Electric Vehicle Technology Roadmap for Canada

A strategic vision for highway-capable battery-electric, plug-in and other hybrid-electric vehicles

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Letter from the Chair of the Industry Steering Committee

The race is on!

The world is racing towards electric traction as the principal means of sustaining the comfort, convenience, and efficiency of the transportation systems used in our modern life.

Canada is in a race with other countries to achieve the industrial, societal, and environmental benefits of electric vehicles. We started the race in a good position, with abundant renewable electric power and with Canadian companies and researchers leading the way in developing exciting new technologies.

However, we have not maintained our competitive advantage while transitioning from research to commercialization. We have allowed other countries' companies and governments to overtake us in setting aggressive goals and investing in achieving them—in getting green vehicles on the road and shaping the future of a new auto industry.

It is not too late. If we act now, we can regain a strong position in bringing electric vehicles to market and achieve the full benefits of this burgeoning industry, including the commercialization of globally leading Canadian technology and the creation of high-end, knowledge-based jobs in Canada. The deployment of electric vehicles will also reduce fuel consumption and improve urban air quality while reducing greenhouse gas emissions.

Achieving these benefits requires immediate action and investment by both governments and industry or it will simply be impossible to meet the 2018 target of at least 500 000 electric vehicles on Canadian roads set out in the Roadmap.

In other words, this Roadmap must not be allowed to sit on a shelf and gather dust. It must not be just another report that studies the opportunities and challenges of electric vehicles but does nothing practical to address them. It must not be the basis of just further discussion – it must be the basis for concrete and early actions.

The race is on and the prize of jobs, investment, and a more sustainable environment is winnable. However, just as we must transition from research to commercialization, we must transition from developing this Roadmap to implementing it.

Only immediate and meaningful actions will make it possible to compete with other countries and realize the full benefits of electric mobility. The Roadmap contains several key recommendations that, if implemented, will allow Canadians to address the key challenges detailed in the document.

I am grateful to the members of the Steering Committee for the many hours they spent on dealing with complex and fast-changing issues and to the Government of Canada for the support and counsel received during the process.

Yours truly,

Mike Elwood

Industry Steering Committee Members

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Important notice about the Industry Steering Committee and this Roadmap

This Roadmap provides the perspective of numerous stakeholders and was prepared under the direction of the Industry Steering Committee. The contents, conclusions and recommendations are not necessarily endorsed by participating organizations and their employees or by the Government of Canada.

GLOSSARY OF TERMS AND THEIR ABBREVIATIONS

Term	Usage in this Roadmap
Battery	A device that stores electrical energy chemically.
Battery electric vehicle, BEV	A vehicle powered solely by energy stored in a battery or other on-board energy storage system.
Battery management system	An electronic system that controls charging and discharging of the battery pack and related functions.
Electric vehicle, EV	A vehicle that depends on one or more electric motors for some or all of its traction.
Extended Range Electric Vehicle, EREV	A vehicle that functions as a BEV (see above) for at least 16 kilometres when driven at high speed or aggressively, and has an auxiliary energy supply that is only engaged when the battery energy is not available to sustain continued operation.
Fuel cell	An electrochemical device for providing electricity that consumes reactants from an external source, which must be replenished.
Hybrid electric vehicle, HEV	An EV (see above) for which an on-board ICE (see below) is the only source of electric power.
Internal combustion engine, ICE	An Otto-cycle or similar engine fuelled by gasoline, diesel fuel, natural gas, biofuel or another combustible liquid or gas.
Plug-in hybrid electric vehicle, PHEV	An EV (see above) that can be refuelled with an off-board source of electricity and that has an on-board ICE (see above) to recharge the battery or provide traction, or both.
Plug-in electric vehicle, PEV	An EV (see above) that can be refuelled with an off-board source of electricity; it includes both BEV and PHEV (see above).
Renewable energy	Energy that can be naturally replenished or renewed within a human lifespan.
Smart grid	A distribution network that allows two-way, digital communication between producers and consumers as well as its basic function of transmitting electric power in one or both directions.

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Executive Summary

By 2018, there will be at least 500 000 highway-capable plug-in electric-drive vehicles on Canadian roads, as well as what may be a larger number of hybrid-electric vehicles. All these vehicles will have more Canadian content in parts and manufacture than vehicles on the road in Canada in 2008.

Electricity as an alternative to traditional transportation energy is becoming a near-term reality for many countries, including Canada. Electric vehicles (EVs) will contribute to promoting sustainable energy development while addressing air quality and climate change.

The market for EVs in Canada is growing as Canadians look for cleaner, more efficient vehicles. Research confirms that consumers in North America are willing to pay more for an EV if the environmental benefits are significant. In Canada, it is expected that these benefits can be achieved because the majority of our electricity is generated from renewable and low-emission sources.

With our significant amounts of energy and a growing EV industry, Canada is well positioned to capitalize on this form of clean transportation. Our industry is well placed to be a major supplier of EV components and vehicles, not only in Canada but also internationally. Canada has the opportunity to link our efforts with those of the United States because of the integrated North American automotive industry.

To achieve the timely and effective commercialization of EVs, governments and industry must work together on ensuring that the necessary steps are taken. These steps include many activities, such as the development of advanced batteries, a charging infrastructure, electricity storage devices, codes and standards, and policies, as well as public education and consumer acceptance.

The most important of these topics is energy storage. Progress toward widespread use of the vehicles covered by the *Electric Vehicle Technology Roadmap for Canada* (the Roadmap) depends above all on one factor: increasing the amount of electrical energy that can be stored in a given volume or weight on board a vehicle, thereby extending electric traction's range.

This Roadmap is intended to provide the strategic direction to ensure the development and adoption of EVs in Canada, while building a robust industry.

The Roadmap provides the perspective of numerous stakeholders, mainly industry, as to how EVs for highway use should evolve in Canada over the next nine years and what should be done to secure this evolution. The Roadmap covers a wide range of topics related to the production and deployment of 500 000 or more EVs in Canada by 2018. The topics include energy storage, components for EVs, vehicle integration, business models and opportunities for EVs, government policies, regulatory and human resource issues, and public awareness and education.

Included in this Roadmap are two types of personal and commercial vehicles that rely exclusively or primarily on electric traction:

- battery EVs that have only electric traction and are almost always charged from the electricity grid
- EVs that have an internal combustion engine (ICE) in addition to an electric traction motor. The ICE can charge the vehicle's battery by powering a generator while the vehicle is in motion, and may also provide traction.

Other EVs that are not considered in the Roadmap include fuel-cell-based vehicles, vehicles with two or three wheels, low-speed and off-road vehicles, military vehicles, and vehicles such as trolley buses that are powered from the grid while in motion.

There is a call for a reduction in carbon emissions by focusing on EVs that rely exclusively or heavily on connection to the electricity grid for recharging their batteries. Part of Canada's potential strength as a focus for EV production and use is the sophistication of the electricity grid and the electrical generation that feeds it.

In Canada, a higher share of this electrical generation is from renewable sources than in almost any other country, which means that conversion of the Canadian on-road fleet to EVs would result in large reductions in the fleet's carbon emissions. Moreover, several of the provincially, territorially and locally owned utilities that provide electrical energy in Canada have a strong interest in electric traction.

The Roadmap includes three recommendations for securing the vision for EVs in 2018. It also identifies numerous matters that require action – strategic initiatives that complement the recommendations.

If the recommendations are adopted and the strategic initiatives are implemented, Canada will retain its vibrant and growing EV industry and play a role in the transition toward a more sustainable energy mix.

The recommendations, addressed to governments, industry and other stakeholders, are these:

1. Make timely and substantial investments in Canadian development and manufacture of EVs and in energy storage devices to build on Canada's already strong presence in these industries.
2. Consider supplementing federal and provincial/territorial mechanisms to promote the development, public acceptance and procurement of personal and commercial EVs, and the installation of the charging infrastructure.
3. Reconstitute the Steering Committee as a Roadmap Implementation Committee mandated to ensure that the strategic initiatives identified in the Roadmap are addressed.

Strategic initiatives

The strategic initiatives identified by stakeholders are summarized below in four categories. All are important, and all should have the timely attention of the Roadmap Implementation Committee. Where feasible, action on each initiative should begin before mid-2010.

Technology

- Improve energy storage through basic and applied research, including improvements in:
  - manufacturing techniques—with the goals of adding scale, improving efficiency and reducing costs
  - energy density—to reduce costs, increase range and achieve smaller, lighter systems
  - management and control electronics—for more efficient use of available energy storage
  - system packaging—to optimize thermal, electrical, mechanical and safety elements.
- Reduce the cost of EV components by a factor of two to three so they can be competitive with equivalent ICE components.
- Reduce the weight of the components.
- Test options for the charging infrastructure in each major region of Canada, including smart charging and vehicle-to-home and vehicle-to-grid arrangements. Recommend changes and improvements, noting impacts of multiple chargers on power quality.
- Demonstrate vehicle use in real-world operation to assess the reliability and durability of energy storage and other components.

Codes, standards, regulations and infrastructure readiness

- Review national, provincial/territorial and municipal regulations that impact the manufacture and use of EVs in Canada. Ensure that the regulations support EV development without compromising safety and other concerns.
- Harmonize North American standards and practices concerning the integration of EV components, including charger interfaces.
- Develop harmonized standards for the conversion of used vehicles to electric traction.

- Amend building codes and other regulations to require that at least the rough-in for outlets for charging EVs is included in all new buildings. Provide model codes and regulations.
- Develop action plans for infrastructure readiness.

Studies and assessments

- Assess the merits of, and develop a mandate for, an Electric Transportation Institute as a Canadian focus of applied EV research and development and other activities required to accelerate widespread use of EVs.
- Assess the potential impacts of incentive programs for the purchase of EVs on EV penetration and the impacts of battery warranty and lease programs.
- Estimate how much EVs will increase the demand for national and regional electrical energy and power over several periods and at several levels of market penetration. Take into account the reduced block heater loads and the additional battery conditioning loads. Assess the current and expected future ability to handle these demands, noting additions that would be required to the generation and distribution infrastructure.
- Estimate the lifetime savings that will result from the shift to EVs from ICE-based vehicles, anticipating changes in electricity rates and fossil fuel prices.
- Identify the effects on government revenue from the shift to EVs from ICE-based vehicles.
- Assess if renewable sources of electricity will be able to support use of the proposed 500 000 or more EVs by 2018.
- Assess the prospects for battery leasing models and the viability of battery "repurposing."
- Compare the social benefits and costs of electric traction with ICE-based traction that uses fossil fuels.
- Identify the feasibility, costs and benefits of creating a Canadian brand of highway-capable EVs.
- Identify new business opportunities for Canadian electrical utilities that could arise from growth in the EV industry.
- Identify and assess the challenges and opportunities for Canada's EV industry posed by the *American Recovery and Reinvestment Act of 2009* and other such measures.
- Identify potential early adopters of EVs, particularly fleets, and how they may be encouraged to become early adopters.

Education and outreach

- Assess the resource requirements for training, education and certification in skills related to the emerging EV industry. Provide this information to organizations that can develop:
  - technical courses on EV repair, service and maintenance and on the conversion of ICE-based vehicles to EVs
  - courses to help graduates of universities and colleges secure employment in high-paying jobs in the emerging EV industry in areas such as battery engineering, power systems engineering, power electronics, manufacturing processes and development of new business models.
- Develop educational and public relations programs that increase awareness across Canada of the benefits of EVs and associated technologies.

An additional task for the Roadmap Implementation Committee could be to review the limited scope of the current Roadmap and, after appropriate consultation, seek to initiate roadmaps in other areas of electric traction.

We live in extraordinary times, from a transportation and energy perspective as well as many others. Our times are fraught with challenge but also brimming with opportunity.

The basic message of this Roadmap is clear: early action, mainly by governments and industry, will sustain Canada's strong position in electric transportation and enhance it for the benefit of all Canadians.

1. Introduction

1.1 Purposes and logic of this document

This document presents Canada's Electric Vehicle Technology Roadmap. The Roadmap is positioned as the starting point of a new transport regime in which vehicles on Canadian roads are increasingly powered by electric traction. Section 1.2 describes the process that led to the Roadmap.

Above all, the Roadmap represents the vision of Canada's electric mobility industries for transport in 2018. The vision is set out in Section 2, with suggestions as to how it might be interpreted and applied.

Section 3 explains why there should be a focus on electric mobility, setting out its many advantages and its main disadvantage. This section also notes that Canada is especially well positioned for electric mobility, chiefly because of its endowment of renewably generated electricity and the potential for much more.

Section 4 raises the challenging questions of securing market penetration of electric vehicles. The rapid ongoing changes in the contexts of automotive markets and in the industries that serve them may present electric mobility with new opportunities. Nevertheless, decades of enjoyment of vehicles powered by internal combustion engines could well have lasting impact on the expectations of a burgeoning electric-vehicle industry.

Sections 5-8 comprise the core of this document where the Roadmap's strategic initiatives—matters requiring action—are set out and justified in detail.

Section 5 concerns technology pathways to attaining the vision. It sets out the technological context, opportunities, and challenges associated with achieving the vision.

Section 6 lays out business models for attainment of the vision, emphasizing that marketing practices used for automobiles and their fuels to date may well not work for electric vehicles and their fuel sources, including batteries and plug-in stations. Section 7 provides an overview of opportunities in the electric-vehicle industry in Canada.

Section 8 concerns institutional pathways to attaining the vision. It deals with non-technological factors that can affect how electric mobility progresses in Canada. Examples are the policies of governments in Canada and elsewhere, and the conditions and trajectories of Canada's automotive industries.

Section 9 sets out the Roadmap's three recommendations, addressed to governments, industry, and other stakeholders. This section also provides advice to the Roadmap Implementation Committee proposed by one of the recommendations. It suggests a mission for this Committee and two additional tasks beyond coordination and facilitation of the strategic initiatives identified in Sections 5-8.

1.2 The Roadmap process

A Technology Roadmap is a process tool to help identify the key technologies that an industry/sector/company needs to succeed in the future and the projects or steps required for development and implementation of these technologies. Technology Roadmaps are developed by collaborators knowledgeable about an industry or a sector and its relevant technologies. The collaborators do the following:

- identify the key future technologies,
- create the Roadmap that will lead to their development, and
- implement the Roadmap's projects or steps.

The process for the Electric Vehicle Technology Roadmap was led by Electric Mobility Canada, an industry association of organizations promoting electric vehicles, with the support of the Government of Canada. It was organized around a series of four workshops, each of which worked in plenary sessions and in groups concerned respectively with four aspects of electric mobility:

(a) interfacing with the electric power grid; (b) batteries and energy storage generally; (c) electric drive components; and (d) vehicle integration and optimization. Electric Mobility Canada collaborated in the identification of the Steering Committee members, in the coordination of some activities leading to the workshops, and in the writing of the final report.

The first workshop, held in Ottawa in June 2008, focused on development of a vision of what electric mobility in Canada could be in 2018. The vision was refined as the Roadmap process continued. It is presented in Section 2.

The second workshop, held in Montreal in September 2008, focused on the needs of private and commercial users of electric vehicles. The third workshop, organized in Vancouver in November 2008, dealt with technology alternatives. The fourth workshop was held in Toronto in November 2008. Its main activity was validating the conclusions from the previous three workshops.

Participants in the workshops are listed here in Appendix C.

The process has been overseen by the Industry Steering Committee whose members are listed on Page 4. A federal secretariat (Appendix F) supported the work of the Steering Committee and provided guidance to its deliberations.

During the Roadmap process, the participants developed an analysis of the strengths, weaknesses, opportunities and threats of Canada's EV industry (SWOT). This SWOT analysis helped guide deliberations. A summary of the analysis appears in Appendix D.

2. Vision of electric mobility in 2018

By 2018, there will be at least 500-000 highway-capable plug-in electric-drive vehicles on Canadian roads, as well as what may be a larger number of hybrid-electric vehicles. All these vehicles will have more Canadian content in parts and manufacture than vehicles on the road in Canada in 2008.

2.1 What the vision embraces

The central statement of the vision is set out above and presented again with the complete vision in Section 2.2. The vision concerns electric vehicles that are readily comparable to vehicles on the road today, i.e., they are 'highway-capable.' Low-speed vehicles (LSVs)—electric-drive vehicles designed to travel at less than 40 kilometres per hour—are excluded because they are not fully highway capable. LSVs are not required to meet several of the safety standards required of highway-capable vehicles.

Also excluded are vehicles that rely on hydrogen fuel cells for electric power rather than generators driven by internal combustion engines, chiefly because work on this technology has been covered by Canada's Fuel Cell Commercialization Roadmap. Other exclusions are noted in Section 2.3.

This Roadmap focuses on the following three types of highway-capable vehicle:

- Electric-drive vehicles that do not have an on-board internal combustion engine (ICE) providing traction or electric power generation, or both. We have identified them as battery electric vehicles (BEVs), while recognizing that there could be means other than batteries of storing electricity on board.
- Electric-drive vehicles for which an on-board ICE is the only source of electric power. They have been identified as hybrid-electric vehicles (HEVs). This type of vehicle is the increasingly familiar 'hybrid' vehicle now produced by most major automotive manufacturers.
- Electric-drive vehicles that have an ICE for traction or generation and, when stationary, can accept electric power from the grid. Such vehicles have been classified as plug-in hybrid electric vehicles (PHEVs). This type of vehicle is designed to have greater electricity-storage capacity than HEVs so that most of the travel in urban areas would be without ICE operation.

