetrain systems so that the drive performance and operational features of hybrid cars can compete with the already established and matured technology of conventional vehicles.

4 Factor Affecting Consumer Acceptance to Hybrid Vehicles

There are several factors that can be held responsible accountable for the rather slow growth in hybrid sales in Canada and are discussed in this section.

4.1 Financial Limitations

The high initial cost of hybrids is main cause of low sales. Most hybrids cost seven to twelve thousand dollars more than their non-hybrid versions or vehicles of the same class. This increase in cost is attributed to low demand and higher cost on additional electric components, particularly the battery. Ford Escape Hybrid, for example, costs \$35,000 compared to the standard Escape that costs \$25,000. In some cases, this sharp difference in initial price makes it difficult for hybrids to payback their purchase cost through

Table 2: Lifetime emission savings by hybrid vehicles

Manufacturer	2008 Model	Fuel Economy city/hwy (L/100 km)	Annual Emis- sions (kilograms)	Lifetime Emissions (tonnes)	Emission Sav- ings (tonnes)
Toyota	Yaris	8.1/6.7	2,837	19.86	9.59
	Prius	4.9/5.2	4,206	29.44	
Ford	Escape	10.1/7.2	5,079	35.55	11.24
	Escape Hybrid	5.8/6.4	3,473	24.31	
Honda	Civic	9.4/6.5	4,560	31.91	9.95
	Civic Hybrid	5.8/5.2	3,139	21.97	
Toyota	Camry	11.2/7.6	5,380	37.66	9.95
	Camry Hybrid	7.1/6.9	3,952	27.66	
Nissan	Altima	10.2/7.6	5,080	35.56	13.04
	Altima Hybrid	5.6/5.9	3,218	22.52	

fuel savings even after ten years. Car prices in are higher in Canada compared to United States and additional cost increase in hybrids discourages consumers to choose hybrid vehicles.

Moreover, maintenance expenditure is a source of concern to vehicle owners. These financial limitations compel buyer to shy away from purchase of hybrid cars since many people are reluctant to pay the price just for better emission standards. Efforts are therefore not only required at the development stage to bring down the component cost but also to provide financial incentives, rebate and tax exemptions to lower the differential cost between hybrids and non-hybrids.

4.2 Consumer Lack of Information

There are many misconceptions associated with the fairly new hybrid technology that misleads consumers away. One such misconception is the high maintenance cost on batteries. Although battery replacement can cost two to three thousand dollars, however most manufacturers now offer 8-10 years/240,000 km warranty and in coming years, with the progress in battery technology, this warranty is expected to go up to vehicle life.

Another reservation towards hybrid vehicles is their failure to deliver the fuel economy numbers verified by Environment Protection Agency in US or by EnerGuide labels in Canada. Vehicle owners need to be made aware of the effect of driving habits on fuel economy. Fast acceleration of a motor vehicle from a start, speeding, sudden braking and flooring the gas at traffic signals all adversely affect the vehicle's fuel economy.

Some consumers also do not recognize the wide-ranging operational performance and fuel efficiency of hybrid cars designed for varied re-

quirements. Not all hybrid cars give a high fuel economy. Mini hybrids give a competitive driving experience but only feature idle-stop, and thus give a very little improvement in fuel economy over its non-hybrid version. Honda Civic Hybrid, on the other hand, shows an improvement of 3.6 and 1.3 L/100 km for city and highway driving respectively over conventional Civic. Speculations that hybrids are sluggish in performance also need clarification as hybrid models such as Camry can now compete with any gas driven vehicle of its class. Buyers, therefore, need to be educated on the wide-ranging vehicle performance and fuel savings offered by HEVs available in the market to help them make informed decisions and consider fuel economy in their choice of vehicle.

4.3 Technology Challenges

The addition of electrical components to the vehicle traction makes the design and control of hybrid electric vehicles a challenging task. Drivetrain components have to be designed specific to HEV application such that the vehicle performance can compete with all other available automobiles in the market. In this regards, hybrid vehicles have several challenges to overcome, particularly in the design and control of its electric drivetrain for enhanced driving performance, advancement in battery technology for longer life, lighter weight and higher power density, and the improvement in the spaciousness of the vehicles to satisfy consumer expectation.

