Prepared by

Fleet Technology Partners
(Bernard Fleet and James K. Li)
and
Richard Gilbert

For

Natural Resources Canada
Canadian Electric Vehicle Industry
Steering Committee

Situation Analysis for the Current State of Electric Vehicle Technology

A report for presentation at the Electric Vehicle Technology Roadmap Visioning Meeting, June 26, 2008

TABLE OF CONTENTS

A. EXECUTIVE SUMMARY

Electricity may be the only fuel for land transportation that can substantially replace oil products while continuing to provide for the amount of movement of people and freight that is essential for modern society. This paper focuses on a particular part of this potential transformation: the use of electric traction in vehicles other than those in which electricity is generated by on-board fuel cells. More specifically, it concerns battery-electric and hybrid-electric vehicles, including hybrid-electric vehicles whose batteries can be charged from the grid (plug-in hybrids). The paper has been prepared to aid discussion at a visioning session to be held on June 26, 2008, in preparation for development of an Electric Vehicle Technology Road Map.

The paper begins by stressing the timeliness of consideration of electric traction. Overwhelmingly, motorized transportation depends on internal combustion engines (ICEs) fuelled by oil products. With the prospect that world supply of oil may soon not keep up with demand, there is urgency in considering alternatives. Electric traction is superior to traction dependent on ICEs in every respect except one: the energy density of the fuel as it can be stored on board a vehicle. The low energy density of batteries allowed ICE-based traction—fuelled by high-density, highly portable oil products—to prevail during the 20th century, notwithstanding ICE-based traction's numerous disadvantages, chiefly air pollution and noise.

As concerns about oil production have grown over the last few decades, so has the energy density of available batteries. Nickel metal hydride (Ni-MH) batteries provide a three- to fourfold improvement over lead-acid batteries. This development has enabled the emergence of hybrid automobiles with electric motors that supplement or provide all traction and ICE-driven generators that power electric motors or charge batteries, or both. The next stage of development is the plug-in hybrid, with a battery that can be charged from the grid or by an on-board generator, thereby allowing much more of the traction to be electric.

Acceptable performance by plug-in hybrids will likely require better batteries; acceptable performance by battery-electric vehicles will certainly need them. They are becoming available in the form of lithium-based batteries, which have roughly twice the energy density of NiMH batteries. Much smaller lithium-based batteries than those required for automobiles have widespread application in electronic devices, chiefly laptop computers, but there are challenges in scaling up this type of battery to automotive applications. The longest part of this paper concerns batteries. This part includes details of the matters just touched on and a range of other matters including cost and the roles of market participants.

Another substantial part of the paper concerns the electric vehicle industry, with a focus on identifying participants and the considerable range of market perspectives available at this time of rapid industrial repositioning. Another focus is on identifying actual and prospective Canadian actors in the electric vehicle and related markets. Today, the greatest interest is in various types of hybrid ICE-electric vehicle. This could well be displaced by interest in pure battery-electric vehicles, or the two could coexist and together challenge the hegemony of pure ICE vehicles.

A final section sets out Canada's many assets in relation to the further development of electric vehicle technology and notes some requirements for this development.

B. TIMELINESS OF A FOCUS ON EV TECHNOLOGY DEVELOPMENT

> I believe strongly we have to get off oil. The electrification of the automobile is inevitable.
>
> Bob Lutz, General Motors Vice-President, quoted in *Newsweek*, December 31, 2007

> [The decisions I most regret are] axing the EV1 and not putting the right resources into hybrids.
>
> Rick Wagoner, General Motors President and CEO, reported in *Motor Trend*, June 2006

This paper has been prepared as a background document for a Visioning Session to be held on June 26, 2008. That session is to initiate preparation of an Electric Vehicle Technology Road Map for Canada under the auspices of Natural Resources Canada, a project supported by Electric Mobility Canada. This paper is concerned with the prospects for widespread deployment of electric vehicles (EVs) used on regular roads that are propelled entirely or in part by electric motors (EMs). It focuses on battery-electric vehicles (BEVs) and hybrid-electric vehicles (HEVs).

In a regular HEV, electricity for the EM is produced on board the vehicle by a generator driven by an internal combustion engine (ICE), which may also provide propulsion. There is usually a battery or other storage device that can power the EM when the ICE is not running and perhaps allow the EM to provide supplementary power when the ICE is running, both for short distances. The battery is larger in a plug-in HEV (PHEV) and can be charged from an off-board source, usually the electricity grid. A PHEV can travel for a few tens of kilometres without recourse to its ICE, which nevertheless remains available to drive the wheels or the generator or both.