The first two types of the electric-drive vehicle have been produced for more than 100 years, although only HEVs are now in mass production. PHEVs have been discussed for almost as long, and occasionally produced, although their mass production is a relatively new concept. Two types of PHEV are proposed. One functions like an HEV with a larger battery, blending traction based on the electric motor and ICE according to circumstance, but with more use of the electric motor than in an HEV. The other has electric drive only, and is known as an Extended Range Electric Vehicle (EREV). In an EREV, the ICE operates only when the battery is approaching depletion, powering the generator to maintain adequate battery output for traction, thereby extending the vehicle's range.

Another term in use, plug-in electric-drive vehicle (PEV), embraces the first and the third of the above types, thereby highlighting the common feature of delivery of electric power from the grid. This combined concept is presented in the vision set out below.

2.2 The vision

The industry vision of electric mobility in 2018 was developed by the participants in the June 2008 workshop and subsequently refined by the Roadmap's Industry Steering Committee. The central statement in the vision is as follows:

By 2018, there will be at least 500 000 highway-capable plug-in electric-drive vehicles on Canadian roads, as well as what may be a larger number of hybrid-electric vehicles. All these vehicles will have more Canadian content in parts and manufacture than vehicles on the road in Canada in 2008.

The target of at least 500 000 EVs means in practice that some 15 per cent of vehicles produced in 2018 would be EVs. Note that the target does not distinguish between BEVs and PHEVs. This reflects participants' views that it would be premature to determine which of these two categories will prevail. At the moment, development and commercialization of both are seen as necessary elements in the evolution of electric mobility in Canada.

In 2008, there were almost no BEVs and PHEVs on the road in Canada. There were 50 000 to 100 000 HEVs on the road, comprising up to 0.5 per cent of all vehicles on the road in Canada.

The emphasis during the Roadmap process has been on personal automobiles which replace passenger cars and light trucks that have only ICE-based drives. However, the vision is intended to accommodate commercial vehicles with electric drives, chiefly larger passenger vehicles and small- and medium-sized delivery vehicles, all mostly for urban use. Such commercial vehicles can be classified in the ways indicated above: as BEVs, HEVs, and PHEVs, with the first and last types together comprising PEVs.

The vision includes other statements, mostly self-explanatory, as follows:

'Highway capable' means that the plug-in electric-drive vehicles will operate on all roads within current infrastructure and meet Canadian Motor Vehicle Safety Standards.

The overall performance of the plug-in electric-drive vehicles, including comfort and convenience, will meet or exceed that of current vehicles. Key parameters of performance will be life-cycle energy use and environmental impacts. Atmospheric emissions of globally and locally acting substances per kilometre will provide the key indicators of environmental impact.

Preference will have been given to technologies that maximize the use of renewable energy.

The cost of ownership of plug-in electric-drive vehicles will be no greater than that of comparable vehicles powered only by internal combustion engines.

Fleet operators will be targeted as early adopters of the plug-in electric-drive vehicles.

Development and production of energy storage and electric components in Canada, and the assembly of new plug-in electric-drive vehicles, will have been advanced by the use of all relevant policy mechanisms.

Ultimately, all new on-road vehicles sold in Canada will have electric drives in response to the environmental, economic, social, and strategic necessity to move away from fossil fuels.

2.3 Future electric vehicle roadmaps

It was noted in Section 2.1 that low-speed vehicles and fuel-cell vehicles are not being included in this Roadmap exercise. Other vehicle types not covered are on-road two- and three-wheel electric vehicles, including bicycles, scooters, and motorcycles, various electrically propelled devices such as skateboards, off-road vehicles, and military vehicles. These types could well be the subject of one or more future roadmap exercises.

Another type of electric-drive vehicle not discussed in the present Roadmap comprises vehicles that receive electric power while in motion, from rails or overhead wires, sometimes known as grid-connected vehicles. Most public transit journeys in Canada's three largest urban regions are made by such vehicles. In energy terms, grid connection is usually the most efficient form of electric mobility, but efficiency is realized at the cost of operational flexibility. Systems of grid-connected personal and other vehicles could be available commercially by 2018, competing with the types of vehicle that are the focus of this report. These could include vehicles that may be grid-connected for parts of the journey. Grid-connected vehicles generally—including inter-city trains, streetcars, and trolley buses, among others—may also be the subject of a separate Roadmap exercise.

3. Why electric vehicles?

Petroleum products presently power ICEs to provide 95 per cent of the world's motorized movement of people and freight. This section suggests that the use of petroleum products to fuel ICEs which provide land transport will likely decline during the next several decades and be replaced chiefly by electric traction. In doubt are the ease and timing of the transformation. Basic tenets of this Roadmap are that the transformation is desirable and should be expedited by enhancing electric traction's technology and acceptance.

3.1 Need for change

The Steering Committee concluded that there are two strong reasons for moving away from the use of oil products as the main transport fuels: reduced availability of oil and avoidance of climate change.

A case can be made that world production of crude oil has already peaked, and few would argue that it will not peak within a few decades, however much is invested by the oil industry.[1] Diminishing supply of oil, rising demand—chiefly from developing countries—and resulting high prices could be a prescription for catastrophe. Most human societies have evolved to be almost completely dependent on motorized transport that in turn is almost completely dependent on fossil fuels. The prospect of energy constraints impels moves to enhance societal resilience by reducing at least one of these two dependencies.

This Roadmap addresses the second dependency by reducing the amount of oil used for transport, in particular by substituting electric traction for ICE-based traction.

The burning of petroleum products in ICEs used in land transport contributes substantially to the ongoing rise in atmospheric concentrations of radiatively active substances, notably carbon dioxide, also known as greenhouse gases. This rise is believed to be a major factor in changing the global climate in ways that could imperil life as we know it. Reducing potential impacts of climate change is presently the main societal concern.

Other reasons to reduce oil use for transport have been advanced. They include avoidance of other global impacts, such as ocean acidification, and improvement of air quality in urban areas.

3.2 Electricity as an alternative fuel for land transport

In the search for alternatives to oil and ICEs, electricity and electric motors figure strongly. Vehicles with electric traction have been available for at least as long as vehicles powered by ICEs. Electric traction has numerous advantages in addition to causing less local and global pollution and obviating dependence on oil. These advantages include the following:

Efficiency: Electric motors convert up to 90 per cent of applied energy to traction. Gasoline engines normally convert no more than 30 per cent of applied energy; diesel engines convert up to 40 per cent.[2] Although the delivered energy cost of electricity per unit can be higher than that of liquid fuels, the cost per unit of traction energy is usually lower.

Torque: Electric motors provide maximum output (torque) at zero or near-zero revolutions, i.e., when it is most required. An ICE's maximum torque is typically delivered at several hundreds or thousands of revolutions per minute, requiring gearing to move a stationary vehicle. Electric motors' high torque at low speeds contributes to their superior performance in stop-start conditions and during acceleration from low speeds. (Electric-drive systems can require simple gearing to provide high speeds.)

1 For example, Fatih Birol, chief economist for the International Energy Agency, anticipates an oil supply crunch in 2011 if demand rises. See http://www.independent.co.uk/news/science/warning-oil-supplies-are-running-out-fast-1766585.html (August 3, 2009).

2 These are maximum values based on http://www.energy.ca.gov/2007publications/CEC-600-2007-003/CEC-600-2007-003-D.PDF, and on Åhman M., *Energy*, 26, 973-989 (2001). Values during operation can be much lower.

Regenerative braking: Electric motors can capture kinetic energy during deceleration, storing it as electrical energy and thereby reducing energy consumption and mechanical brake wear.

Power per unit weight or unit volume: For a given power output, electric motors are much smaller than ICEs, even without the ICEs' required emission control systems. Setting aside the matter of energy storage—discussed below—electric motors' higher power/weight ratios mean less energy is required to move traction systems and more room is available within vehicles.

Simplicity: Electric motors typically have one or a few moving parts. ICEs usually have hundreds of moving parts. In principle, electric vehicles are thus more reliable and cheaper to maintain.

Silence: Electric motors are almost silent in operation. ICEs harness controlled explosions of fuel and air mixes. They are intrinsically noisy, adding to urban stresses. Their noise can be substantially muffled but at the cost of reduced energy efficiency.

Storage of grid energy in vehicles (V2G): The storage devices in electric vehicles can, in principle, be used as storage for the electric grid, potentially reducing requirements for peak generation.

Flexibility as to ultimate energy source: Electric vehicles that use externally supplied electricity (e.g., BEVs and PHEVs) are indifferent as to how the electricity is generated. Nothing has to change at the vehicle if the fuel for electricity generation changes. Such electric vehicles are thus readily compatible with a transition to renewable generation. ICEs, by contrast, usually need substantial modification to accommodate change of the energy source(s) for which they were designed.

The one disadvantage of electric traction—which allowed ICE-based automobiles to prevail—is the energy density of the fuel as stored on-board vehicles. The liquid fuels used for ICEs have high usable-energy content per unit weight or volume. The available energy densities of gasoline and diesel fuel are near 45 megajoules per kilogram (MJ/kg).[3] The density of a nickel metal hydride (NiMH) battery—the type that is most commonly used in HEVs—is about 0.25 MJ/kg (≈ 70 watt-hour/kg).[4] Thus, a NiMH battery would have to be about 180 times as heavy as a full gasoline tank to provide the same amount of usable energy (and take up about 100 times as much space). Allowing for different conversion efficiencies (using those noted above), the effective energy density of gasoline is about 45 times that of a NiMH battery; the density of diesel is about 55 times. Lithium ion batteries are now about twice and are expected to be about three times as energy dense as NiMH batteries, reducing gasoline's advantage to about a factor of 15.[5]

Low energy density means one or more of the following: short range, high battery cost, and high battery weight and volume. The disadvantage of low energy density has offset the numerous advantages. It is the strongest focus of research associated with electric mobility, as will be discussed below in Section 4.5. Notwithstanding the disadvantage, electricity remains the best alternative fuel for land transport. No other traction fuel alternative to petroleum products is as potentially plentiful or available. Electricity can be produced wherever the sun shines, and wherever there is wind, moving water, geothermal heat, and non-fossil sources of heat such as surplus biomass and nuclear energy. Electricity can also be produced from fossil fuels, as most of it is now produced worldwide, but doing so counters the imperative to move away from these fuels.

Compared with other fuels, electricity can be easily distributed within continents although providing for distribution can be as challenging as generating the electricity. For example, all the electricity now used in North America, plus what would be required if the continent's land transport were electrified, could be produced from an array of concentrated solar power (CSP) units covering an area of the California-Nevada desert about 250 kilometres in diameter. The major challenge in exploiting such a system could be reconfiguring the North American grid to make use of such generation.

3 Gasoline is 48 MJ/kg, diesel fuel 43 MJ/kg; see http://bioenergy.ornl.gov/papers/misc/energy_conv.html.

4 See the specifications for NHE modules at http://www.saftbatteries.com, and the first source in Note 5.

5 For the energy densities of lithium ion batteries, see http://www.arb.ca.gov/msprog/zevprog/zevreview/zev_panel_report.pdf. For expected energy densities also see, for example, Kojima et al, *J. Power Sources*, 189(1), 859-863 (2009).

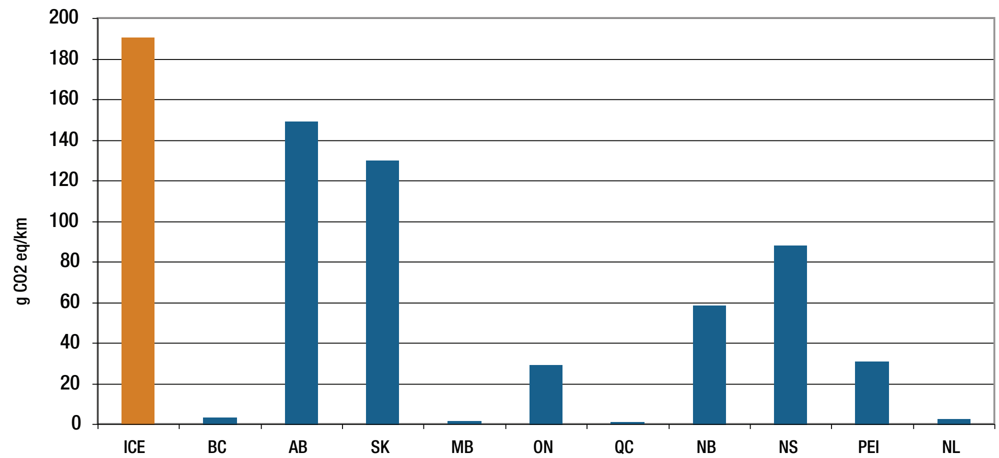


Figure 1. Estimated unit greenhouse gas emissions from a 2006 compact automobile moved by an ICE engine (Canadian average) and by electric traction (provincial averages for 2006)[6]

3.3 Improvements that could be achieved through electrification

The reduction in greenhouse gas emissions achieved through electrification of land transport depends on the source of electricity. Where it is generated renewably, as in British Columbia, Manitoba, Newfoundland and Labrador, and Quebec, the reduction can approach 100 per cent. Where electricity is generated almost entirely from fossil fuels, as in Alberta, Nova Scotia, and Saskatchewan, the reduction is much less, although still important. These differences are illustrated in Figure 1.

Figure 1 shows typical greenhouse gas emissions per kilometre in Canada in 2006 for a regular compact car (left bar) and for a comparable BEV in each of the ten provinces. Note that in all cases emissions are lower for the BEV. Reductions exceed 97 per cent for the four provinces where almost all the generation is hydroelectric. Note too, for example, that for Ontario, which has a provincial/territorial target of reducing these emissions by 80 per cent by 2050, the target in respect of automobiles could be achieved by conversion to electric traction, which would reduce emissions overall by 85 per cent.

3.4 Electricity is Canada's most available and renewable alternative

Canada already generates most of its electricity renewably. In four provinces, hydroelectric sources provide close to 100 per cent of the generation: British Columbia, Manitoba, Newfoundland and Labrador, and Quebec. Other provinces, notably Ontario, have substantial renewable generation.

Indeed, all provinces could readily become fully reliant on renewable generation, with Saskatchewan and Ontario providing the greatest challenges. Alberta, sometimes thought of as being the most problematic in this respect, has substantial high-temperature geothermal resources, as well as much potential generation from sun, wind, and falling water.

6 Figure 1 was kindly supplied by Roger Martin of Unicell Ltd. Emissions for the ICE vehicle were based on Natural Resources Canada data at http://oee.nrcan.gc.ca/transportation/tools/fuelratings/ratings-search.cfm. They assume fuel consumption of 8 L/100km and 2.4 kg CO2eq per litre of gasoline. Electricity use per kilometre for BEVs was assumed to be 160 watt-hours, based on information at http://www.spectrum.ieee.org/print/7928. Emissions per kilometre of BEV for each province were based on unit emissions of generation, as reported by Environment Canada at http://www.ec.gc.ca/pdb/GHG/inventory_report/2006_report/a9_eng.cfm.

All provinces could add generation from sun and wind, and some from falling water. Several provinces could benefit from generation of marine energy: from waves, currents, tides, and temperature differences. Canada has the world's longest coastline and, in places, the highest tides.

If nuclear energy is considered an acceptable alternative to fossil fuels, as it is by many environmentalists, Saskatchewan and Ontario are especially well positioned. Saskatchewan is the world's major producer of uranium; it has some 70 per cent of the world's first-grade uranium ore. Ontario has some of the world's largest installations of nuclear generation.

Canada is already as much an energy giant in electricity as it is in oil and natural gas.
The huge potential for renewable-energy expansion—as well as for the existing resources in automotive production discussed in Section 7.1 below—helps qualify Canada as a likely leader in the worldwide transformation to electric traction.

4. Marketing considerations for electric vehicles

The first three sub-sections concern three recent surveys of perceptions of electric vehicles; two were conducted in Canada and one in the US. The next section overviews some market forecasts for electric vehicles, noting the economic downturn during the second half of 2008. The final sub-section looks beyond these surveys and forecasts in order to explore how the attractiveness of electric vehicles could change with circumstances.

4.1 Survey by Pollution Probe and Environics of Canadians' perceptions of EVs

In January 2009, Pollution Probe and Environics conducted an online survey of 2,001 Canadians. The survey was supported by focus groups held in Montreal, Toronto and Vancouver in February 2009. Some of the key findings of this process were the following:

- Canadians have both positive and negative impressions of electric vehicles, with environmental benefits (on the positive side) and range and battery/charging concerns (on the negative side) emerging as key top-of-mind perceptions.
- Six in ten Canadians are at least somewhat interested in purchasing a plug-in hybrid electric vehicle (PHEV), once they become available. Interest is highest in urban areas and increases with education and familiarity with current hybrids and with electric vehicle technology in general.
- Reliability and maintenance/operating costs are seen as key barriers to considering purchasing a PHEV, with more than six in ten considering these very important reasons not to purchase a PHEV. Purchase price and limited access to plug-in locations are also important concerns.
- The most common perception of the BEV is of a small vehicle with less power and a more limited range than conventional vehicles or current hybrids. While most assume that BEVs will be cheaper to operate, there is little real understanding of the potential cost savings, especially when factoring in the initial purchase price and the cost of battery replacement.
- Consistent with the perceived advantages of electric-powered vehicles, more than nine in ten Canadians rate reduced environmental impact, reduced dependence on gasoline, and savings on operating costs as important reasons to consider a PHEV.