While above mentioned are the most dominant inhibitors to market diffusion of hybrid vehicles, there are several other noticeable issues. Availability of technicians and maintenance equipment for hybrid cars is still not common in many Ca-

nadian cities. Moreover, delivery of hybrid vehicles, takes two to six months from the time of order due to low production.

5 Federal and Provincial Policies and Incentives to Promote Hybrid Vehicles in Canada

5.1 Federal Programs and Policies

The federal government is beginning to recognize the urgency of encouraging fuel-efficient vehicles in an effort to control GHG emissions in the country. Within the federal government, several Departments have the responsibility for transportation and the environment, particularly Transport Canada and Environment Canada. They are dedicated towards improving the quality of Canada's environment specially by reducing emissions from transportation through rebates and national programs some of which are discussed in this section.

5.1.1 Automotive partnership Canada

Automotive Partnership Canada (APC) is being established by five partnering agencies within the portfolio of Industry Canada. The objective of this five-year, \$145 million initiative is to support significant, incremental, collaborative R&D activities of benefit to the Canadian automotive industry; partnerships between industry and academia and/or National Research Council. Automotive Partnership Canada will support research and development activities that includes the improvement of automobile's environmental performance through advanced powertrain, energy storage and application of alternative fuels.

5.1.2 ecoTECHNOLOGY for vehicles

With \$15 million in funding, this program conducts in-depth testing and evaluation of safety and environmental performance of a range of innovative technologies used in vehicles. Results of these studies are showcased across the country to provide information on the potential of emerging technologies to help reduce the damaging impact of vehicles on the environment. Under this umbrella, ecoTECHNOLOGY (eTV) program evaluates different categories of advanced environmental vehicle technologies which are:

- eTV program is currently evaluating a number of vehicles that use alternative fuel technologies including bio-fuel, biodiesel, ethanol, clean gasoline and diesel, compressed natural gas and liquefied petroleum gas.

- The program is currently conducting research on a number of different advanced vehicle technologies to evaluate their performance in Canada, including hydrogen, electric and hybrid electric vehicles.
- Advanced engine/power train design refers to technologies that can help improve vehicle fuel economy by achieving greater efficiencies while emissions controls include all technologies that monitor and control the air pollutants released from a vehicle. eTV tests technologies such as, but not limited to, 42-volt electrical architecture, engine control unit and advanced transmissions, to improve power train design and emissions control systems, balanced against the need for performance and safety.

eTV program also works in cooperation with the automotive industry and consumers to identify and remove barriers to the introduction of advanced technology vehicles in Canada, fosters collaborations with the automotive industry and consumers to identify and remove barriers to promotion of advanced technology vehicles.

5.1.3 Excise tax

The federal budget for 2007 proposed a vehicle efficiency incentive aimed to encourage the purchase of fuel-efficient vehicles in Canada through rebates for highly fuel-efficient vehicles, neutral treatment for vehicles of average fuel efficiency and a new green levy on fuel-inefficient vehicles based on fuel economy ratings. This excise tax, starting at \$ 1,000, will be payable by the automobile manufacturer or importer at the time of vehicle delivery. The tax will, however, not apply to vehicles manufactured in Canada or exported to other countries.

5.1.4 ecoENERGY for personal vehicles

Ministry of Natural Resources announced \$21 million in February 2007 for this program that provides fuel consumption information and decision-making tools such as vehicle labels, guides and interactive websites. Under this umbrella several tools were developed to assist consumers in making informed decision on vehicle purchase. EnerGuide labels for vehicles are issued with all new passenger cars, light-duty vans, and pickup trucks not exceeding a gross vehicle weight of 3,855 kg that indicate city and highway fuel consumption ratings and an estimated annual fuel cost for that particular vehicle. The program offers teaching tools, on-line resources and publications by providing vehicle owners with in-

formation that will help them save fuel and protect the environment through their buying, driving and maintenance habits. Under this program, the annual ecoENERGY for Vehicles Awards are presented by Natural Resources Canada's Office of Energy Efficiency for the most fuel-efficient vehicles sold in Canada to encourage automakers to manufacture low emission vehicles.