Two potential features of EVs are regenerative braking and vehicle-to-grid operation (V2G). In regenerative braking, the EM is automatically reconfigured to act as generator during deceleration, allowing storage of converted kinetic energy. In V2G, energy moves from the battery to the grid when required. In effect, the EV is part of a distributed storage system for grid electricity. Figure 1 shows all the foregoing energy transfers.

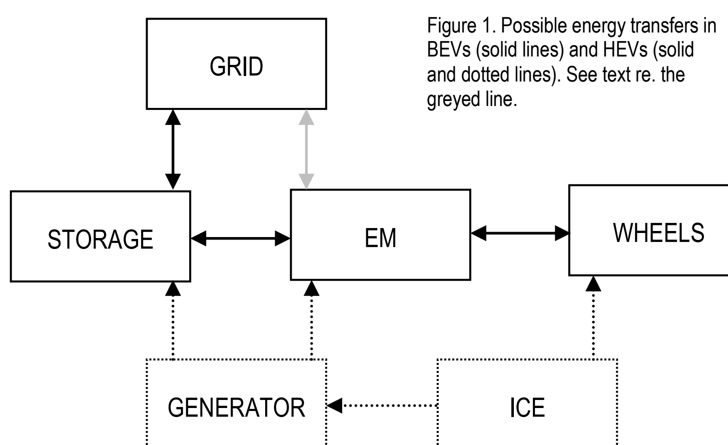


Figure 1. Possible energy transfers in BEVs (solid lines) and HEVs (solid and dotted lines). See text re. the greyed line.

Two other kinds of EV for road use are noted in passing. In one, there is an on-board electricity generator other than one driven by an ICE, e.g., photovoltaic or fuel cells or solar panels. These cells or panels would substitute for the generator in Figure 1. Hydrogen fuel cell vehicles have attracted the most investment in research and development on EVs in Canada over the last few decades. They remain an option, but issues related to cost and hydrogen supply put them outside the scope of this exercise.

The other kind of EV for road use noted in passing is the trolley bus, which receives electricity from an off-board source while in motion through direct connection to overhead wires linked to the grid. This energy transfer is shown by the greyed two-headed arrow in Figure 1, two-headed to indicate the possibility of the transfer to the grid of energy from regenerative braking.[1]

To the extent they are not already being addressed, these other road EVs, and also rail EVs, could be covered by one or more future Technology Road Maps.

In practice, several combinations of the above types of EV exist. For example, Rome has trolley buses with batteries said to allow up to ten kilometres of off-wire movement. Athens has trolley buses with diesel generators that allow more off-wire movement.

In 1900, about a third of the few motorized road vehicles were powered by electric motors (EMs); another third had internal combustion engines (ICEs); the remainder had steam engines. HEVs were known even then. In 1899, Ferdinand Porsche—later the architect of the Volkswagen 'beetle'—had designed a hybrid racing car with a one-cylinder gasoline engine that powered an electricity generator. The generator drove four wheel-mounted EMs that provided the vehicle's traction. This automobile won races in Europe taking advantage, as have all later hybrids, of EMs' superior performance and gasoline's high energy density.

There was no battery in Porsche's automobile. In this respect it resembled the then-not-yet-introduced diesel-electric locomotives, in which diesel engines drive generators that power electric motors. Diesel engines provide insufficient torque at low speeds to move a heavy railway train without massive gearing. EMs have maximum torque at low speeds and their use for traction obviates many of the gearing requirements. Diesel-electric locomotives now provide most traction on rails, although in many places outside North America they are being rapidly replaced by electric locomotives whose EMs are linked directly to the grid.