A compilation of all the key findings of the process conducted by Pollution Probe and Environics can be found in Appendix A of this Roadmap.

4.2 Electric Mobility Canada's survey of fleet owners and individuals

Respondents to this survey were recruited by general invitation to EMC's contacts, and through them their colleagues, to participate in an on-line survey conducted during August 2008. Among respondents there were 28 fleet operators and 213 individuals.

Fleet operators included operators of private, municipal, and provincial/territorial fleets. Almost half (49 per cent) of the fleet vehicles were buses; others were vans (39 per cent) and cars (12 per cent). Fleet sizes were as follows: less than 100 vehicles, 41 per cent; between 100 and 1000 vehicles, 41 per cent; over 1000 vehicles, 18 per cent. Most fleet vehicles travelled about 100 kilometres per day. Several travelled much more. Most fleets (59 per cent) included some form of HEV; 30 per cent included one or more BEVs; 15 per cent included a PHEV, usually a conversion from an HEV.

A third of operators expected that all or almost all of their fleet would be electrically powered in the future. Most operators would prefer to own rather than lease batteries. More electric-vehicle truck and van designs would be welcome.

Here are advantages of electric vehicles as stated by fleet operators:

- Excellent PR which leads to a “positive public image”
- Existing electrical infrastructure
- Low noise
- Reduced lifetime costs of vehicle operations and lower operating costs
- No more “budget surprises” because of fuel commodity price fluctuations
- General environmental benefits including reduced dependency on fossil fuels
- Desire to meet provincial/territorial regulatory targets

Here are fleet operators’ concerns about electric vehicles:

- Economics: Initial cost, pay-back period, prices of parts and service
- Occupational health and safety
- Reliability
- Recharge time
- Recycling and disposal
- Weight and efficiency issues
- Repair costs and access/availability of in-field technicians for repairs

Of the 213 individual respondents, less than a sixth had vehicles with electric traction. Almost all lived in houses or townhouses in urban or suburban areas, with access to one or more personal vehicles. Only 27 per cent said they would be able to charge an electric vehicle at work. Most respondents would pay 20 per cent more for an electric vehicle.

A conclusion from the survey was that penetration of fleets by electric vehicles will be more achievable than penetration of personal vehicle ownership. Fleet operators are much more pragmatic in their approach. Individuals see vehicle ownership as an expression of their personal characteristics. Accordingly, electric vehicle ownership would have to become socially as well as technologically and financially acceptable.

4.3 Synovate’s survey of US consumers

This 2008 survey of 4 084 US owners and prospective buyers of personal vehicles was part of an annual tracking study of consumer attitudes towards advanced propulsion and alternative fuel technologies. Even though the survey was conducted at a time of rising fuel price, fuel economy was not among the top ten reasons for purchasing a particular new vehicle. Battery concerns were cited as the leading reason for not considering BEVs and PHEVs, although these concerns did not feature so strongly in relation to HEVs.

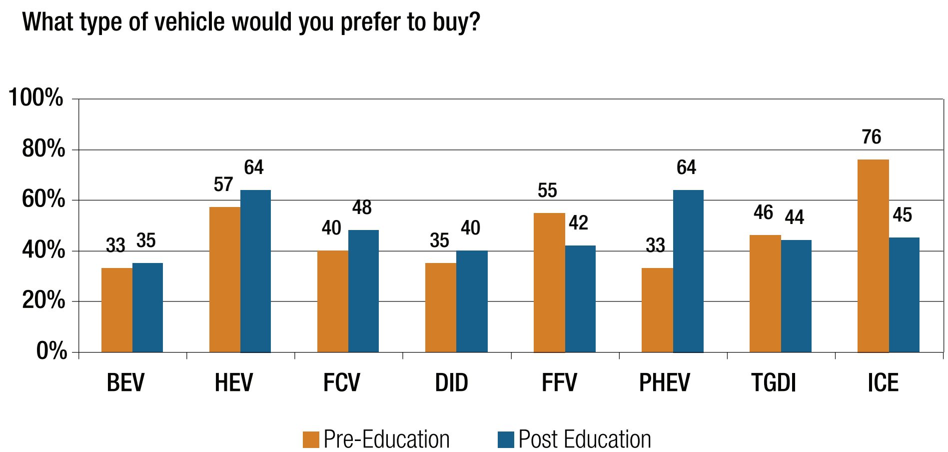
Nevertheless, almost three quarters of respondents said they would consider paying $1,500 more for a vehicle that achieves 30 per cent better fuel economy than a comparable model, and $2,000 more for a vehicle “that is significantly better for the environment.”

Survey respondents were given the opportunity to read about the costs and benefits of each of these technologies and respond again. Responses shifted, particularly in favour of PHEVs and away from ICE-based vehicles, as shown in Figure 2.[7]

7 A summary of the Synovate survey report, including the chart reproduced here as Figure 2, is available at http://www.synovate.com/news/article/2008/06/new-survey-shows-concern-over-fuel-prices-and-environment-drive-consideration-of-hybrid-electric-vehicles-to-highest-level-ever.html#.

Synovate concluded, "Manufacturers need to do a better job of communicating the benefits to potential buyers. For example, our survey shows that purchase consideration of plug-in hybrids almost doubles when respondents learn what it actually is, while consideration for flex-fuel vehicles drops significantly after respondents learn about their benefits and liabilities."

4.4 Market forecasts for electric vehicles



BEV: Battery-Electric
HEV: Hybrid-Electric
FCV: Fuel Cell
DID: Direct-Inject Diesel / Advanced Diesel
FFV: Flex-Fuel
PHEV: Plug-in Hybrid
TGDI: Turbo Gasoline Direct-injection
ICE: Internal Combustion Engine / Traditional Gasoline

Figure 2. Responses to Synovate's survey

Numerous market forecasts are available, usually at high cost. Some of these were noted in the foundation document prepared for this Roadmap process. The relevant section of that document is reproduced here in Appendix B.

The compilation in Appendix B does not include reference to a March 2008 market analysis by Morgan Stanley's Tokyo branch, which concluded the following: "Our proprietary hybrid demand model has demand for hybrid vehicles in the US growing from approximately 355 000 units in 2007 to about 1.2 million units by 2015. We see PHEVs being introduced gradually into the market in 2010-11 and eventually growing to 250 000 units in the US and 325 000 units worldwide by 2015."

In early 2008, continued growth in sales of hybrid vehicles seemed plausible. However, sales of hybrid vehicles in the US declined by more than 10 per cent during 2008 to 317,000 units. Hybrid sales were rising much faster than those of ICE-only automobiles during the first part of the year, but fell faster towards the end of the year. This finding suggests that hybrids were doing well when gasoline prices were rising, but not so well when gasoline prices, and the economy, declined. It also suggests that if one or both of gasoline prices and the economy rise again, so will sales of hybrids and perhaps other electric vehicles.

4.5 The above considerations could change with circumstances

Recent events—including a 22-per-cent fall in sales of light-duty vehicles in Canada and a 49-per-cent fall in Canadian production of light-duty vehicles (both 1Q09 vs. 1Q08)[8] —suggest that change can happen quickly whether in consumer behaviour generally or in transport practices in particular. Regarding consumer behaviour, recent work at the Wharton School of Business identified the 20 most significant 'life-changers' during the last three decades, including internet via broadband, personal computers, mobile phones, email, and office software. In most cases, the innovations had their transformative impact within a few years, even though the technology development may have occurred many years earlier.

Rapid transformations can occur in transport. The book *Transport Revolutions* focused on five such transformations. One is of particular note: it was called 'the great pause in motorization' and happened in the US during the early 1940s. In 1941, 3.8 million automobiles were manufactured in the US. In 1943, this total was less than 150. Just about all automobile assembly facilities had been dedicated to military production. Meanwhile, also in response to gasoline and tire rationing, inter-city trips by automobile fell by more than 50 per cent; inter-city trips by trains and buses tripled.

Transport revolutions do not require wars or even profound technological innovations. The revolution in freight transport wrought by FedEx in the 1980s arose through logistical rearrangements to meet a barely recognized need for overnight delivery of small packages.

The lesson from history is that if the circumstances are right, substantial transformation to electric traction could happen quickly. We may well be in such an era of change. Who anticipated in mid-2008 that by mid-2009 the largest North American auto company would be mostly under government ownership, and the third largest would be owned by its union?

At least as important in terms of setting the context for radical change could be indications that world production of oil is about to decline, or that the US government is adopting new policies with respect to climate change or that breakthroughs in storage technology may be likely.

A transport revolution involving electrification of vehicle traction may be imminent, and Canadian enterprise would be prudent to prepare for it. The remainder of this document sets out how this could be achieved.

8 Sales and production data are from http://www.ic.gc.ca/eic/site/auto-auto.nsf/eng/h_am01302.html

5. Technology pathways

This section addresses in some detail the main technological themes of the Roadmap exercise: energy storage, vehicle components, vehicle system integration, and the electric power delivery grid. It builds on Sections 0–4, gives rise to several of the Roadmap's strategic initiatives and sets the scene for Sections 6–8, where further strategic initiatives are identified, and for Section 9, where the Roadmap's three recommendations are presented.

The term 'strategic initiative' is used in this document to refer to matters for early action, usually before mid-2010. Who should take the action is in most cases evident; however, in some cases, it is clearly stated. The three recommendations are addressed to governments, industry, and other stakeholders.

5.1 Energy storage

In Section 3.2, the one disadvantage of electric traction—which allowed ICE-based automobiles to prevail—was said to be the energy density[9] of batteries used to power EVs. Thus, the first and most important task of this section is to review current progress and prospects for storing electricity in a manner useful for electric vehicles.

5.1.1 Energy pathways for electric traction

Electric vehicles can be powered via one or more of four energy pathways: from an electrical storage device (battery, ultra-capacitor), from an on-board generator (usually powered by an ICE), from an on-board electrochemical conversion device (fuel cell), and directly from the grid while in motion. For reasons given in Section 2, the last two pathways are not being considered here. The primary focus in what follows is on batteries, with some reference to ultracapacitors, charged by an on-board ICE generator or through connection to the grid while stationary.

The strong message from the Roadmap exercise, which reflects industry's perspectives and activity, is that advanced battery technology will be the main driver of the automobile industry of the future. There is also a continuing interest in ultracapacitors, operating alone or in concert with battery storage, and in fuel cell applications, already noted earlier.

Batteries and fuel cells store energy chemically in a manner that allows use of the energy as electricity. Ultracapacitors store electrical energy directly, specifically as an electrostatic charge on a finely sculptured mechanical interface. Storage capacity increases with the surface area of the interface. A surprising amount of surface can be fitted into a small volume, but ultracapacitors nevertheless usually have low energy density. They can be charged and discharged very quickly and can accept and deliver high voltages. Ultracapacitors are being developed to provide power assist during acceleration and hill climbing, as well as recovery of braking energy. They are potentially useful as energy storage devices in HEVs, providing load-levelling services to chemical batteries.

There is also interest in using ultracapacitors as the primary energy source for EVs and as back-up storage in conjunction with batteries. This would require substantial increases over the energy densities observed today. Successful efforts in these directions could have major impacts on the EV industry because of ultracapacitors' high efficiencies, relatively low costs, and ability to handle large power surges.

5.1.2 Batteries are the key

Batteries are the key element in the viability of the EV industry. Improvements in battery technology over the last few decades have caused the present renaissance in the industry. Since the dawn of the automobile age, the Achilles' heel of electric vehicles has been the weight and poor energy performance of the type of battery in general use: the lead acid battery.

A breakthrough in battery technology in the 1980s was the introduction of the nickel metal hydride (NiMH) battery, which has been the workhorse for the first generation of hybrid electric vehicles. Now, notwithstanding improvements in both lead acid and NiMH batteries, one or another type of lithium-based battery is widely believed to be most likely to power EVs that will be available between now and 2018, the target year for this Roadmap.

9 The energy density and power density of batteries are explained below in Section 5.1.3.

The energy density of lithium-based batteries is about twice that of NiMH batteries, which in turn is about twice the density of lead acid batteries. NiMH batteries are accepted as a mature technology, but lithium batteries are still undergoing development for use at the scale required for EV applications. Despite their wide application in the computer and IT industry, lithium batteries for electric traction remain a young technology with considerable potential that could be realized over the timeframe of this Roadmap.

Table 1. Major Challenges for EV Battery Technology

Challenge	Target
Improved performance	Energy density of 300 watt-hours/kilogram
Price	Reduce enough to allow EVs to compete on price
Service life	10-15 years; 2 500 charge-discharge cycles (for BEV)
Intermediate energy storage	To maximize capture of energy from braking – ultracapacitors?
Safety	Improved thermal management/battery management
Recycling	Ensure adequate facilities in place
Repurposing	Identify effective end-of-life reuse options such as use in other vehicles or backup energy storage

Worldwide, at least a dozen companies have battery systems for electric traction at the pre-production stage. Before the 2008 economic downturn there were at least 60 companies worldwide that were planning to launch an electric vehicle within next two to three years. Lithium batteries were generally the technology of choice. Improved performance of lithium batteries requires advances in materials sciences to develop improved electrodes and electrolytes. The challenges being addressed are summarized in Table 1.

Battery companies often have several technologies under development that can be implemented to produce the familiar, small cylindrical cells. Fewer manufacturers can make the larger prismatic cells needed to provide higher energy densities for transport operations. Integrating large numbers of cells into battery packs requires expertise in battery engineering, thermal engineering, power electronics, mechanical engineering, and electrical engineering. Battery pack technology is not trivial; it contributes significantly to the performance of battery systems.

5.1.3 Why energy density matters

Battery performance is generally measured in terms of two key parameters, *energy density* and *power density*:

Energy density: This is the amount of energy—usually expressed in watt-hours (Wh)—that can be delivered per unit weight (kilogram) or volume (litre) of a battery (Wh/kg or Wh/L). It is an approximate indicator of vehicle range for BEVs.

Power Density: This is the rate at which energy can be provided or received (W/kg or W/L), indicating acceleration and ability to accept power during charging and braking.

Energy density is often considered the most important metric of a battery. Energy densities are currently in the range of 75-200 Wh/kg (see Section 3.2). Effective energy densities are less due to energy use for battery controls and thermal management systems. There are indications that the energy density limit for lithium battery technology may be about 300 Wh/kg. Achieving such a density would reduce the battery size substantially and perhaps the cost, as well.

Energy density is usually the limiting factor in EV applications. EVs generally have more than enough acceleration, often much more than comparable ICE-based vehicles.

5.1.4 Battery life: Calendar and cycle

Among the most important features of a battery's performance is its lifetime, generally characterized in two ways. The first is calendar life: how long before the charge capacity of a (mostly) unused battery degrades to a specified level, for example, 80 per cent of target specification. The second feature is cycle life: how many charge-discharge cycles the battery can undergo before its performance degrades to a specified level.

Assessment of calendar life is difficult because lithium batteries are still undergoing development and long-life performance data are few. Preliminary measurements of some lithium batteries, mostly at the cell level and extrapolated over several years, allow cautious optimism that a 10- to 15-year calendar life can be met. Such operating lifetimes may be achieved with NiMH batteries. There is anecdotal evidence that many 10-year old Toyota Rav4-EVs are performing well on their original NiMH batteries.

Assessment of cycle life is more complex and is related to the profile of vehicle usage. In a hybrid vehicle, each time the battery is activated, the generator, driven by the ICE, causes it to be recharged. Thus, the battery is subjected to many charge-discharge cycles. This mode is referred to as a 'charge-sustaining mode'. In contrast, a BEV or a PHEV with a relatively long battery-only range will operate on a 'charge-depletion mode' and will be subjected to far fewer, although deeper, charge-discharge cycles.

Batteries are optimized in their design for one or another mode; it is difficult to optimize for both. Thus, PHEVs can present special challenges for the manufacturers of their batteries.

Similarly to the battery design, the actual battery life—calendar and cycle—depends on numerous other factors. These include system design (notably temperature management), ambient temperature and humidity, and, above all, how the vehicle is used.

5.1.5 Safety

There are safety challenges whenever energy is stored in a confined space, whether as a liquid such as gasoline in a fuel tank or as chemical precursors for electricity, as in a battery. There have been special concerns about lithium batteries due to instances of laptop fires. They have now been for the most part resolved. Battery safety issues are now routinely addressed in the EV industry as a systems management problem.

Thermal management is critical to optimizing battery performance and ensuring safety, both of which can depend on maintaining a specified temperature range. Variations in temperature from module to module in a battery pack can result in reduced performance. The overall operating temperature of a battery pack can have a marked effect on its power and energy output, and on its acceptance of charge during regenerative braking. In turn, these can affect vehicle operating and maintenance expenses. Thus, a key element of any EV is its battery management system.

Battery performance and safety are even more important in automobile manufacture than in the production of laptop computers. There is considerably less tolerance of failure. Competing factors may be stronger too, particularly the need to reduce the size of battery compartments and to increase energy density through the thinning of battery cell components.