5.1.5 Moving on sustainable transportation

Moving on Sustainable Transportation (MOST) Program was launched in 1999 by Transport Canada to support projects that create awareness and develop tools that can increase sustainable transportation options for Canadians. The program fulfils a commitment made by Transport Canada's first Sustainable Development Strategy in 1997 and has three major goals [24]:

- Development of innovative tools, approaches and practices for increasing the sustainability of Canada's transportation system and the use of sustainable modes of transportation
- Realize quantifiable environmental and sustainable development results on Transport Canada's sustainable development priorities
- Provide Canadians with practical information, tools and opportunities for better incorporating sustainable transportation options into their daily lives

MOST has committed funding innovative projects across Canada involving more than 500 environmental groups, community associations, academic institutions, business groups and professional associations. With financial support from MOST, these organizations are promoting education and awareness, conducting advanced research, and developing needed tools to promote sustainable transportation.

5.1.6 Urban transportation showcase

The Urban Transportation Showcase Program, an initiative by Transport Canada under the Government of Canada's Action Plan 2000 on Climate Change, is expected to continue through 2009. Its aim is to measure the impacts of strategies designed to reduce urban GHG emissions from transportation. Under this program, the following objectives have been identified [3]:

- Support the development and integration of strategies, transportation planning tools and best practices to reduce GHG emissions
- Demonstrate, measure and monitor the effectiveness of a range of integrated urban GHG emissions strategies
- Establish a comprehensive and pro-active

national network for the dissemination of information on successful GHG emissions reduction strategies for sustainable urban transportation.

The program supports innovative projects including hybrid buses, to attract Canadians to sustainable transportation options.

5.1.7 ecoAUTO rebate

ecoAUTO rebate was an initiative under the ecoTRANSPORT Strategy which aimed to reduce GHG and air pollutant emissions from the transportation sector. Under this initiative, to encourage Canadians to adopt more fuel-efficient vehicles, federal government of Canada offered rebates of up to \$2,000 on the purchase or long-term lease of fuel-efficient vehicles, including most hybrids that met the required fuel economy standards. The rebate was valid on eligible 2006, 2007 and 2008 models purchased between March 20, 2007 and December 31, 2008. Generally cars getting Combined Fuel Consumption Rating (CFCR) of 6.5 L/100 km or better and light trucks getting 8.3 L/100 km or better qualified. CFCR was determined by adding 55% of the vehicle's city fuel consumption rating to 45% of the vehicle's highway fuel consumption rating. As of Friday March 27, 2009 this program received over 180,000 applications and issued over 167,000 rebates totalling \$187.7 million [25].

5.2 Provincial Initiatives

In addition to the federal programs, several provinces have also taken initiative to promote sales of efficient vehicles in their jurisdiction in an effort to combat greenhouse gas emissions.

5.2.1 Ontario

Ontario offers a rebate of the 8% sales tax paid on alternative fuel vehicles to a maximum of \$2,000. Govt. of Ontario is also considering special license plates which would entitle high occupancy vehicle lanes and parking discounts to owners of fuel-efficient cars. Various cities in Ontario including London and Windsor have incorporated hybrid public transits in their fleet.

5.2.2 British Columbia

Hybrid and other fuel-efficient vehicles in British Columbia (BC) are eligible for a maximum rebate of \$2,000. BC is also the first jurisdiction in North America to introduce a carbon tax of \$10/tonne beginning July 2008 which will rise by \$5 a year until 2012. The BC government already operates a fleet of 584 hybrid vehicles, and since

2007, has had a policy of only leasing or purchasing HEVs for government use. Under Eco-taxi Initiative, hybrid taxis have been incorporated in regular fleet. The number of hybrids in taxi fleet has been steadily increasing as constitutes 36% of all taxis in Victoria.

5.2.3 Other provinces

Provincial sales tax rebate for fuel-efficient vehicles in Prince Edward Island is \$3,000, the highest among all Canadian provinces. Saskatchewan provides a 20% rebate on registration fees and insurance premiums on fuel-efficient vehicles. Alberta, Manitoba and Quebec also provide a rebate of \$2,000 on fuel-efficient vehicles.

6 Conclusion

This paper demonstrates the growing need for sustainable transportation in Canada and the role of HEVs as a possible solution. Through technology review and comparative analysis it shows that HEVs can significantly reduce GHG emissions. This paper summarizes the key initiatives and policies adapted by the Canadian government to encourage the purchase of fuel-efficient vehicles, particularly hybrid electric vehicles.

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