EMs have numerous advantages over ICEs. Indeed, they are superior to ICEs in every respect except one, to be noted below as the disadvantage that caused ICE-powering to prevail during the 20th century. In brief, the advantages are these:

- **Torque:** As noted, EMs provide maximum torque at zero or near-zero revolutions, i.e., when maximum torque is required. An ICE's maximum torque is typically delivered at several hundreds or thousands of revolutions per minute, requiring much gearing to move a stationary vehicle. EMs' high torque at low speeds contributes to their superior performance in stop-start conditions and during acceleration.
- **Reverse operation:** Through regenerative braking, noted above, EMs can capture and store kinetic energy during deceleration, potentially reducing energy consumption.
- **Efficiency:** EMs convert about 95% of applied energy to traction. Gasoline engines normally convert no more than 30% of applied energy; diesel engines convert up to 40%. Although the unit energy cost of electricity is often higher than that of liquid fuels, the cost per unit of traction energy is usually lower.
- **Power per unit weight or unit volume:** For a given power output, EMs are much smaller than ICEs, even without the ICEs' required emission control systems. Setting aside the matter of energy storage—discussed below—their higher power/weight ratios mean that EMs use less

energy to move the traction system and their higher power/volume ratios provide more room within the vehicle.

- **Little or no pollution at the vehicle:** Almost all the pollution from operation of an ICE vehicle consists of the products of fuel combustion at the vehicle. Electric traction has no such products at the vehicle although it may be responsible for atmospheric pollution where the electricity is generated. Pollution from generation is usually less per vehicle-kilometre and, having fewer sources, is intrinsically more controllable.
- **Silence:** ICEs harness controlled explosions of fuel and air mixes. They are intrinsically noisy. Their noise can be substantially muffled, but at the cost of reduced energy efficiency. EMs are almost silent in operation. (Indeed, the quietness of EVs has been considered dangerous to blind people and others.)
- **Simplicity:** EMs typically have one or a few moving parts. ICEs typically have hundreds of parts. In principle, EVs are thus usually more reliable and cheaper to maintain.
- **Flexible as to ultimate energy source:** EVs 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 EVs are thus readily compatible with a transition to renewable generation. ICEs, by contrast, usually need substantial modification to accommodate change from the energy source(s) for which they were designed.

The one disadvantage of EMs—which allowed ICE-based automobiles to prevail—is the energy density of their fuel as stored. 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 both close to 45 megajoules per kilogram. That of a nickel metal hydride (NiMH) battery—the type that is presently most commonly used in EVs—is about 0.25 MJ/kg (≈ 70 watt-hour/kg; see Figure 2 below). 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 the typical conversion efficiencies noted above, the effective energy density of gasoline is about 50 times that of a NiMH battery; that of diesel is greater. Lithium ion batteries are about twice as energy dense as NiMH batteries (although with a wider range; see Figure 2), reducing the ICE fuel's advantage to about a factor of 25.

Until the development of NiMH batteries, EVs were mostly dependent on lead-acid batteries, which have even lower energy densities (see Figure 2), severely restricting driving ranges between charges. A further problem was the charging time to replenish the battery, usually several hours. These limitations have been the major factor in confining electric traction almost entirely to low-speed—usually off-road vehicles—such as milk floats and golf carts, and to grid-connected vehicles (which, if vehicles on rails are included, carry most transit passengers in most of Canada's major cities). However, as is discussed later in this report, battery technologies have advanced dramatically over the past decade.

Two other factors relevant to the expansion in use of EVs should be noted, They are heightened concern about vehicle emissions and, more recently, heightened concerns about the price of crude oil and the security of the supply.

Harmful emissions from light-duty ICE vehicles in Canada have declined substantially during the last few decades, notwithstanding the growth in numbers of vehicles on the road. Emissions per kilometre of heavy-duty vehicles have also declined, although not always enough to offset growth in their activity. Nevertheless, substantial concern about the health and other effects of vehicle-related pollution remains. It has been heightened by concern about potential climate change, to which vehicle emissions could be a major contributor, and concerns in and outside poorer countries about rapid growth in the numbers of vehicles on the road.

Concerns about emissions have been such as to impel California—usually a leader in these matters—to require manufacturers to sell PHEVs as well BEVs or other 'zero-emission' vehicles. Thirteen other states and five Canadian provinces have generally supported California's requirements. The world's first vehicle emission standards were introduced by California in the 1960s in response to poor air quality in parts of the state. More recently concern has been broadened to include global impacts, notably those that might contribute to climate change.

During the last few months, as discussed further below, Israel and Denmark have committed to establishing the means for widespread use of BEVs, fuelled by renewably generated electricity. In these countries the expressed motivation was more explicitly that of reducing oil consumption in the face of growing uncertainty about future availability of oil-based vehicle fuels.