5.1.6 Battery cost: Storage

The main issues concerning lithium batteries are cost, energy density, and lifetime. In contrast to lead-acid and NiMH batteries, which are now considered mature technologies, lithium batteries for EVs are at a prototype stage of development. They have yet to experience cost reductions from economies of scale. Such economies of scale are a major factor in the regular automobile industry, which has had a hundred years' experience in cost reduction.

As battery production volumes increase, lithium battery prices should fall from their present range of $800-1,200 per kilowatt-hour. Some in the business have claimed that $200-250/kWh is achievable. The US Advanced Battery Consortium and the Electric Power Research Institute have said the target for a mass-produced, cost-effective battery should be $400-500/kWh. Discussions with several major battery manufacturers suggest there is a good possibility of reaching this target. These prices are for the batteries themselves. Battery management systems and system integration add 10-15 per cent.

The present high cost of storage via lithium batteries can perhaps best be understood by comparing it with the cost of electricity. The cost of storing the electricity is about seven times the cost of the electricity itself. Charging a 20-kWh battery pack costs about $1.40 for the electricity and about $10.00 for the use of the battery (i.e., the cost per cycle of a $15,000 battery having a life of 1 500 cycles). The low electricity cost when charging a vehicle can be exploited by business models that add relatively high fees for dispensing electricity, as discussed in Section 5.4.

Figure 3 shows how the present relatively high cost of electricity plus battery could become similar to the cost of gasoline. The future scenario assumes that gasoline rises to $1.30 a litre (which it reached during the summer of 2008), battery costs fall to within the range indicated above, andbattery cycle life—discussed further below—increases from 1 500 to 2 500 cycles.

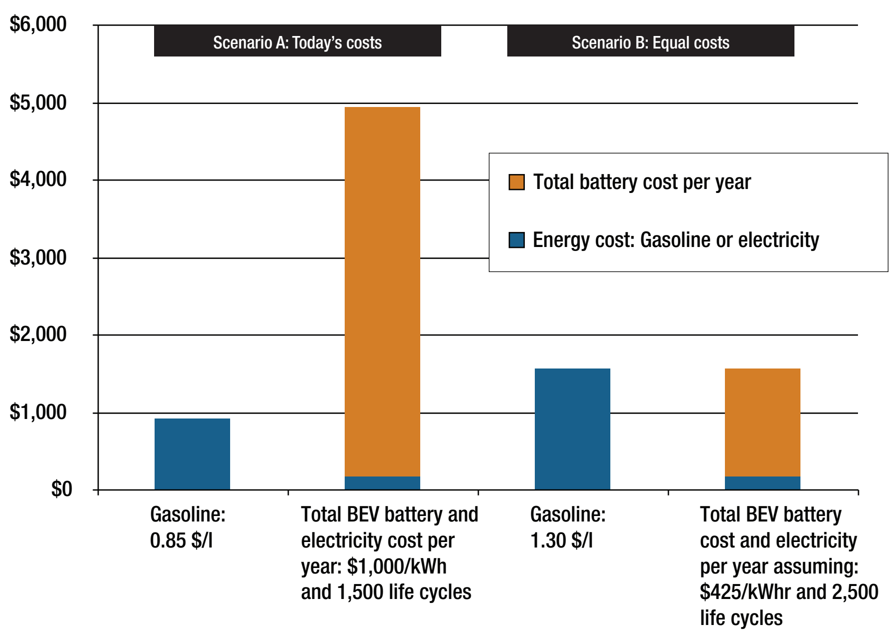


Figure 3. Gasoline costs compared to battery and electricity costs in two scenarios[10]

10 Further assumptions in are that compact cars are compared using 8.0 L/100km (ICE) and 160 Wh/km (BEV), travelling 60 km/day. The electricity price for both scenarios is $0.07/kWh and the real cost of battery financing is 4%/y.

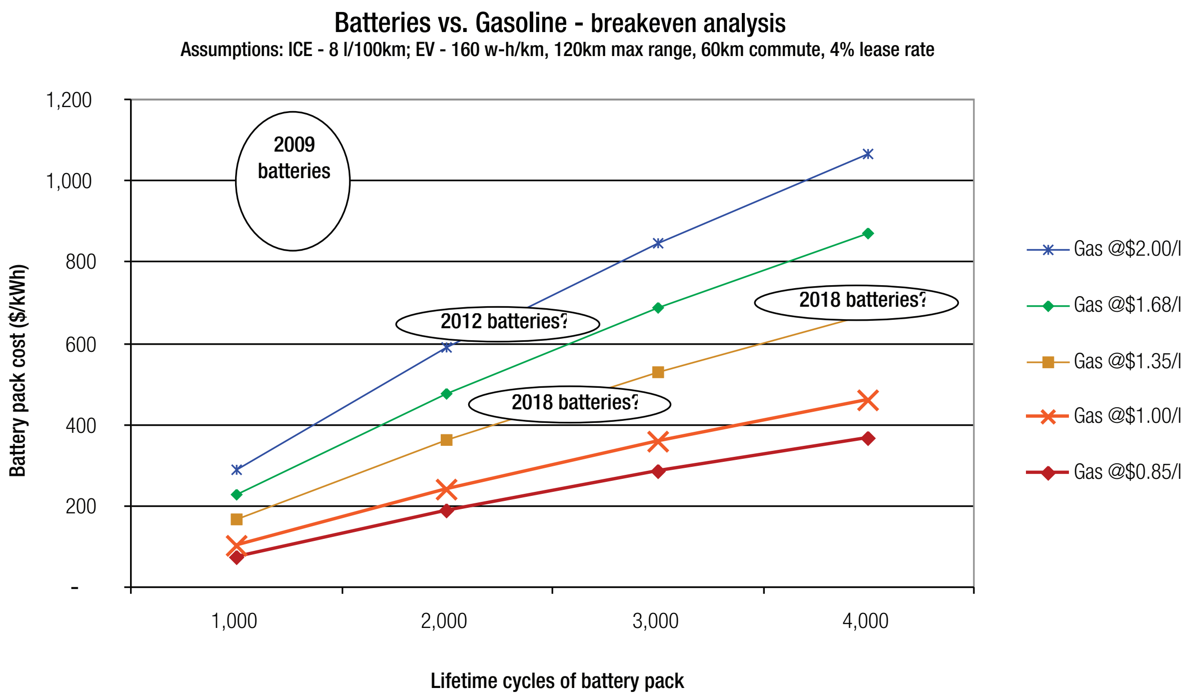


Figure 4. Breakeven analysis – Battery cost vs. cycle life for a range of gasoline prices

5.1.7 Battery cost: Cycle life

The cost per cycle can be a more accurate indicator of the real cost of storage than the cost per unit of energy stored.

The ellipses in Figure 4 provide a conservative picture of current battery performance ('2009 batteries') and three industry experts' views of how performance will improve: one for 2012 and two for 2018. Thus, present batteries cost about $1,100/kWh and are good for about 1000 cycles. In 2012 the cost will be down to $750/kWh and cycle life will be 2 000 or more cycles. In 2018, according to one expert, cycle life will have almost doubled, although cost per kWh will be about the same. The other expert expects lesser improvement in cycle life, but a reduction in unit cost.

The sloped lines in Figure 4 represent combinations of battery cost and battery cycle life that break even with the indicated gasoline prices, using the relevant assumptions of Figure 3. The estimates of battery performance thus correspond to a breakeven price with gasoline of $2.00/litre in 2012 and $1.35/litre in 2018.

The analysis suggests that as battery prices come down and performance improves, and gasoline prices increase, the breakeven point for BEVs could occur between 2012 and 2018 (and similarly for PHEVs). In the meantime, financial intervention by governments may be imperative to support the early stages of the industry's development.

5.1.8 Canadian conditions

Canada has an unusually broad range of core competencies in all areas of transport electrification. These competences concern batteries, EV systems integration especially for commercial vehicles and low-speed vehicles, and battery management and power management systems. Per capita, at least at the moment, these resources are substantially larger than those in the US, and should be supported and exploited.

Canada has unusually severe climatic conditions, with temperatures of -40°C to +40°C. Both low and high temperatures can degrade battery performance, particularly storage capacity. This is seen as a manageable problem. In winter, optimum battery temperatures can be initially secured by a plug-in battery warmer, which may be needed to supplement the heating of the battery that occurs as a result of recharging. Once in operation, the battery's internal temperature rises to well above ambient levels.

Because vehicle ventilation, heating, and air-conditioning systems are entirely or mostly electrically powered, summer and winter temperature extremes can reduce an EV's operating range. A solar panel embedded in the upper body shell can provide additional power for interior heating or cooling, as well as some battery charging.

5.1.9 Lithium resources, recycling, and repurposing

Recent reports suggest that there may be a scarcity of supplies of lithium as the demand for lithium batteries increases. However, the most optimistic forecasts for the EV market have the industry accounting for less than 20 per cent of global lithium demand. Moreover, there appear to be ample sources of supply including deposits of spodumene—a lithium-bearing mineral—in Quebec and Manitoba.

The major components of lithium batteries are inert, except for some solvents. However, there is a regulatory requirement for safe disposal of used batteries. Canada has such a facility in place. The disposal system involves cryogenic cooling before dismantling the batteries and conversion of the residual lithium compounds to lithium carbonate for resale. Hazardous materials, including solvents, if present, are neutralized to form stable compounds before safe storage. Plastic casing materials are recovered for recycling. Cobalt is recovered for reuse, if present.

When lithium batteries are no longer capable of holding enough charge for a regular EV, they may be 'repurposed' for use in smaller electric vehicles or by electric utilities that could use storage for peak load shaving or to store intermittently produced energy from wind or solar sources. Availability of resale opportunities for EV batteries could reduce initial costs.

5.1.10 Other battery types

Although this section has focused on lithium-based batteries, work on other types of battery should not be overlooked. This includes work on mature battery types, notably lead acid and NiMH batteries. It also includes work on less familiar types such a nickel-zinc and zinc-air batteries.

5.1.11 Energy storage: Key issues restated

Further development of energy storage systems is the key to success of the EV industry. Here is a restatement of the key issues:

- Electric vehicles, probably with lithium batteries, are the likely future of land transport generally and automobiles in particular. Worldwide, there are more than 60 companies that have launched or have plans to launch some kind of electric vehicle, whether hybrid, plug-in hybrid or battery electric vehicle by 2018.
- The battery is the most critical component of an EV and the most costly, representing up to 50 per cent of the total vehicle cost. In early 2009, the battery industry may be relatively more developed in Canada than in the US, with at least five companies involved in lithium-battery development and vehicle integration, including one OEM.
- Manufacture of EVs, batteries, and components is highly subsidized elsewhere. In the US in particular, the federal government has created a $25 billion investment pool for EVs of all kinds, battery development, and electric transportation infrastructure. Canadian companies are no longer on a level playing field.

5.1.12 Strategic initiatives: Energy storage

The Roadmap process identified the following strategic initiatives concerning energy storage:

- Achieve improvements in energy storage through basic and applied research, including improvements in:
  - manufacturing techniques—with the goals of adding scale, improving efficiency, and reducing costs
  - energy density—to reduce costs, increase range, and achieve smaller, lighter systems
  - management and control electronics—for more efficient use of available energy storage
  - system packaging—to optimize thermal, electrical, mechanical, and safety elements.

5.2 Components

5.2.1 EV components

The basic body shell and interior components, wheels, and lighting are common to all vehicles; but EVs have key components that differ from their equivalents in an ICE vehicle, as illustrated in Table 2. EVs also have many fewer components overall, which should result in lower maintenance costs, other things being equal. Such savings have been estimated to be about 25 per cent for commercial delivery vehicles.

Table 2. Major EV components and systems that differ from their ICE equivalents[11]

EV component	Function
On-board battery charging system	Converts AC power from the grid to DC power to charge the battery
Battery thermal management	Ensures that the battery operates within its optimal temperature range
DC/DC converter	Converts the high-voltage output of the battery (300–700 V) to low voltage for use with vehicle systems such as lighting (12–42 V)
Motor controller	Converts the battery's DC output to a form that controls and powers the motor, often variable frequency AC
Traction motor	Drives the vehicle's wheels though the transmission/gearbox
Cooling system for motor and controller	Cools the traction motor and motor controller, usually with liquid coolant
Transmission/gearbox	Couples the traction motor to the vehicle's drive wheels; usually incorporates speed reduction
Brake controller to blend regenerative and conventional brakes	Manages braking using an appropriate mix of conventional friction brakes and regenerative braking by the traction motor
Electric power steering	Replaces the belt-driven hydraulic pump and hydraulic assist system for conventional power steering with an electric motor
Electric power brakes	Replaces the pneumatic-powered brake booster on an ICE charged by engine vacuum with an electrically powered system.
EV heating system	Provides comfort for passengers using one or more of several options that include: (i); any liquid/gas fuelled heater; (ii) heat storage when the battery is charged; (iii) use of a solar thermal or photovoltaic panel integrated into the upper surface of the body shell; (iv) resistive heating (draws down the battery).
Electric air conditioning system	Replaces the belt-driven pump of a conventional vehicle air conditioning system with one driven by an electric motor, perhaps powered in part by a photovoltaic panel integrated into the upper surface of the body shell.
EV heating system	Provides comfort for passengers using one or more of several options that include: (i) any liquid/gas fuelled heater; (ii) heat storage when the battery is charged; (iii) use of a solar thermal or photovoltaic panel integrated into the upper surface of the body shell; (iv) resistive heating (draws down the battery).
Electric air conditioning system	Replaces the belt-driven pump of a conventional vehicle air-conditioning system with one driven by an electric motor, perhaps powered in part by a photovoltaic panel integrated into the upper surface of the body shell.

11 Table 2 was kindly provided by Roger Martin of Unicell Ltd.

Table 3. Technical targets for the electric vehicle propulsion system[12]

	2010	2015	2020
Cost, $/kW	<19	<12	<8
Specific power, kW/kg	>1.06	>1.2	>1.4
Power density, kW/L	>2.6	>3.5	>4.0
Efficiency (10 per cent-100 per cent speed at 20 per cent rated torque)	>90 per cent	>93 per cent	>94 per cent

5.2.2 EV component costs

There are no major technological challenges involved in developing the EV components and systems identified above. However, with the exception of electric power steering, none has been produced in large quantities. They have not been optimized for cost and performance as much as conventional automotive components have.

The cost of EV components must decrease by a factor of two to three to be competitive with corresponding components for ICE vehicles, and their performance must improve. Table 3 illustrates the scale of this challenge for the traction motor and motor controller only—to make them competitive in performance and cost to ICE-based equivalents.

5.2.3 Canada's core competencies

To participate in the EV market, Canadian manufacturers of EV components will need to attain similar or more stringent targets. Canada has a strong parts-and-components industry. It includes at least one company that has begun to manufacture EV components and systems for major global OEMs. Section 7 details the extent of this industrial sector. It is a major asset that can support Canadian development of EVs in most transportation modes and classes of vehicles.

Canada also has several small companies developing new expertise in the design and assembly of concept vehicles using new materials, such as composites, that can contribute to reducing the weight of vehicles.

The industry is presently underfunded in terms of the research and commercialization capital needed to produce EV components in automotive quantities. It is hard pressed to compete with well-funded competitors in the US and elsewhere. Significant financial support is required to retain this expertise and to support jobs within Canada.

5.2.4 Challenges for component manufacturers

The critical challenge for EV component manufacturers is to reduce costs by a factor of two to three. The reasons for the current high costs of EV components have been discussed. Solutions to this problem are key to the survival and growth of the EV industry.

The automotive component industry is highly competitive with substantial offshore competition, especially from China and India, but support is needed to remain competitive.

A further area of development is weight reduction (lightweighting) of parts, including the use of new materials. Reducing the overall vehicle weight without sacrificing strength and safety is a major undertaking of the whole automotive sector.

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12 Table 3 is Table 1 of the FreedomCar and Fuel Partnership's *Electrical and Electronics Technical Team Roadmap*, November 2006, at http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/ eett_roadmap.pdf.

5.2.5 Strategic initiatives: Components

The Roadmap process identified the following strategic initiatives concerning components for EV vehicles:

- Reduce the cost of EV components by a factor of two to three so they can be competitive with equivalent ICE components, meanwhile reducing the weight of the components.
- Demonstrate vehicle use in real-world operation to assess the reliability and durability of energy storage and other components.

5.3 Vehicle integration

5.3.1 System integration

System integration for electric vehicles is a complex matter involving several disciplines. The disciplines include mechanical integration, electrical integration, power electronics, thermal management, and standards.

Overall, the major challenges concern the integration between the battery (fuel) and the power train. There are two elements:

- development of the battery and battery management system
- integration of these with the electric power train—charger, motor, drive train, power management system, and regenerative braking application.

5.3.2 Mechanical and electrical integration

The major challenges in the mechanical integration are the design of the battery unit and its location within the vehicle to ensure stability, weight distribution, protection of the battery from moisture and dust, and security of electric cabling especially to and from the battery. As well as accommodating the battery, which can be deployed in two or more elements, weight distribution may have to allow for the lower weight and volume of the other EV components compared with the ICE-based equivalents. For example, in a BEV there is no gasoline tank or emissions control system, and the electric motor is likely to be much smaller and lighter than the equivalent ICE.

The major elements in electrical integration are the connections involving the battery and the battery management and power management systems, and the generator and motor. Operating voltages can range from 300–700V. Reliable disconnection systems need to function during collisions and other emergencies.