Crude oil prices have risen seven-fold during the last six years and have doubled in the last year. There is increasing concern about an imminent peak in world oil production followed by a possible steep decline. Projections are for demand for oil to increase. Without preparation in the form of anticipatory reductions in demand, only high or even very high prices might bring supply and demand into balance. Oil products now fuel 95% of world transport activity and transport activity consumes 60% of oil production. Both shares are higher in Canada. The need to reduce demand for oil, to avert scarcity and high prices, is gathering urgency.

Several recent analyses have concluded that among potential alternative fuels for land transportation, only electricity could maintain something like present levels or comfort and convenience.[2] The opinions expressed in this paper's epigraphs reinforce that view.

C. OVERVIEW OF MAJOR STUDIES AVAILABLE SINCE 2005

In surveying the major studies available since 2005, two difficulties were encountered. The first is that this period has seen a major revival in the fortunes of the EV industry and thus many reports—often taking more than a year to prepare—do not reflect this changed environment. The second is that many relevant documents are market forecasts. They are expensive and thus relatively unavailable, and subject to the same limitations in accurately assessing a rapidly moving target.

Four major groups of documents are noted in what follows: (i) documents already identified or added by the project team (other than market forecasts); (ii) documents identified by the steering committee; (iii) EV market forecasts; and (iv) EV battery market forecasts.

Documents noted in the proposal or added by the project team (other than the market forecasts noted below)

- *Status and Prospects for Zero Emission Vehicle Technology*, Report of the ARB Independent Expert Panel, State of California Air Resources Board, Sacramento, California, April 13, 2007. This comprehensive (200+ page) report was compiled by an expert team led by Dr. Fritz Kalhammer. It included Dr. David Swan of Halifax, N.S. The technical level of the report is excellent. About half of it concerns fuel cells and the hydrogen economy.

- *Battery Electric Vehicles: Technology Update, Market and Competitive Environment*, Fleet Technology Partners for Industrial Research Assistance Program (IRAP) and Electrovaya Corp, Mississauga, Ontario, January 12, 2008.
  This study relied heavily on interviews with industry leaders and insiders as well as available technology/market studies.

- *The 2007 Advanced Automotive Battery and Ultracapacitor Report*, M. Anderman, Advanced Automotive Batteries, Long Beach, CA, April 2007.
  Dr. Anderman's background is mainly in capacitors and this study has been strongly criticized by EV insiders.

- *Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet,* M.A.Kromar and J.B. Heywood, Sloan Automotive Laboratory, Laboratory for Energy and Environment, Massachusetts Institute of Technology, Pub. # LFEE-2007-02 RP May2007. This is a comprehensive study with good coverage of EV technology.

- *Proceedings of the International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium and Exhibition:* -
  - *EVS 21*, Monaco, April 2005
  - *EVS 22*, Yokohama, Japan, October 2006
  - *EVS 23*, Anaheim, California, December 2007

  These voluminous conference proceedings have been included here as providing useful regular overviews of trends and aspirations regarding electric vehicles.

Documents identified by members of the Steering Committee

- *GHG Emissions from Sugar Cane Ethanol, Plug-in Hybrids, Heavy-duty Gasoline Vehicles and Hybrids, and Materials Review*. Prepared by (S&T)^2 Consultants Inc. for Natural Resources Canada, January 2006 (53 pages)
  This report describes the application of the GHGenius model to the matters set out in the report's title. It estimated the cost per tonne of CO_2 reduced for HEVs, BEVs, and PHEVs, compared with an ICE vehicle, as $79.05, $262.29, and $242.10. Fuel prices used in the estimation were not provided.

- *Experts Workshop on Electric Mobility, Plug-in Hybrid Electric Vehicles (pHEVs): Summary Report*. National Research Council, Ottawa, Ontario, 2006.
  This workshop, held on July 24, 2006, was attended by more than 50 experts from the

Canadian and US federal governments, universities, industry, and the private sector, covering the major areas of energy storage, batteries, supercapacitors, drive components, and powertrains. The workshop was designed to identify the resource needs to support the Canadian pHEV community. The resulting planning document was a catalyst and an important baseline on which to develop the proposed EV Roadmap.

- *Electricity Technology Roadmap, Summary and Synthesis: Power Delivery and Markets*, Electric Power Research Institute (EPRI), Palo Alto, November 2003.
  This document has a section on 'Electric Transportation' (Pages 54-58) that gives a good indication of the position of the electric power industry in relation to aspects of electric mobility.

- *A Global Survey of Highly Fuel Efficient, Low Greenhouse Gas Emitting Vehicles,* Pollution Probe, Toronto, Ontario, November 2007.
  This survey provides brief, up-to-date profiles of several types of electric vehicle.

- *Status Overview of Hybrid and Electric Vehicle Technology, Annex VII: Hybrid Vehicles*, International Energy Agency, Paris, France, December 2007 (277 pages).
  Compiled mainly by TNO Delft (The Netherlands), this comprehensive report elaborates all aspects of hybrid vehicles, particularly from a European perspective. It concludes, among many other things, that "PHEV technology has even more potential to reduce GHGs and improve air quality (particulates and NO_x) in Europe than in the U.S."

- Bleser, J, *Electric Transportation, Sustainable Development and the Canadian Space Agency,* J. Bleser, Masters of Environmental Studies Study Report, University of Sherbrooke, April 2008.
  An impressive piece of work that has relevance to the current endeavour. It includes an account of the work of the Canadian Space Agency's Working Group on electric Mobility (Pages 43-44).

- Kromer MA, and Heywood JB, *Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet*. Massachusetts Institute of Technology, May 2007.
  This auto- and oil-industry-funded report favours HEVs, noting too the PHEVs have greater opportunity to reduce GHG emissions and petroleum use. The viability of hydrogen fuel cell vehicles is regarded as uncertain.

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 told us that many the forecasts were wildly inaccurate, and recent forecast may well be.

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

- *Hybrid & Electric Vehicle Market 2005-2015, Impact on the Battery Market*, Avicenne, Puteau, France, November 2006.[3]
  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[4]
  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 on 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* [5]
  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.[6]
  This 300-page report, which costs $5,500, predicts that the global demand for hybrid-electric vehicles (HEVs) will grow 20% 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 Web site[7] provides links to several commercial market surveys ranging in cost from $500 to $9,000. They include:

- *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

Electric vehicle battery commercial market forecasts

Several battery forecasts are noted below. They often also address the size of the market for electric vehicles, directly or indirectly.

- *Batteries to 2011*, Freedonia, Cleveland, OH, March 2007.[8]
  This 312-page report, costing $4,500, predicts that U.S. demand for primary and secondary batteries will grow 4.3 percent annually through 2011. Growth will be driven by strong demand for battery-powered products including EVs and by an ongoing shift toward more expensive, better-performing batteries.

- *Batteries in China to 2010*, Freedonia, Cleveland, OH, February 2007.[9]
  This 255-page survey, costing $4,900, suggests that demand for batteries in China will grow 13.2% annually through 2010. Gains will be driven by the emergence of electric bicycles and strong domestic consumer demand for battery-powered products. Alkaline and lithium batteries will be the fastest growing primary type while rechargeable lithium batteries will pace the secondary battery segment.

- *World Batteries to 2010*, Freedonia, Cleveland, OH, August 2006.[10]
  This 492-page report, costing $5,700, suggests that global battery demand will grow 6.9% annually through 2010, led by China, India, Indonesia, South Korea, Poland, Brazil, and Russia. Industrialized country markets will grow more slowly. Non-lead-acid secondary batteries will outpace primary and lead-acid secondary types. The consumer segment will lead gains by market.

D. BRIEF OVERVIEW OF BATTERY TECHNOLOGY AND PERFORMANCE

Battery requirements for the EV market

The success of the EV industry will hinge on energy storage, specifically on battery development. Battery development remained almost dormant for most of the twentieth century, but there have been major advances in the last few years, helped by massive investments in the IT and laptop computer industries.

The requirements for batteries for EVs are substantially different from those for the computer industry. In the early 1990s, the US Advanced Battery Consortium (USABC), an industry-government cooperative program, set out criteria for batteries that would meet the requirements for full-featured electric cars.[11] The initial report has been amended and updated over the years to include criteria for energy density, power density, weight, cycle life, calendar life, safety, and cost.