5.3.3 Power management

Power management is a key area distinct from battery management. Power management systems control flows of energy between batteries and motors. They must be capable of accommodating the large current spikes that occur during regenerative braking.

Power is also required for space cooling and ventilation, windshield wipers, lighting, entertainment systems, information displays, and signals. Reducing these devices' energy use is more important when only battery power is being used. Power management systems can help reduce consumption, but the main contribution comes from the use of more efficient devices such as light emitting diode (LED) lighting.

5.3.4 Thermal management

Thermal management has two aspects: management of temperatures within the battery pack to ensure optimum performance, as discussed in Section 5.1.5, and management of the temperature of the passenger space to ensure comfort.

In hybrid vehicles, waste heat from the ICE can be used for heating the passenger space, as in regular automobiles. The ICE can drive air-conditioning systems directly, also as in regular automobiles, although always with a fuel economy cost.

In BEVs, and in PHEVs when the ICE is not being used, the battery may be the only source of energy for space heating and cooling. The loads can be substantial, especially for heating. Further development is needed to address optimization of occupant comfort with minimal use of energy.

As noted above, one approach is the use of embedded solar photovoltaic modules in the upper body surface areas of the vehicle to assist with cooling. This can power fans and even some cooling. Night-time operation remains a challenge as does space heating generally unless a separately fuelled device such as a butane heater is available (which could affect a zero-emission status).

5.3.5 Standardization and testing

Transport Canada grants vehicle manufacturers the authority to apply a National Safety Mark (NSM) signifying vehicle compliance with the safety standards applicable at the time of manufacture. Federal rules require that each vehicle has a vehicle identification number (VIN), assigned by the manufacturer. VINs communicate specific vehicle attributes based on accepted standards. They are important identifiers, critical to activities such as vehicle recalls.

Transport Canada develops and enforces the Canada Motor Vehicle Safety Standards, pursuant to the *Motor Vehicle Safety Act*. These regulations specify the safety performance of new and imported motor vehicles sold in Canada. They set minimum safety requirements for energy sources widely used in Canadian vehicles. The Standards are self-certified by manufacturers, monitored by Transport Canada, and largely harmonized with US standards.

Many voluntary standards bodies exist, including the Society for Automotive Engineers (SAE), the International Organization for Standardization (ISO), and the Canadian Standards Association (CSA). They help ensure production of safe and standardized components and may be referenced by the regulatory bodies having jurisdiction over vehicles. Topics of their standards include vehicle charging, plug dimensions and contacts, safety, and charging times.

Provincial and territorial governments are responsible for regulating public road use as well as vehicle and driver licensing, and for aftermarket equipment, including retrofits and conversions. They may require additional safety requirements for vehicle licensing.

Federal regulations specify two types of vehicle modification, according to whether the modification is being applied to an incomplete or complete vehicle. In the former case, the manufacturer making the modifications is responsible for certification to the various federal safety standards. These vehicles will have received a VIN from the original manufacturer, but the NSM is the responsibility of the final-stage manufacturer.

If a complete vehicle is modified, the application of many standards must be reviewed. For example, if the power train system was changed from gasoline to battery electric, the crash test safety performance for the occupants could change. Thus, the vehicle may have to be recertified.

Transport Canada and the US National Traffic Safety Administration (NHTSA) are participating in an international working group that is drafting requirements for electric vehicles. The working group is presently updating the in-use requirements of the European electric safety standards. It will then continue discussion of post-crash requirements in use in North America. Once these discussions have been completed, Transport Canada will consider adopting relevant requirements. These requirements would be applicable to electric and hybrid electric vehicles with operating voltages of up to 1 500 VDC and 1 000 VAC.

A matter for further investigation is the regulation of aftermarket conversions for electric vehicles that fall under provincial/territorial jurisdiction. There may be a need for standards concerning the installation of electric components in used vehicles in a way that does not reduce safety. This question may be raised with the Canadian Council of Motor Transport Administrators (CCMTA), the organization responsible for coordinating the regulation of motor vehicles by provincial, territorial, and federal governments. The requirement above all is for harmonization of standards and regulations with those of the US.

Building codes may require upgrading to cover appropriate electrification of existing and new home garages and exteriors, parking lots, and public facilities. Such upgrading should take into account new charging infrastructure guidelines being developed by BC Hydro with support from Natural Resources Canada that could be adopted by all provinces.

Environment Canada develops and enforces Canadian On-Road Vehicle and Engine Emissions Standards, and certifies compliance by manufacturers. These standards apply to all on-road vehicles. Compliance is a minor matter for BEVs but a significant matter for HEVs and PHEVs.

5.4 Canadian electricity supply for electric vehicles

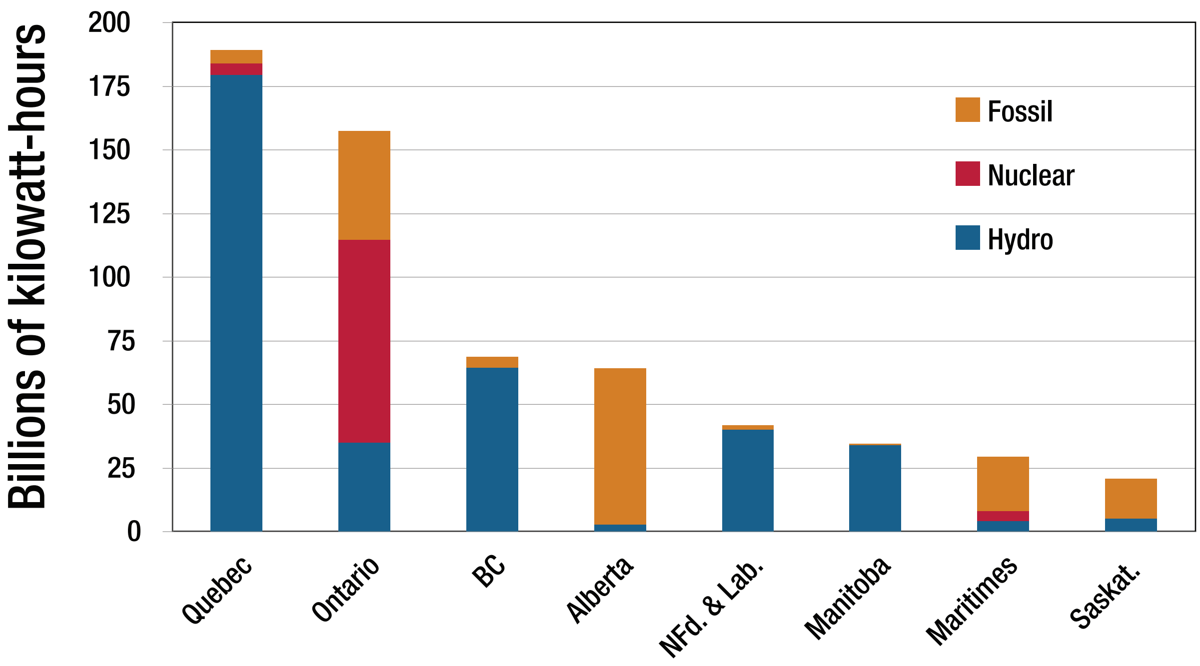

Figure 5. Electricity generation in Canada in 2007[13]

13 The data in Figure 5 are from tables 8-1 and 9 of the report on Energy Supply and Demand in Canada. Catalogue 57-003-XWE, Statistics Canada, February 2009, at http://www.statcan.gc.ca/bsolc/olc-cel/olc-cel?catno=57-003-XWE&lang=eng.

5.4.1 Generation

About 75 per cent of Canada's electricity is generated without use of fossil fuels. Methods of production include hydroelectric and nuclear generation, and production from biomass and other renewable sources. The most important source is hydro, which in 2006 contributed 59 per cent of the total supply of electrical energy, i.e., 350 terawatt-hours of a total 593 TWh. Canada is a world leader in hydroelectric generation, capable of a power output of over 72 gigawatts from this type of source. The total installed electrical generation capacity in Canada is 110 GW. Figure 5 shows that hydroelectric generation is primarily in Quebec, and also in British Columbia, Ontario, Newfoundland and Labrador, and Manitoba.

Fossil fuels are Canada's second most important source of electricity. About 17 per cent of the total supply of electrical energy comes from coal, five per cent from natural gas, and less than two per cent from petroleum. Fossil fuel generation is particularly important in Alberta and Saskatchewan where several power stations have been built adjacent to large coal deposits. Fossil fuel generation is also important in the Atlantic Provinces, Ontario, and the territories.

Nuclear energy is the third largest source of electricity in Canada. About 16 per cent of the supply is generated in 20 Canadian-developed CANDU reactors. Of these, 18 are in Ontario and one is in each of New Brunswick and Quebec.

Non-hydro renewable sources currently contribute less than two per cent of Canada's electricity supply. The predominant non-hydro renewable source is biomass (e.g., wood waste, spent pulping liquor). Other sources—wind, solar and tidal—provide a small but growing amount of electricity.

Because of the efficiency of electric motors, electric traction makes sense even where electricity is generated from coal.[14] Thus, electric vehicles should be considered even in places such as Alberta where most electricity generation uses coal as a fuel.

5.4.2 Electricity supply infrastructure: Outlook and challenges

Without the additional load from road EVs, by 2018 the Canadian electric grid would be required to supply a further 99 TWh to meet normal load growth, i.e., 17 per cent more than the 2006 total. If a road EV consumes 3 000 kWh in moving 15 000 kilometres a year (200 Wh/km for a medium-sized vehicle), the 500 000 EVs targeted by this Roadmap to be on Canadian roads by 2018 will use an additional 1.5 TWh of electrical energy. This would be about 0.2 per cent of the projected total supply in that year, and should not present a challenge in respect of generation of electricity.

The current peak load of electric power in Canada is about 100 GW, some 90 per cent of the maximum possible generation of 110 GW. If all EV charging is from 240 V, 15 A chargers, each EV would represent a 3 kW load. In the unlikely event they were all being charged at the same time, the additional total load would be 1.5 GW, or about 1.5 per cent of present peak output. This should be readily manageable. In any case, it could be moderated with time-of-use rates. As well, EV charging could come under the direct control of a distribution utility through a smart grid or in other ways.

The change in demand for electric power across 24-hour periods is illustrated in Figure 6, which shows actual summer and winter values for Ontario, as well as the corresponding wholesale prices. Note that demand falls by about 25 per cent at night, and also that there is little difference between summer and winter peak load. In other provinces winter demand is generally higher.

14 See, for example Jaramillo J, Samaras C, Wakeley H, Meisterling K (2009) Greenhouse gas implications of using coal for transportation: Lifecycle assessment of coal-to-liquids, plug-in hybrids, and hydrogen pathways *Energy Policy*, 37, 2689-2695. Also see Figure 1 on Page 27.

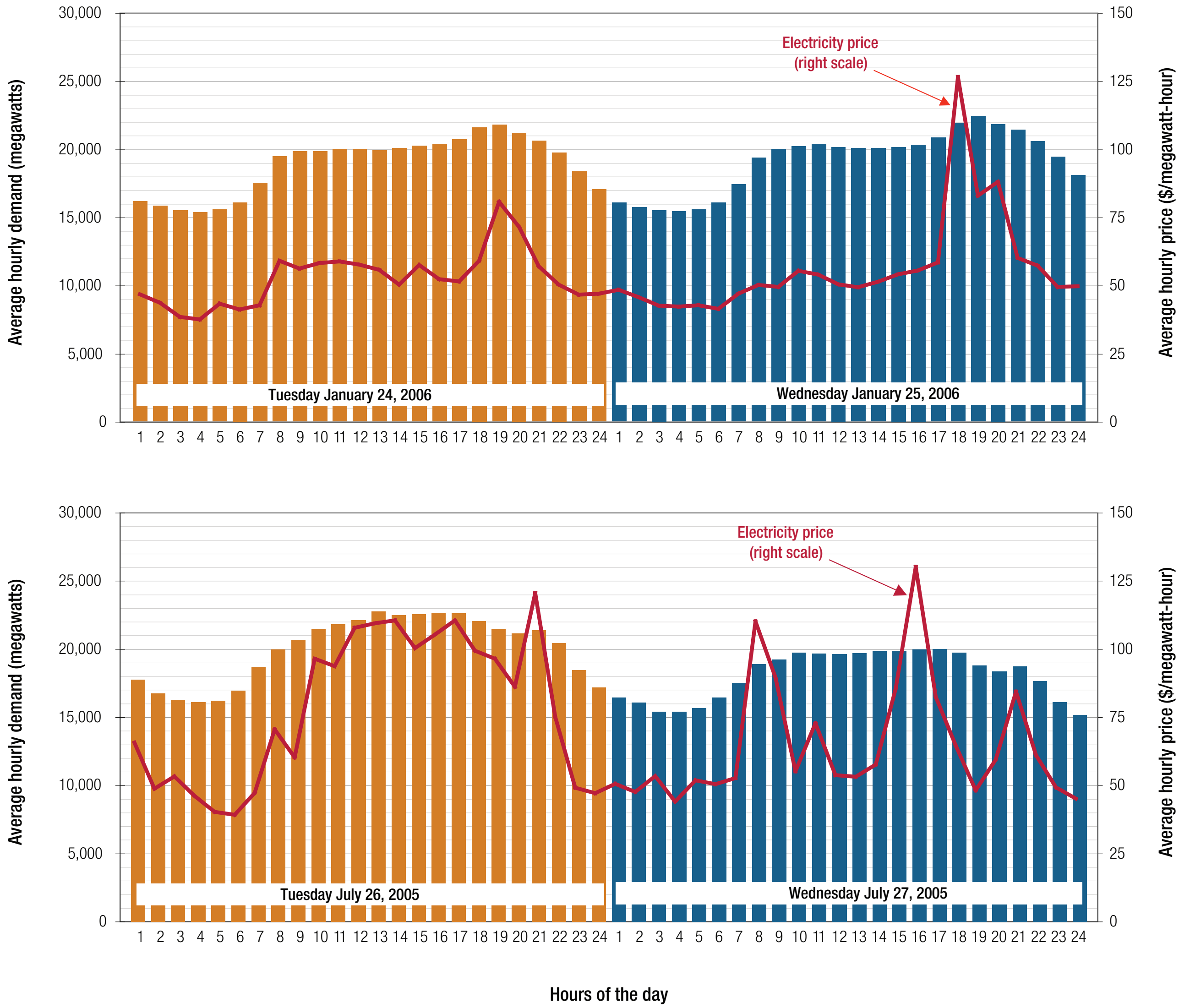

Figure 6. Hourly electricity demand and wholesale price in Ontario for a Tuesday and Wednesday in each of January 2006 and July 2005[15]

Night-time charging would not require new generation capacity, and would require only very local changes to the distribution system. Perhaps a quarter of EV charging will be done during the day. New generation capacity may not be required, but the daytime charging could strain distribution systems to the extent that additions or upgrades could be required. Clusters of EV load could stress certain feeders and the associated distribution transformers. A smart grid may be able to alleviate some of this stress, but eventually replacement or upgrades could be required. Infrastructure for public charging (120–600 V) may have to be added in some locations.

15 Figure 6 is based on data available from Ontario's Independent Electricity System Operator (www.theimo.com).

5.4.3 The case for renewable energy

Surveys conducted in the US and Canada indicate that public acceptance and willingness to pay a premium for EVs is linked with environmental benefits (see Section 4). EVs' significantly lower emissions are an important selling point and should be part of the business model. This view leads to the conclusion that if new generating capacity is required for electric vehicles, it should ideally make use of renewable source of energy. As noted above, the proposed 500 000 EVs could require 1.5 TWh of electrical energy in 2018. This could, for example, be supplied by:

- a 190 MW biomass plant running at 90-per-cent capacity, or
- a 230 MW hydroelectric installation running at 75-per-cent capacity, or
- a 490 MW wind-turbine installation running at 35-per-cent capacity.

To put the last two options in context: The hydroelectric requirement would be less than a quarter of the output of a new one-gigawatt installation such as is being planned in Canada. The wind requirement represents 22 per cent more capacity than was installed in Canada in 2007.

Another context is the cost of such new generation in relation to the cost of the batteries for the anticipated 500 000 EVs. If each EV has a 20 kWh battery pack costing $16,000 per vehicle, the total required investment in batteries for the EVs would be $8 billion. If the cost of providing new hydro generation is $4 million per megawatt of capacity, the investment in generation, taking into account hydro plant life but excluding interest, would be less than $330 million, i.e., less than four per cent of the battery cost.

5.4.4 EVs and the grid: Charging and communication

Participants in the Roadmap process were assured that substantial progress is already being made in standardizing how EVs are charged from the grid and how they might communicate with the grid. The following is a very brief account of the current status of the issue.

EVs may one day become an important part of smart grids that will help utilities and consumers manage electricity supply and demand with precision.

The Society of Automotive Engineers (SAE) is revising its J1772 standard for the general physical, electrical, and performance requirements for EV conductive charge systems and couplers in North America. These recommended practices prescribe the power level, cables, plugs, and connectors to be used to transfer energy between the grid and EVs, as well as how EVs can communicate across the grid.

The primary purpose of another SAE standard, J2836, is grid-optimized energy transfer for plug-in EVs. The specification supports energy transfer from grid-to-vehicle and from vehicle to grid (or vehicle to home). J2836 supports other applications between vehicles and the grid including participation in a utility-controlled charging plan and in a home-area network of utility-managed electrical devices.

Other SAE standards should be noted including J2836 and J2847 on communications (2836 – use cases; 2847 – messaging), J1711 (measuring emissions and fuel economy of hybrid vehicles), and J2344 (guidelines for electric vehicle safety).

Overall, the main challenge for the deployment of charging hardware in Canada lies with the harmonization of Canadian electrical standards with the American ones, and this is a small challenge that is already being undertaken.

Projects under way in British Columbia will help establish Canadian electrical code updates for charging electric vehicles. The City of Vancouver is working on updated building codes to accommodate such charging. BC Hydro, with support from the federal government and input from other utilities, is leading the development of charging-infrastructure guidelines. The results of these projects will be available for adoption throughout Canada.

One strategic initiative identified below with regard to charging infrastructure concerns inclusion of a 120V charging option on both 15A shared and 20A dedicated circuits. This will provide convenience and affordability to users and ensure that much of the existing grid and most now-available chargers can be used.

5.4.5 Strategic initiatives: Electricity supply and grid

The Roadmap process has resulted in identification of the following strategic initiatives concerning the Canadian electricity supply and electrical grid:

- Conduct tests of options for charging infrastructure in each major region of Canada, including smart charging and vehicle-to-home and vehicle-to-grid arrangements. Recommend changes and improvements, noting impacts of multiple chargers on power quality.
- Estimate EVs' contribution to national and regional electrical energy and power demand over several periods and at several levels of market penetration, taking account of reduced block heater loads and additional battery conditioning loads. Assess present and expected ability to handle these demands, noting additions that would be required to generation and distribution infrastructure.
- Assess whether renewable sources of electricity will be able to support the use of the proposed 500 000 or more EVs by 2018.

6. New business models and incentives for EVs

6.1 Introduction

Section 3 outlines the large and pressing reasons, social and environmental, to switch our on-road transportation to EVs. If these benefits are to be realized, business models and incentives must be established promptly to address the current market factors that make the economics of an EV unattractive compared to those of an ICE-based vehicle. In the longer term, economies of scale, improvements in battery cost and performance, and increases in the price of gasoline will likely make EVs directly competitive with ICE-based vehicles.

6.2 Current adverse market factors that need to be addressed

New business models and short term incentives must be developed to address these realities of EV economics:

1. **The higher cost of EVs.** For the short term, EVs—not including their batteries—will be more expensive than ICE-based vehicles. This is because EV-specific components are not yet produced in large quantities (see Section 5.2.2). The premium will decrease or disappear when EVs are produced in sufficient number. Some industry experts expect EVs to cost 5–10 per cent less than ICE-based vehicles when they are mass produced.
2. **The high initial cost of batteries.** Purchasing a battery is like 'buying a lifetime of fuel up front' at a cost that can be half that of the vehicle itself. Gasoline is an operating expense, paid every week or so, but batteries today are a capital expense, paid for a decade or so ahead when a vehicle is purchased.
3. **The cost of batteries plus electricity over the life of a vehicle is now higher than lifetime gasoline costs.** This is discussed in Sections 5.1.6 and 5.1.7. The cost disadvantage of batteries is likely to disappear with performance improvements and volume production, likely helped by rising gasoline prices.
4. **The 10-year performance of lithium batteries has yet to be demonstrated in EV applications.** Laboratory testing at the cell level indicates that future lithium batteries should meet the longevity requirements for EV applications, in cycle life and in calendar life. However, this has yet to be demonstrated at the pack level in a vehicle. The technology is too new to have a lifetime track record in real-world automotive applications. An effect of this is that neither battery manufacturers nor auto manufacturers can offer a lifetime battery warranty without oversizing the battery pack by a factor of two or more, making the batteries uneconomic.
5. **Today's low cost of gasoline** does not reflect its social costs or its future scarcity and discourages the development of alternatives such as EVs.

6.3 Illustration of the adverse market factors

Table 4 provides a comparison of the present economics of an ICE-based vehicle and a BEV. Table 5 on the next page provides a future comparison.

These tables illustrate most of the points made in Section 6.2. The values in

Table 4 and Table 5 are necessarily approximate, but accurate enough for the purposes of this illustration. They have been vetted by several industry experts. Where the experts differed in their advice, a mid-range or more conservative value has been used.

Readers are invited to apply their own assumptions to this simple model. This can be done manually or by downloading the Excel model from www.emc-mec.ca. For simplicity, the annual distance travelled is assumed to be the same for the ICE-based vehicle as for the BEV. The energy use per kilometre for both vehicles is the same for the present scenario (Table 4) as for the future scenario (Table 5). Differences from Table 4 are italicized in Table 5. The economics of a PHEV would generally fall between those of an ICE-based vehicle and a BEV chiefly because PHEV batteries are smaller that those in BEVs.

Table 4. Present comparison of the consumer costs of an ICE-based vehicle and an EV[16]

	ICE-based vehicle	Units	BEV	Units
Initial price (without EV batteries)	25,000	$	30,000	$
Cost of energy	1.00	$/litre	0.07	$/kWh
Energy consumption	8.0	litres gas/100km	160	Wh/km
Annual distance travelled	20,000	km	20,000	km
Annual energy cost	1,600	$	224	$
Cost of batteries			1,000	$/kWh
Cycle life of batteries			1,500	cycles
Maximum window of battery use			80	% of capacity
Range			120	km
Required battery capacity			24	kWh
Initial battery cost			24,000	$
Annual fill-ups or charge cycles	53	fill-ups	250	charges
Battery life based on cycles used			6	years
Period of ownership	8	years	8	years
Initial cost of vehicle	25,000	$	54,000	$
Capital and energy costs for 8 years	37,800	$	63,792	$

16 Table 4 and Table 5 were developed by Roger Martin of Unicell Ltd.

Table 5. Future comparison of the consumer costs of an ICE-based vehicle and an EV

	ICE-based vehicle	Units	BEV	Units
Initial price (less batteries)	25,000	$	*23,750*	$
Cost of energy	*1.50*	$/litre	0.07	$/kWh
Energy consumption	8	litres gas/100km	160	Wh/km
Annual distance travelled	20,000	km	20,000	km
Annual energy cost	*2,400*	$	224	$
Cost of batteries			*600*	$/kWh
Cycle life of batteries			*2,500*	cycles
Maximum window of battery use			80	% of capacity
Range			120	km
Required battery capacity			24	kWh
Initial battery cost			*14,400*	$
Annual fill-ups or charge cycles	53	fill-ups	250	charges
Battery life based on cycles used			10	years
Period of ownership	8	years	8	years
Initial cost of vehicle	25,000	$	*38,150*	$
Capital and energy costs for 8 years	*44,200*	$	*39,942*	$

6.4 Strategic initiatives: Business models and incentives

The Roadmap process has identified the following strategic initiatives concerning new business models and incentives to reduce the present unattractiveness of EVs:

- Assess the potential effects of incentive programs for the purchase of EVs on EV penetration, and also the impact of battery warranty and lease programs.
- Estimate lifetime savings to purchasers resulting from shifts to EVs from ICE-based vehicles, anticipating changes in electricity rates and fossil fuel prices. Identify corresponding revenue implications for governments.
- Assess the prospects for battery leasing models and the viability of battery 'repurposing' for Canada.
- Compare the social benefits and costs of electric traction and of ICE-based traction that uses fossil fuels.

7. New EV business opportunities in Canada

The momentous events of 2008 have had profound implications for Canada's automotive sector. In Canada, sales of light-duty vehicles were 20.4 per cent lower during the first four months of 2009 than during the same period in 2008. This decline, alarming as it is, was considerably below the corresponding 38.4-per-cent fall in sales of light-duty vehicles throughout the US. The massive US decline is of importance to the Canadian industry because for many years most of the Canadian automotive production has been sold in the US.

The dramatic fall in sales of new vehicles—and coincident declines in numbers of kilometres travelled—appeared to be direct responses by consumers to gasoline prices that have been rising in real terms for many years and that began rising with unusual steepness late in 2007, reaching unimagined peaks in mid-2008. There were, however, other factors at play, including problems in the US housing and financial sectors. Although, most economists give these other factors prime billing in explanations of the ongoing global economic recession, some economists give the high oil prices and their impact on the auto industry a central role.

What is not in question is that the present period is among the most challenging the North American auto industry has experienced. Two of the three major domestic manufacturers in North America have entered and exited bankruptcy, one being now mostly government-owned and the other being mostly owned by its major union. The overseas manufacturer with the largest presence in Canada reported its first ever annual loss. However, this period may also offer the most opportunities.

This section begins by sketching the scope of Canada's regular automotive industry in 2007. This is the latest year for which comprehensive data are available. These data may well be woefully out of date, but they nevertheless give a sense of Canada's automotive resource, particularly in terms of human factors.

The section continues with an overview of Canada's burgeoning electric- mobility industry. This resource, plus what is available from the regular automotive sector, provides Canada with what many would regard as a head start in the race to electric traction.

The sub-sections that follow discuss how this resource can be used and identify strategic initiatives that should be addressed.

7.1 Canada's automotive industry

This sub-section is mostly based on material available at the Industry Canada's website concerning the automotive industry as it was in 2007. The year of 2007 may have been the last year, for some time to come, during which the industry was relatively stable. Little of what follows may now be accurate. However, the condition of the industry in 2007 remains relevant because it shows not only what Canada is capable of but also the scope of the human resource that for the most part could still be made available.

The Canadian automotive industry produces light-duty vehicles (including cars, vans, and pick-up trucks), heavy-duty vehicles (including trucks, transit and school buses, and military vehicles), and a wide range of parts, components, and vehicle systems. To complement its manufacturing activities, the industry has well-developed sales and service networks.

The Canadian automotive industry is:

- the eighth largest in the world
- globally competitive, with a positive trade balance
- a major contributor to the Canadian economy, employing over half a million people.

The industry has a proven, global reputation for innovation, research and development, expertise, quality, and productivity.

The light-duty vehicle sector:

- has 12 high-volume assembly plants producing cars, minivans and light trucks
- produces 2.5 million vehicles annually
- has shipments of $53.2 billion
- exports about 90 percent of production value.

The heavy-duty vehicle sector:

- has 25 relatively low-volume assembly plants producing heavy-duty chassis and vehicles
- produces 74 000 vehicles annually
- has shipments of $6.6 billion
- exports about 86 per cent of production value.

Auto parts and component manufacturing:

- has more than 650 establishments with 92 000 employees that produce original equipment and aftermarket auto parts, components and systems
- has shipments of $31.7 billion
- exports about 62 percent of production value.

The motor vehicle body and trailer sector:

- has 290 facilities with 18 500 employees that manufacture motor vehicle bodies and cabs, truck trailers, and non-commercial trailers
- has shipments of $3.9 billion
- exports about 29 per cent of production value.

The automobile dealer network:

- comprises over 3 000 dealers representing 25 vehicle manufacturers
- employs some 170 000 people including automobile wholesale distributors and dealers
- has retail sales of more than $74.8 billion in new vehicles.

The automotive aftermarket:

- consists of distribution, retail, and service organizations employing over 160 000 people
- includes used-vehicle sales, auto parts, accessories and tire stores, automotive repair and maintenance, and new and used wholesale parts distributors
- has retail sales of $17.8 billion
- has manufacturing strengths in garage tools, diagnostic service and repair equipment, automotive accessories, and performance and appearance products.

7.2 Canada's burgeoning electric mobility industry

Manufacturers of EVs and their suppliers do not presently form a distinct industrial sector. Many suppliers to EV assemblers also supply the assemblers of ICE-based vehicles and thus are part of the more general automotive sector. Other suppliers of products and services used for EVs are small firms that do not produce in the quantities seen in the conventional auto industry.

Nevertheless, in relation to its population, Canada has a relatively large number of companies involved either exclusively or partially in EVs. In 2008, Electric Mobility Canada completed its Directory of Electric Mobility Resources in Canada, which contained the following listings:

- 29 companies involved in vehicle manufacturing or assembling
- 25 companies involved in the manufacture of components for EVs
- 7 distributors of EVs

- 3 integrators/converters
- 24 consulting firms doing work in EVs
- 5 electricity providers involved in EV research, development, and demonstration projects
- 22 research centres with EV-related projects
- 16 not-for-profit organizations monitoring EV developments and advocating their use.

In the companies and organizations involved in ICE-based vehicles and EVs, Canada has a great wealth of core competencies across the broad field of transport electrification, ranging from grid-connected systems (e.g., light rail) to BEVs. Also, as a world leader in fuel-cell technology, Canada has skilled personnel across a wide range of energy storage, power management, and control systems.

In academia and business, there is also a range of fundamental research expertise in electric mobility, specifically battery development, battery management systems, and materials science.

7.3 Bridge to the future

In order to marshal this wealth of expertise in support of an emerging EV industry, all aspects of the EV industry in Canada need to be coordinated. These include linkages to the electric utility industry, investment strategies, business models, technologies, markets, and critical issues such as customer acceptance, safety, and costs.

Exercising such a mandate will require extensive collaboration among many organizations with the goal of accelerating the use of all forms of electric drive in Canada by private and public transport systems delivering services in the movement of people and freight. Such coordination would embrace every aspect of the development of electric mobility. The focus on research and teaching would emphasize commercialization of electric transportation and the integration of electric mobility with societal requirements rather than fundamental work. This is elaborated in Section 8.

7.4 Conversion and retrofit opportunities: The gap

Many opportunities exist for the conversion of ICE-based vehicles to electric drive mode. Several companies are involved in such conversions and they have identified many potential clients for their services, mainly among fleets. This can be from ICE-based vehicles to BEVs or from HEVs to PHEVs.

To date, no standards exist to ensure that such conversions are made without compromising the safety requirements of the initial vehicles and to ensure that the owners and drivers of such converted vehicles are not exposed to undue safety hazards.

The inspection of converted vehicles is a provincial or territorial responsibility. An early effort is needed to develop an inspection protocol that could be adopted by provinces and territories thereby ensuring uniform regulations across the country. This protocol could also be part of required training programs for the mechanics and technicians who will do these conversions.

Current initiatives to promote EVs in the US include a significant effort with respect to conversions, also known as retrofits. Significant funds are dedicated to this activity, and safety standards to guide these retrofits are being developed. Canada should adopt similar safety regulations to support the several companies that are now organizing themselves to do conversions on a commercial basis. The initial market is expected to be fleets whose managers understand the economic and environmental advantages of EVs but have ICE vehicles with many useful years of service left.

7.5 Canadian joint venture: The bridge

A significant business opportunity became evident during the Roadmap process: there now exists a window to develop a Canadian joint venture that could deliver EVs in many classes of on-road vehicles for domestic use and export.

Canadian industry has the core competencies—from a skilled labour force to modern production facilities—to build a Canadian EV brand, i.e., an EV mass-produced in Canada by a company headquartered in Canada. Exploration of this opportunity needs coordination and support by Electric Mobility Canada, senior governments, and others.

The need for such a Canadian-led initiative was noted several times during the Roadmap consultation sessions. Conditions favouring such an initiative are changing rapidly. To capitalize on the potential, Canadians should consider the worldwide shift from ICEs to electric traction and lead from a position of strength and confidence. A Canadian EV brand was regarded as feasible by most—but not all—Roadmap process participants, and perhaps even necessary to compete with the surge in EV activities in the United States. This surge could well lead to significant losses in Canadian employment if the Canadian EV industry redirects its energies to pursue commercial operations in well-funded US jurisdictions.

7.6 Electricity: The fuel of the future

As EVs penetrate the transport market, electricity will become the 'fuel of the future' and present new business opportunities to Canadian utilities. As seen in Section 5.4, proposed electrical supply capacity could readily accommodate the amount of electric traction contemplated by the Roadmap's vision. Section 6 noted new business models may be needed with respect to vehicle batteries, ranging from leases to service-provision models. Batteries are charged from the grid, and thus utilities could well give serious consideration to being 'providers of energy for EVs' through involvement in the battery business.

Additionally, there are needs for the installation of charging stations at residences and at public and commercial buildings. These present new business opportunities for utilities including involvement in the installation of technologies for charging vehicles at the most appropriate times of day and for allocating charges to the vehicle owners no matter when they are connected to the grid. Homeowners in particular will need help and support with the home installation process.

Canadian utilities may need amendments to their provincially or territorially legislated mandates to become involved in these opportunities which should be explored.

7.7 Mineral resources for batteries and other EV components

Lastly, Canada's endowment of natural resources is of great importance since some resources could become of special value in a world with more electric traction. Mention has already been made of Canadian resources of spudomene, a lithium-bearing mineral. If zinc- rather than lithium-based batteries prevail, Canada is also well placed, being among the world's major producers. The most powerful permanent magnets incorporate the rare earth neodymium, of which Canada is becoming a major producer. These and numerous other Canadian resources would complement a vibrant, Canadian EV industry.

Canada is already the world's largest exporter of minerals and metals. A Canadian EV industry would help expand Canada's mining industries and ensure domestic application of many of its products.