The battery chemistries that have attracted the most interest and application for electric vehicles are lead acid (Pb-Ac), nickel metal hydride (Ni-MH), lithium metal, lithium ion, and lithium ion-polymer, and, to a lesser extent, nickel-cadmium (NiCd) and sodium nickel chloride (as in the Zebra battery). In earlier times, Pb-Ac was the only type of battery available for EVs. Its high weight and poor performance limited development of the EV industry. Some types of EV, especially low-speed vehicles, still rely on Pb-Ac, but the newer generation of hybrid EVs require substantially higher performance and have moved to Ni-MH. The energy storage requirements of the three main categories of EV discussed in this report are set out in Table 1 on the next page.[12]

As will be shown below, Ni-MH can meet the needs of HEVs and some PHEVs. However, pure battery BEVs and PHEVs with a longer electric-only range require the higher power characteristics of lithium-ion batteries.

Table 1. Energy Storage Requirements for HEV, PHEV and BEVs

		Power		Energy	
EV Type	Max. weight kg	Peak (min. kW)	Density (min, W/kg)	Storage capacity (min. kWh)	Density (min. Wh/kg)
HEV[a]	50	40-60	800-1200	1.5-3 [0.7][b]	30-60
PHEV[c]	120	65[d], 50[e]	540[d]; 400[e]	6[d]; 12[e]	50[d] 75[e]
FPBEV	250	50[f]; 100[d]	200[f]; 400[d]	25[f]; 40[g]	100[f]; 160[g]

a. Data for full-size hybrid
b. Minimum energy required to perform the electric launch function
c. Preliminary estimate of PHEV specifications
d, e Requirements for mid-sized PHEVs with electric ranges of 32 and 64 kilometres respectively
f, g Requirements for small and mid-sized FPBEVs with weight, performance comparable to similar size ICEVs; specifications for LSC and City EVs are approximately 10 to 25.

Lithium batteries were first introduced in the early 1990s and have evolved rapidly during the past decade. Many millions of small lithium batteries have met the demand for portable power for laptop computers, cameras, power tools, and many other devices. The requirements for EVs pose a different set of challenges. These include size, as large as 100 kWh and larger. This scale up demands a change in cell geometry from cylindrical to prismatic design to support the thinning of electrodes and cell components required for increased energy density. Battery management is critical, including control of cell charging and discharging as well as temperature control. Thermal management has been a major challenge for the industry especially after extensive media coverage of several spectacular fires in lithium-based laptop batteries. Battery pricing is the third major challenge the industry needs to address and there are issues too of calendar life, cycle life, and charge time.

Performance requirements for EV batteries

The main performance requirements of batteries and energy storage systems vary according to the type of EV, as outlined in Table 2.[13]

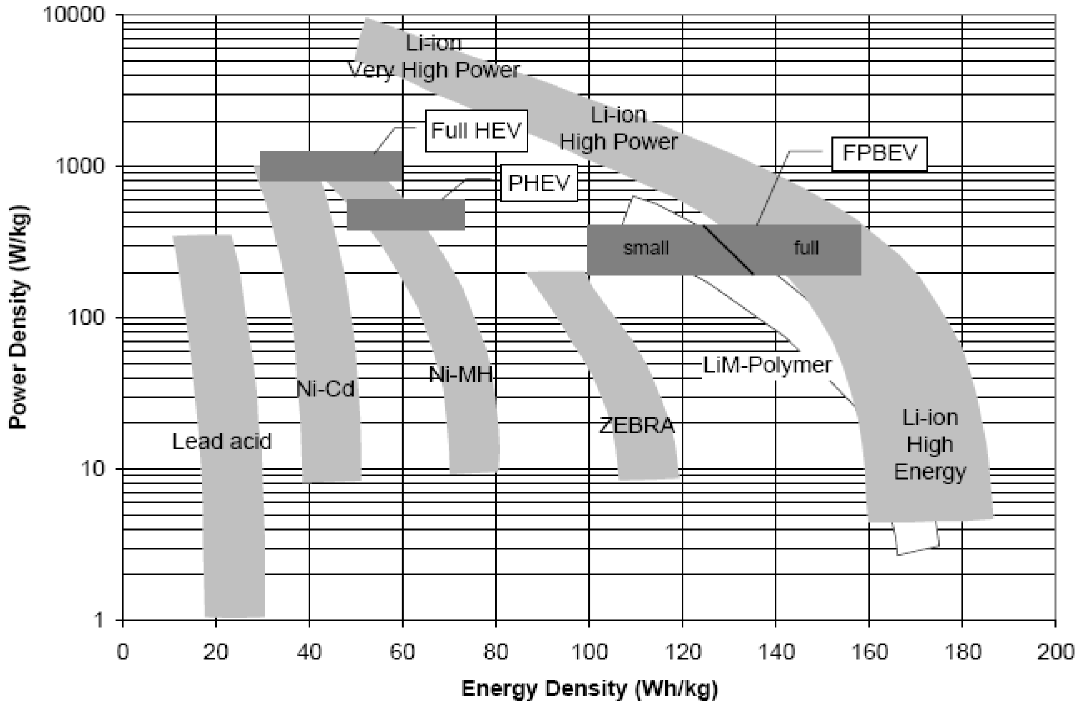
Table 2. Functional Requirements for HEV, PHEV and BEVs