7.8 Strategic initiatives: New business opportunities

The Roadmap process has identified the following strategic initiatives concerning new EV business opportunities in Canada:

- Identify the feasibility, costs, and benefits of creating a Canadian brand of highway-capable EVs. Also, identify new business opportunities for Canadian electrical utilities that could arise from growth in the EV industry.
- Identify potential early adopters of EVs, particularly fleets, and how they may be encouraged to become early adopters.

8. Institutional pathways

8.1 Purpose and focus of this section

This section addresses the roles that public institutions can and should play in the progress of electric mobility in Canada. Public institutions include governments at all levels and government agencies concerned with the movement of people and goods, including the production of vehicles and infrastructure. Here, public institutions include places where there is research and development relevant to these matters, and also education and retraining. These places are notably, but not only, tertiary-level academic institutions such as universities and community colleges. This section covers the following topics:

- government policies and initiatives
- regulatory issues
- human resource issues
- public awareness and education
- general institutional recommendations

8.2 Government policies and initiatives

8.2.1 The importance of government policies and initiatives

Governments at all levels have a profound influence on which technologies are used in transportation systems. This influence is the result of policies, regulations, codes, fiscal measures, and other tools governments use. The present worldwide interest in electric mobility is to a large extent the consequence of government actions aimed at reducing the use of fossil fuels and resulting emissions, supporting promising domestic technologies, and reducing transportation costs.

Given the interest in EVs described earlier, a thorough review of the policies and initiatives of Canada's public institutions is appropriate to ensure that they support the progress and deployment of all forms of EVs across the country. The review should help ensure that existing policies and initiatives do not produce unintended barriers and do indeed provide the support required for preferred technologies to prosper.

8.2.2 Government policies and initiatives in Canada

There are numerous government departments and agencies involved in EV-related matters across Canada. Their current initiatives, programs, and policies include:

- government-led research and development projects, notably AUTO21, Canada's national industry-academic automotive research network, which invests about $2 million per year in EV-related work
- government support to academia for research and studies
- support to industry for research, development and demonstration activities and other product commercialization
- incentive programs for purchasers of vehicles with environmentally friendly technologies
- standards concerning vehicle safety, fuel efficiency, and emissions
- infrastructure funding priorities
- vehicle procurement policies
- building and electrical codes
- regulation of fuel prices
- fiscal measures including taxes and duties.

In existing programs and work:

- There is information-sharing among public institutions, but it needs to be accelerated to reduce duplication of effort and to avoid gaps in needed activities.
- EVs are rarely mentioned in the purpose of most of these initiatives, programs, and policies, an exception being Natural Resources Canada's interdepartmental Program for Energy Research and Development (PERD) noted below.

There are encouraging initiatives, programs, and policies including:

- Provincial financial incentives for purchasers of EVs. These apply to personal vehicles only, except Ontario's Green Commercial Vehicle Program.
- PERD devotes resources to government- and industry-led research and development (R&D) initiatives concerning EVs. There was considerable industry input in the organization of this program.
- Automotive Partnership Canada (APC), a five-year, $145-million initiative of the federal government was announced on April 17, 2009. It is "to support significant, incremental, collaborative R&D activities of benefit to the Canadian automotive industry [through] partnerships between industry and academia and/or the National Research Council. … any project (or program of research) funded by APC must be *driven by industry needs*, and must have *active industrial participation and collaboration*. … emphasis is being placed on transformative proposals …" To the extent that EV manufacturing is considered to be part of the Canadian automotive industry, this initiative would appear to have criteria for support that strongly align with the benefits of EVs.
- Local initiatives in Vancouver, Toronto, Montreal, Québec City, and Saint-Jérôme where by-laws and other policy tools support EVs and their infrastructure. These initiatives are relatively few in relation to initiatives of this kind in other places.
- There are a few provincially led or supported demonstration projects for PHEVs and other EVs.
- The establishment of diagnostic laboratories for testing batteries and various types of EV in academic institutions and making these facilities available to the private sector.

8.2.3 EV research and development in Canada

Governments, particularly at the federal and provincial/territorial levels, support many programs that fund research and development projects on several aspects of EVs. These programs are aimed at eventually supporting industrial growth. Several strategic issues need to be addressed in their execution.

Many research and development programs fund work in universities. With the exception of AUTO21 and the Automotive Partnership Canada programs, industry's role is secondary in the determination of projects and their timelines and outcomes. The fundamental and applied research is of high quality and potential utility, but a project with a three- or four-year timeframe may be of limited use to industry unless it is focused on an industry priority and done in collaboration with industry stakeholders.

- Projects funded through academia are many and diverse in order to meet as many needs as possible. This spreads available funds around, but often with too little in one area to be effective and useful in the short term.
- More support is needed in Canada on commercialization activities; in particular, assistance for both SMEs and larger companies to commercialize advanced technologies would help Canada to build a leadership position in electric vehicles and related technologies.

Industry requires a focused determination of priorities for allocating R&D funds and funds for other pre-commercialization activities. (The recently announced Automotive Partnership Canada program may contribute towards resolving some of these issues.)

8.2.4 Canada in relation to happenings elsewhere

Appendix E provides a brief overview of government policies and initiatives in other places.

The world is moving rapidly towards embracing EVs as a major solution to several transportation issues, mainly the need to reduce the consumption of fossil fuels for economic, environmental, and security reasons. Canada has several advantages, noted above, that should stimulate strong, progressive policies and programs supporting EVs of all forms for the movement of people and freight. These advantages include a qualified workforce, much electricity from renewable sources and the potential for more, an established and dependable electric grid, and large numbers of private and fleet owners wanting more energy-efficient vehicles.

8.2.5 Strategic initiatives: Government policies and initiatives

The Roadmap process identified these strategic initiatives concerning government policies and initiatives:

- Identify and assess the challenges and opportunities for Canada's EV industry posed by the *American Recovery and Reinvestment Act of 2009* and other such measures.

8.3 Regulatory issues

8.3.1 The importance of government regulations

Government regulations provide critical support for all modes of transportation. They dictate safety features for vehicles, their expected emissions, the ways they are to be operated and by whom. Regulations apply to vehicles from their manufacture to their disposal.

Regulations are regularly updated to reflect available technologies and societal needs. Often they provide specific standards to be met. Advocates for regulatory changes can be inside governments but often represent industry groups with a particular agenda reflecting their constituents' needs.

With the increasing interest in EVs, actions should be taken to ensure that regulations are updated to allow new EV technologies.

8.3.2 Federal regulations

Section 5.3.5 of this Roadmap sets out the federal standards that apply to the vehicle industry. They have been developed for an automotive industry that produces ICE-based vehicles. As new technologies emerge, these regulations should be examined to determine if there are better and safer ways of achieving intended performance.

Federal regulations mostly dictate how a vehicle must be built. They are usually in harmony with those of the US, reflecting the integrated nature of the auto industry.

Federal regulations also concern EV-related infrastructure. They provide building codes, electrical codes, environmental standards for power generation, and other features.

8.3.3 Provincial/territorial regulations

Once a vehicle is built or imported in accordance with federal regulations, its day-to-day operation is largely governed by provincial/territorial regulations. These ensure that the vehicle's maintenance, repairs, and modifications do not violate the safety or other requirements of the federal regulations. Provincial/territorial regulations also specify operational constraints, including speed limits and hours of operation. They also concern infrastructure.

Provincial/territorial regulations address workplace safety issues, a matter of new importance for those working on EVs and for first emergency responders.

8.3.4 Municipal regulations

Municipal regulations are usually by-laws concerning building codes, electrical codes, and traffic regulations. The latter—framed by provincial/territorial regulations—include restrictions as to use by particular vehicles on particular roads at particular times of the day.

8.3.5 Need for inter-jurisdictional harmony

The vehicle manufacturing industry in Canada is closely integrated with that of the US, with many companies doing business in both countries from one or more locations. They include vehicle assemblers and the manufacturers of the components and software used in modern vehicles. Standards and other regulations adopted in Canada should be in harmony with those of the US. This is the objective of Canadian regulators with respect to vehicle safety standards where harmonization is well advanced. Similar considerations are needed in respect of charging infrastructure standards. Deviations from harmonization should be rare.

Table 6 Strategy to achieve plug-in cities[17]

Stakeholders:	Required Enablers:
Dedicated Project Leader	• Establish a: ➔ Public charging infrastructure plan; ➔ Local/provincial incentives plan; ➔ Marketing and educational outreach plan
Federal Govemment	• Provide Plug-in vehicle consumer tax credit that parallels what has been established in the U.S.: $2,500 min for vehicles with 4kWh battery, with increased credits of $417 for every additional kWh battery capacity up to a maximum of $7,500 • Provide tax credit for charging equipment /installation at home/multi-family home/ workplace/public up to $3,000/home, $30,000/ site with at least 10 charge ports (meeting SAE J1772 level 2 (240v) and J2836 standard) • Eliminate GST on Plug-in vehicle purchase • Commit / fund government fleet purchases (300 vehicles)
Provincial Govermment	• Provide a Plug-in vehicle tax credit: >$2,500 for a vehicle with a 16kWh battery (scaled incentive based on battery charge capacity) • Provide tax credit for charging equipment /installation at home/multi-family home/ workplace/public up to $3,000/home, $30,000/ site with at least 10 charge ports (meeting SAE J1772 level 2 (240v) and J2836 standard) • Eliminate sales tax on vehicle purchase • Commitment government fleet purchases (100 vehicles)
City/Municipalities/ Clean Cities Orgs	• Provide incentives for vehicle purchasers and charging equipment and installation in coordination with Provinces • Install public charging spots in key locations (30 distributed locations; meeting SAE J1772 level 2 (240V) and J2836 standards) • Establish free parking and free charging (Ideally underground/enclosed – avoid outside locations) • Commitment City/Municipal fleet purchases (25 high-profile vehicles)
Ministries of Transportation	• Provide HOV lane access for Plug-in vehicles • Eliminate vehicle registration and license fees for Plug-in vehicles
Permitting and Code Officials	• Prepare for eased/fast/self-permitting of home/public charging installation; Ensure new homes/building codes/major renovations provide for 240V vehicle charging
Utilities (municipal & regional)	• Provide incentives and services for home/commercial charging installations (i.e. provide no/low cost installation financed thru monthly utility bill) • Provide free charging or low-cost Plug-in vehicle rates (3-4 cents/kWh off peak) • Provide "green" renewable electricity options • Commit to fleet purchases (15 high-profile vehicles)
Large Local Employers (as Early Adopters)	• Major corporations provide work-place charging (25 park/charge spots) and employee vehicle purchase incentives (add'l $1000/vehicle) Commit to corporate fleet purchases (20 vehicles)
Universities	• Provide campus charging and free parking (10 distributed charging locations); Commit/fund university fleet purchases (5 high-profile vehicles)

17 Table 6 was provided by General Motors of Canada Ltd.

8.3.6 Current gaps concerning regulatory issues

The rebirth of EVs is a recent phenomenon. Current regulations reflect the technologies, manufacturing processes, and operating protocols applicable to ICE-based vehicles. Most of these can also apply to EVs, but some do not and need early attention.

Table 6 illustrates the view of a prominent actor in the automotive industry as to the regulatory needs of EVs. Although this appears to be an extensive list of players and tasks—it is only a thumbnail sketch—early attention and action are required to ensure that the necessary regulatory requirements are in place to facilitate the timely adoption of EVs in Canada.

8.3.7 Strategic initiatives: Regulatory issues

The Roadmap process identified these strategic initiatives concerning regulatory issues:

- Review national, provincial/territorial, and municipal regulations that impact the manufacture and use of EVs in Canada. Ensure that the regulations support EV development without compromising safety and other concerns.
- Secure harmonization of North American standards and practices concerning the integration of EV components, including charger interfaces.
- Develop harmonized standards for conversion of used vehicles to electric traction.
- Amend building codes and other regulations to require at least the roughing-in of outlets for charging EVs in all new buildings. Provide model codes and regulations.
- Develop action plans for infrastructure readiness based on best practices.

8.4 Human resource issues

8.4.1 The importance of human resource issues

Humans remain critical to the manufacture, servicing, and maintenance of all vehicles. This is notwithstanding the high usage of robotics and testing equipment with sophisticated software, and the mechanization of vehicle assembly and servicing. Canada's major role in the auto industry has resulted in a highly trained workforce skilled at assembly and maintenance. This workforce benefits from education at all levels as well as on-the-job training. The education and training involve federal and provincial/territorial agencies and the private sector. Programs have evolved over the years to address the specific needs of ICE vehicles. They need refreshing to reflect the arrival of EVs in the marketplace.

8.4.2 Current situation concerning human resource issues

ICE-based vehicles and EVs have much in common in terms of parts and manufacturing processes. But the differences are significant and require new skills of employees involved in vehicle assembly, repair, and servicing. Prominent are those concerning the safe handling of high-voltage battery packs. During the consultation process leading to this report, the following matters were noted:

- There are severe shortages of EV-focused education and training programs in Canada.
- At the vocational level, automobile programs have yet to consider electrification, despite the rapid shift to computerization and 'plug-and-play' trends in auto electronics.
- Community colleges typically offer industry-sponsored training modules and these modules do not yet address any type of EV–not even hybrids.
- Universities need to direct students towards the high-paying jobs that will be found in the EV industry and offer training in new business models, battery engineering, relevant chemistry and physics, power system engineering, manufacturing processes, and other disciplines needed to advance EVs.

- Education is primarily a provincial/territorial responsibility, but there is little evidence of inter-provincial/territorial sharing of new curriculum materials to address emerging EV issues.
- The Council for Automotive Human Resources (CAHR) recently put out a request for proposals for a study to define job standards for “the automotive industry of the future”. It included no reference to EV trends.
- A similar project was recently announced by The Council for Automotive Repair and Services (CARS) looking for skills training services. As with CAHR, the CARS’ request for proposals seemed to project a business-as-usual approach.
- Canadian universities offer good programs in areas of materials science, but are currently weak on battery technology.
- Emergency responders need training on EVs to ensure they execute their duties in a safe and timely manner. They need to know how to deal with high-voltage batteries and flows of electricity within vehicles in order to safely extricate victims at times of collisions.

8.4.3 Current gaps concerning human resources

There is an urgent need for a national review of training programs, apprenticeship programs, and the curricula used in high schools, colleges, and universities. Most of these functions are under provincial/territorial jurisdiction, but it is important that efforts to prepare Canadians for the switch to EVs be harmonized across Canada. They should also take advantage of new training materials being developed in the US.

8.4.4 Strategic initiatives: Human resource issues

The Roadmap process identified these strategic initiatives concerning human resource issues:

- Assess the resource requirements for training, education, and certification in skills related to the emerging EV industry. Provide this information to organizations that can develop:
  - technical courses on EV repair, service, and maintenance, and on conversion of ICE-based vehicles to EVs.
  - courses to help graduates of universities and colleges secure employment in high-paying jobs in the emerging EV industry in areas such as battery engineering, power systems engineering, power electronics, manufacturing processes, and development of new business models.

8.5 Public awareness and education

8.5.1 The importance of public awareness and education

As demonstrated in Section 4, prospective buyers of EVs need more information to make appropriate purchasing decisions. Despite the best efforts of the industry and governments in promoting EVs, vehicles are purchased by individuals, corporations and agencies that are in need of information about the available technologies.

8.5.2 Current situation concerning public awareness and education

Based on Section 4, Canadians:

- are generally confused about the different types of EVs now available or soon to be available.
- do not understand that many potential benefits of EVs are realized in the long term.
- are favourably disposed to the acquisition of EVs but could make wrong purchasing decisions if not better informed.
- cannot rely on vehicle sales personnel to present a balanced view of various types of EVs and their comparison to ICE-based vehicles.

8.5.3 Policy-makers need information

The need for information about EVs also applies to policy-makers charged with developing and making difficult policy decisions in many areas concerning the progress of EVs. Policy-makers need information that explains the technologies and their benefits, and the actions needed to move them forward.

8.5.4 Current gaps concerning public awareness and education

Educational and awareness programs are required to address the issues identified in 7.7.2 above. Such programs need input from the EV industry, educators, and marketers. They need to be available through the Web and other media in ways that are perceived as credible and unbiased.

8.5.5 Strategic initiative: Public awareness and education

The Roadmap process identified this strategic initiative concerning public awareness and education:

- Develop educational and public relations programs designed to increase awareness across Canada of the benefits of EVs and associated technologies.

8.6 Implementation

8.6.1 Roadmap Implementation Committee

A government-industry focus is needed to ensure implementation of this Roadmap. One way of doing this would be to reconstitute the Steering Committee for the Electric Vehicle Technology Roadmap as a Roadmap Implementation Committee with membership changes as required to fulfill its mandate.

The Committee's mandate would be to address and promote the implementation of the Roadmap's recommendations including the areas of research, development and demonstration, codes, standards and safety, incentives and regulations, studies and assessments, and education and training, including technical services.

8.6.2 Electric Transportation Institute

Section 7 summarized the current automotive industry in Canada and highlighted its strengths in respect of electric mobility. In the companies and organizations involved in ICE vehicles and EVs, Canada has a wealth of core competencies across the broad field of transport electrification, ranging from grid-connected vehicles to BEVs. As a world leader in fuel-cell technology, Canada has generated skilled personnel across a wide range of energy storage, power management, and control systems.

There is also an extensive range of research expertise in the field of electric mobility that includes battery development, battery management systems, and materials science.