EV Type	***Functional Requirements***
Micro HEV	Automatic start and stop plus regenerative braking
Mild HEV	As for micro HEV plus power assist to IC engine
Full HEV	As for mild HEV plus electric launch
Plug-in HEV	As for full HEV plus electric range and grid-charge capability
LSV and City EV	Solely electric propulsion power with grid-charged energy
FPBEV	As for LSV but with appropriately sized larger battery

Power vs. energy

Two key characteristics of EV batteries are power density, measured in W/kg, which is the rate at which energy can be delivered, and energy density, measured in Wh/kg, which is the total amount of deliverable energy. The former defines acceleration capability while the latter is an approximate measure of the vehicle range. How the two vary with each other in different batteries is shown in the Ragone Plot in Figure 2.[14] The breadth of each of the curves indicates different performance levels due to variations in manufacturing within a single family of devices.

Figure 2. Battery Performance Characteristics for EV Applications



For each battery chemistry, the Ragone Plot shows whether the various configurations can meet the performance requirements for the main EV classes of HEV, PHEV and BEV. While Ni-MH meets the criteria for HEV and some PHEV applications, lithium-based batteries are presently the only option that will satisfy the demands of both higher-performance PHEVs and FPBEVs. Figure 2 also shows the performance of the Zebra battery. This type of battery offers a reasonable level of energy and power density, but uses a molten salt electrolyte, sodium chloroaluminate ($NaAlCl_4$), that operates at a temperature of around 250˚C.

Several battery chemistries are not represented in Figure 2, including those that incorporate a zinc anode. Electric Mobility Canada (EMC) compared a nickel-zinc battery with many others and concluded that it had an energy density of 65 Wh/kg and a power density of 850 W/kg, the second highest among those tested.[15] The same assessment also examined zinc-air systems, which have some of the properties of batteries and some of fuel cells. These systems showed a relatively low power density (<300 W/kg), but by far the highest energy density (220 Wh/kg).

Commercial development

Nickel metal hydride (Ni-MH) is still the dominant battery technology for hybrids and is predicted to play a significant role in the development of HEVs and some PHEVs over the next few years.

However, Ni-MH offers insufficient power or energy performance to support larger PHEVs and the newer BEVs that are emerging. As well, there are intellectual property issues. Cobasys—formed from the merger of ECD Ovonics, developer of large format Ni-MH batteries, with Chevron—appears to have prevented newer EV companies gaining licenses to use the technology. The major OEMs had already secured licensing arrangements.

Pb-Ac still dominates the market for low-speed and City EVs, and Ni-MH may continue to dominate the hybrid market. However, the future of the EV industry will almost certainly hinge on lithium-ion technology and specifically on its ability to meet the numerous challenges outlined below.

Lithium battery chemistry

Lithium batteries are based on the highly electroactive nature of lithium in its metallic and ionic forms. By their nature, batteries are highly energetic items and present design challenges, especially in the scale-up to the larger format designs required for EV applications. Moreover, for these applications, even the lowest acceptable failure rate of batteries for computers and most other electronic equipment—one in several hundred thousand—is unacceptable.

Lithium-ion battery chemistry has evolved from lithium metal as the anode material to lithium ion intercalated (diffused) in a carbon host. The original lithium-ion chemistry that was based on cobalt oxide has now been largely superseded by chemistries that use inert materials such as lithium iron phosphate of mixed metal oxides and also by lithium polymer (Li-Poly) systems where the metal-salt layer is held in a sold polymeric matrix rather than in a liquid. This design allows very thin prismatic cells to be assembled, thus facilitating the design of larger format units (up to 100 kWh) suitable for EV applications.