To marshal this wealth of expertise in support of an emerging EV industry, there is a need to coordinate all aspects of the EV industry in Canada. These include electric utility concerns, investment strategies, business models, technologies, markets, and critical issues such as customer acceptance, safety, and costs. This will require extensive collaboration with many organizations towards the single goal of accelerating the use of all forms of electric drive in Canada. This would cover all private and public land-based transportation systems concerned with the movement of people or goods, or both.

Industry sees the establishment of an Electric Transportation Institute as a means of supporting this coordination. It could be a stand-alone organization or an organization located in a university or another institution. In both cases, its agenda, timetables, and pace of accomplishment would be set largely by industry.

8.6.3 Strategic initiative: Implementation

The Roadmap process identified this strategic initiative concerning implementation:

- Assess the merits of and develop a mandate for an Electric Transportation Institute as a Canadian focus of applied EV research and development and other activities required to accelerate widespread use of EVs.

9. The way forward

As well as the strategic initiatives identified during the Roadmap process and set out during Sections 5-8, the process has resulted in three recommendations addressed to governments, industry, and other stakeholders:

1. Make timely and substantial investments in Canadian development and manufacture of EVs and energy storage devices to build on Canada's already strong presence in these industries.
2. Consider supplementing federal and provincial/territorial mechanisms to promote the development, public acceptance, and procurement of personal and commercial EVs, and also the installation of charging infrastructure.
3. Reconstitute the Steering Committee as a Roadmap Implementation Committee charged with ensuring that the strategic initiatives identified in the Roadmap are addressed.

The Roadmap Implementation Committee will, at least initially, be the key agent for progress on addressing the strategic initiatives identified in this Roadmap. This section provides guidance for that Committee.

The mission of the Roadmap Implementation Committee should be to help ensure that in 2018 Canadians will be able to move themselves and their goods with comfort, convenience, and efficiency, and that this is done in ways that are in the best interests of the Canadian economy. Specific tasks are to help achieve the following objectives:

(i) that Canadian-made electric vehicles are commercially available, and

(ii) that they are bought.

Attainment of these objectives will depend above all on improving electric storage, which in turn will depend on making the best use of and expanding Canada's available resources in this area. Attainment will also require provision of inducements and incentives during the period while markets for electric vehicles are expanding to the point where economies of scale can make these vehicles competitive.

Two other matters to which the Implementation Committee should devote much attention are as follows:

(i) ensuring that institutionally Canada is ready to welcome electric traction by having appropriate standards and guidelines in place and a sufficient skilled work force; and

(ii) ensuring full cooperation among provinces and with the US in matters of standards and exchange of technical information.

Another area of important work for the Implementation Committee will be in fostering public awareness of the importance of electric traction.

Finally, the Implementation Committee should note the limited scope of the present Roadmap and, after appropriate consultation, seek to initiate roadmaps in the several other areas of electric traction.

Appendix A: Pollution Probe-Environics survey results

This appendix reproduces in full the Key Findings section of the report by Pollution Probe and Environics, *Canadians' Perceptions of Electric Vehicle Technology*, discussed briefly here in Section 4.1.

Canadians' perceptions: Awareness and knowledge of electric-vehicle technology

- Almost nine in ten Canadians have seen or heard something about vehicles powered fully or in part by electricity, with awareness somewhat higher in Ontario and western Canada than in the east.
- Canadians have both positive and negative impressions of electric vehicles, with environmental benefits (on the positive side) and range and battery/charging concerns (on the negative side) emerging as key top-of-mind perceptions.
- Relatively few Canadians profess familiarity with electric vehicles. They are somewhat more likely to indicate awareness of how they compare with conventional vehicles than familiarity with the technology or plans for introduction. Younger Canadians, men and those living in urban areas are most likely to indicate familiarity with electric vehicles.
- With the exception of the Prius, Canadians are generally unable to name vehicles currently on the road that make use of electric power.
- Awareness of hybrid vehicles is generally high; more than eight in ten are aware, with men and younger drivers most likely to indicate awareness.
- Among those who do not currently own a hybrid, just over one-quarter have some experience with them, either first-hand (through having driven one) or, more commonly, by knowing someone who has owned or driven one.
- Those who have considered purchasing a hybrid cite environmental benefits, fuel efficiency and cost savings (all in about equal number) as the reasons for which they have considered such a vehicle. Those who have actually purchased a hybrid generally cite these same factors, but the environmental benefit is mentioned twice as often as fuel efficiency or cost savings by this group.
- The initial cost of purchase is by far the biggest obstacle cited by drivers who have considered (but have not purchased) a hybrid.
- There is marked confusion as to the types of hybrid vehicles available today: just over half of those aware of hybrids believe "gasoline-powered vehicles with an electric motor to provide more power when needed" are currently available, with an equal proportion believing plug-in hybrid vehicles are currently available. About four in ten among those aware of hybrids believe battery electric vehicles are currently available.
- Fuel efficiency and, to a somewhat lesser extent, cost savings and fewer emissions are seen as key advantages of hybrids by those aware of these vehicles. However, about half of Canadians cannot name any limitation associated with these vehicles; about one in ten cite range and purchase price as limitations.
- Electric-vehicle technology awareness is similar across most driver segments, including current vehicle type.

Canadians' perceptions: Hybrids including plug-in hybrids

- Six in ten Canadians are at least somewhat interested in purchasing a plug-in hybrid electric vehicle (PHEV), once they become available. Interest is highest in urban areas and increases with education and familiarity with current hybrids and with EVT in general. Interest is similar in driving a hybrid as a rental car. Interest in PHEVs is uniform across many driving-behaviour segments and by type of vehicle currently driven, but the interest is highest among those most cognizant of fuel efficiency and pollution issues and by those who see these issues as important in making a vehicle choice.
- Consistent with the perceived advantages of electric-powered vehicles, more than nine in ten Canadians rate reduced environmental impact, reduced dependence on gasoline, and savings on operating costs as important reasons to consider a PHEV. Driving a vehicle with more advanced technology is seen as a less important reason, while "making a personal statement" is relatively unimportant (though still seen as important by some four in ten).
- Reliability and maintenance/operating costs are seen as key barriers to considering purchasing a PHEV, with more than six in ten considering these very important reasons not to purchase a PHEV. Purchase price and limited access to plug-in locations are also important concerns.
- Although lack of access to electrical outlets for vehicle charging at home is not a major barrier on an overall basis, it is more of a concern for those living in the urban core. In addition, four in ten among those who do not have easy access to an outlet right now indicate it would be difficult to install one. Lack of access to an electrical outlet at work is a far greater factor, especially in the eastern part of the country.
- A small majority of those with some interest in purchasing a PHEV would pay up to a 10 per cent premium, while one in five would pay more than a 10 per cent premium.
- When those not interested in purchasing a PHEV are asked to rate a number of potential incentives, support is strongest for a 10-year/160 000 km battery warranty, with just under four in ten indicating that this would definitely make them more likely to consider such as vehicle. A $2,500 tax rebate and free battery charging in the community are also strong inducements.

Canadians' perceptions: Battery electric vehicles

- There is little awareness or understanding of battery electric vehicles (BEVs). Most are unable to name examples of such vehicles and are unfamiliar with the technology to the extent that they do not understand many of the key differences between electric motors and internal combustion engines (no exhaust system or transmission, less maintenance required).
- There is also little understanding of the battery that would be needed in such a vehicle. Beyond the fact that the battery would be large and expensive, not much is known.
- The most common perception of the BEV is a small vehicle with less power and a more limited range than conventional vehicles or current hybrids. While most assume that BEVs will be cheaper to operate, there is little real understanding of the potential cost savings, especially when factoring in the initial purchase price and the cost of battery replacement.
- BEVs are generally considered to be quieter and cleaner than conventional vehicles. However, perceptions of the environmental advantage of the BEV are affected by the source of the electricity used to power the vehicle (coal-fired vs. hydro, for example) and concerns about the environmental impacts of battery production and disposal.
- Limited range (especially when power-consuming options are used), long recharge times and concerns about the availability of plug-in locations top the list of perceived barriers to purchasing BEVs. There is a perception that a BEV is not sufficiently versatile to be really useful (despite its lower cost of operation) and that owning a BEV would force the owner to make too many lifestyle changes (most notably having to plan vehicle usage in advance to a much greater degree). Many feel that a BEV takes away the sense of spontaneity currently associated with vehicle ownership—the ability to just jump in the car and go wherever you want.

Appendix B: Market Forecasts

This appendix reproduces in full a section of the report *Situation Analysis for the Current State of Electric Vehicle Technology*, prepared for the present Roadmap process in June 2008.

Electric vehicle market forecasts

The main limitation of market studies has been noted earlier: the market environment has changed dramatically since 2005. The high cost of these studies is also a limiting factor in their use. (Prices are noted below for the possible interest of readers.) A review of several pre-2005 studies indicated that many of the forecasts were wildly inaccurate, and recent forecasts may well also be.

We have been able to access a few of the following reports. For others we relied on available descriptions. Websites are provided in the end notes.

- *Hybrid & Electric Vehicle Market 2005-2015, Impact on the Battery Market*, Avicenne, Puteau, France, November 2006. This 200-page document, costing the equivalent of $9,694, analyses the current state of HEV technology and presents a forecast of the market.
- *Hybrid-Electric Vehicle (HEV) Market Study, 2005-2006* – (English and Chinese) *Research* and Markets, February 2006. This 80-page report—which costs $2,800 for the print and $2,675 for the electronic version (for both languages) surveys the global HEV industry (including China) and addresses the factors that impact the technology. It characterizes the main categories of HEVs and provides market forecasts for the HEV industry compared to other sustainable transport options.
- *Electric Vehicle Forecasts, Players, Opportunities, 2005-2015*, *P. Harrop, lead author*
  This 228-page report costs $2,400 for the printed version and $2,800 for the electronic version. It predicts that the size of the EV industry, estimated at $31.1 billion in 2005, will grow sevenfold by 2015.
- *World Hybrid-Electric Vehicles to 2010*, Freedonia, Cleveland, OH, October 2006.
  This 300-page report, which costs $5,500, predicts that the global demand for hybrid-electric vehicles (HEVs) will grow 20 per cent annually through 2010. Gains for these fuel-efficient vehicles will be driven by erratic fuel prices, increased emissions regulations and reduced HEV cost disparities. This study analyzes the $2.8 billion world hybrid-electric-vehicle industry with forecasts to 2010, 2015, and 2020 by HEV type, segment (passenger car, light truck), and by world geographical region. The study evaluates producer market shares and profiles 36 major industry players including Toyota, Honda, Daimler-Chrysler, Ford, General Motors, Nissan, and Peugeot.
- The MarketResearch.com Website provides links to several commercial market surveys ranging in cost from $500 to $9,000. They include the following:
  - Hybrid Light Vehicles, Technologies and Trends to 2015, Automotive World, February 2008.
  - PHEVs: On the Road to Being Part of the Distribution System, IDC, September 2007.
  - *Electric Vehicles*, Global Industry Analysts, July 2007;
  - Hybrid Cars Market Outlook, RNCOS, June 2007

Appendix C: Participants in the Roadmap process

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Appendix D: SWOT analysis

This section provides a brief SWOT analysis of Canada's EV industry, i.e., a statement of strengths, weaknesses, opportunities, and threats.

Strengths

1. High share of renewably generated electricity that would be made higher still.
2. Three Canadian hydro utilities have advanced plug-in expertise; they are leaders in this area.
3. Ontario has a strong base of automotive expertise: engineering, design, parts manufacturing, and vehicle assembly.
4. Ontario has the world's largest producer and assembler of vehicle parts, a company that has an interest in producing electric vehicles.
5. Quebec has a focus of EV activity at St. Jérôme.
6. The Vancouver Region has several EV-related companies.
7. Canada has three aspiring battery companies and a key cathode material supplier.
8. Natural Resources Canada and Transport Canada are active in supporting EV development.
9. Canada has five bus builders and the world's most prominent manufacturer of rail systems.
10. There is some autonomy of decision making within Canada by major automotive companies that have headquarters outside Canada.

Weaknesses

1. No major passenger-car producer is headquartered in Canada.
2. Canada has a relatively small population and tax base (although Ontario's alone are larger than those of Sweden).
3. Battery companies in Japan, China, Korea, and the US are much larger and more advanced, with access to more investment.
4. Canada has a relatively unfavourable climate for EV deployment.

Opportunities

1. Sharing of public and private automotive development resources between the US and Canada is well established.
2. The ongoing convulsions in the automotive industry may create opportunities for EV production in Canada, including development of a Canadian EV.
3. Canada's population is highly urbanized with relatively short commute trips.
4. There is a strong certainty of limited availability of fossil fuels in the near future.

Threats

1. The US automotive industry could move out of Ontario.
2. We will be passed by efforts in the US and elsewhere and relegated to consumer status in the automotive world.
3. Canadians are lulled by current low prices of fossil fuels and see no urgency to move to EVs.
4. Support for other fuels could continue at a relatively high level and preempt support for development of the EVs that are the focus of this Roadmap.

Appendix E: Government initiatives, programs,and policies elsewhere

Describing the government initiatives, programs, and policies that support EVs elsewhere is difficult because of their extent and the speed with which they evolve. Here are some current efforts, as of mid 2009.

United States

What is happening in the US has the most relevance to this Roadmap because the US is Canada's principal trading partner and because of the integration of our automotive industries.

Early in 2009, the US Congress passed the *American Recovery and Reinvestment Act*. This legislation provides for a near-$800-billion program that includes massive investment in the auto sector, with some $25 billion going to the electric mobility sector. Specific allocations (including some from the 2008 *Emergency Economic Stabilization Act*) include:

- $400 million to support new electric vehicle technologies
- $2 billion to support manufacture of advanced lithium batteries
- $2.5 billion for R&D into energy efficiency and renewable energy
- over $ 1 billion for electric drive and advanced vehicle demonstration, deployment and procurement
- $2 billion in investment tax credits in advanced energy projects, including energy storage and plug-in vehicle manufacturing investments
- A new consumer credit of up to $7,500 for the purchase of plug-in vehicles
- increased tax credit for installation of electric and other alternative-fuel vehicle recharging equipment
- a large investment in energy independence and in reduction in carbon emissions, including development of grid technology
- $8 billion for development of infrastructure for high-speed electric rail

These investments are aimed at creating jobs (particularly next-generation jobs), achieving energy security, protecting the environment, and securing the future of the automotive industry.

As well, there are many state and local support programs for EVs. They include financial incentives for buyers, R&D programs, and many other supportive initiatives.

European Union

European policy-makers are mostly not sympathetic to copying the US stimulus initiative as a means of reinvigorating their and global economies. There is some discussion of an EU-wide program for sustainable transportation, but most initiatives are at the national level.

The government of France provides €7,000 (C$11,300) rebates to purchasers of EVs. The UK government has initiated a £100-million (C$180 million) EV investment program. London EV drivers do not pay congestion charges, worth an estimated £2,000 (C$3,600) annually. London's congestion charge program has proven successful and popular; it may soon be applied in other UK cities. In Norway, EVs are exempted from the onerous 100-per-cent sales tax on cars, providing savings of up to C$100,000.

Other initiatives in EU countries include:

- UK: all new cars to be BEV or PHEV by 2020
- Spain: to have one million EVs on the road by 2014
- Ireland: a tenth of road vehicles to be electric by 2020
- Italy: a subsidy of up to 65 per cent of the extra purchase costs of EVs

- France: a €400-million (C$650-million) R&D program for EVs
- EU: moving towards required automobile fuel economy of 4.7 L/100km, with stiff fines for non compliance.

China

China is undertaking a massive effort to establish its position as the global leader in electric mobility. Already, China has more than 50 million electric two-wheelers on its roads and many rapidly expanding and profitable auto companies. Discussion with the secretary of the Electric Vehicle Association of China (EVAC) indicated that there are over 500 companies involved in an electric mobility business. The association lists over 100 members described as EV experts.

China is moving rapidly to become a leading supplier of auto parts and accessories for the global EV industry, including batteries and motors. EVAC has forecast 20- to 30-per-cent penetration of electric cars by 2030. Warren Buffet's purchase of a 10-per-cent stake in Shenzhen-based BYD Auto for US$250 million may indicate the favourable prospects of the Chinese EV industry. There are clear signs that China can be a leader in changing EVs from a specialty technology to the global standard for the auto industry.

China's Ministry of Science and Technology (MOST) has announced a program that will fund the launch of a demonstration program with 10 000 EVs deployed into ten cities during the next two years.

Japan

Japan was among the first countries to invest heavily in battery research and PHEVs although its level of investment has now been dwarfed by that of the US.

Japan's Ministry of Economy, Trade and Industry provides purchase of subsidies of about 50 per cent of the price difference between an EV and an equivalent ICE-based vehicle. Kanagawa Prefecture and other local authorities are considering incentives along the lines of the congestion charge waiver in London, UK.

Other jurisdictions

The Government of Singapore, which applies heavy purchase taxes on new automobiles, provides substantial tax rebates to drivers of 'green' vehicles. There is also a program similar to London's congestion charge waiver.

Several jurisdictions—among them Denmark, Portugal, Israel, Ireland, Western Australia, San Francisco, and Toronto—are interested in participating in an EV service model with charging spots, battery switching stations, and software that manages interactions between EVs and the grid.

Korea has many important players in battery manufacture.

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