After discovery that under certain conditions (see safety concerns below), cobalt-oxide-based cells (cobalt oxide is a highly pyrolytic material) could experience overheating and thermal runaway, various alternative chemistries have been developed. These include lithium iron phosphate, $LiFePO_4$, lithium manganese oxide $LiMn_2O_4$, and several mixed oxides, known as spinels. The formulations of most battery manufacturers are proprietary. Some of the materials that have been described include a lithiated mixed oxide of nickel, cobalt, and aluminum with approximate composition $Li(Ni_{0.85}Co_{0.1}Al_{0.05})_2$, and a mixed lithium nickel, cobalt, and manganese oxide, $Li(Ni_{0.33}Co_{0.33}Mn_{0.33})$.

Role of nanostructures

Recently there has been much interest in the application of nanotechnology structures applied to battery design, i.e. structures smaller than 100 nanometres (i.e., less than one ten thousandth of a millimetre). Use of such structures as electrode helps overcome lithium ion batteries' relative slowness to charge and discharge. Two groups lead these efforts: A123—an MIT spin-off funded by Motorola, venture capital Qualcom, and On Point (US Army Venture Capital group)—has developed a lithium iron phosphate battery claimed to provide twice the power density and five times the energy density of a regular lithium battery. This battery has achieved some commercial success. It has been selected by Chevrolet as a contender for the planned Saturn Vue and Chevy Volt PHEVs. Think Norway also plans to use an A123 battery.

The second player in the nanotech field is Altair Nanotechnologies, which has developed lithium titanate as an electrode material. Many of the rapidly developing battery companies in Japan, Korea , Europe and the U.S. (see Table 3) are likely also exploring this approach. There are disadvantages to nanotechnology chemistries: although highly reversible they can produce lower voltage and energy densities than competing lithium-ion polymer chemistries.

Calendar and cycle life

Batteries degrade during operation due to cumulative effects of changes in the battery cell chemistry and structure caused by repeated charge-discharge cycles. The most important parameters are cycle life and calendar life. USABC set a 10-year calendar-life target, but the California Air Resources Board's target is 15 years. As battery design and chemistry is a rapidly evolving field, and calendar-life measurement cannot be accelerated, these assessments need repeated revision. Calendar life measurements for NiMH batteries and early stage lithium cobalt oxide cells suggest that 10- and 15-year targets are readily achievable.

The battery cycle conditions for HEV and BEV operation are particularly demanding. HEV batteries are subject to repeated shallow charge-discharge cycles because, as soon as the electric power drive is initiated, the ICE acts via the generator to recharge the battery albeit usually at a lower rate than the discharge. In contrast, BEV batteries are required to sustain deep-cycle discharges and provide high energy density in order to maximize the interval between charges. PHEVs can require batteries meeting both shallow and deep charge-discharge cycles.

This situation is more complex than can be summarized here. Battery cycle and calendar life are critical parameters that affect battery pricing. They will be especially important for battery lease and exchange programs to operate effectively. (One of these is discussed below in Section E.)

Safety concerns

In 2006, the development of lithium batteries suffered a major setback with the occurrence of several spectacular laptop battery fires and resulting media coverage. It was mainly batteries containing cobalt oxide that caught fire; there were some instances involving batteries based on metallic lithium. The fires caused widespread concern in the battery industry, including restrictions on the bulk air transportation of lithium batteries. The problem was traced to a defect resulting from metallic impurities introduced during manufacture of the batteries. EV manufacturers considering use of lithium batteries had to embark on major safety evaluation programs.

Lithium ion polymer designs do not appear to present a fire hazard. Canada's Electrovaya has extensive video footage of its safety test protocol. This includes driving a nail through a fully charged battery pack and other tests designed to create short circuits. No problems were experienced. In EV applications, battery cooling, thermal management, and automatic shutdown circuitry can provide further security.

Price point

After safety, the most critical factor for EV batteries is cost. Because Ni-MH batteries are unlikely to satisfy the demands of some PHEVs and all FPBEVs, lithium ion polymer will likely be the technology of choice. The challenge will be to bring the cost of this technology down to a viable level. Pricing will involve several factors;

- Economies of scale as battery volume increase exponentially, including the impact of Asian manufacturers with lower labour costs;
- Potential technology advances making use of lower-cost materials;
- Increasing oil prices that help make battery prices competitive.

Battery price is usually stated in price per watt (actually watt-hour), one of two components of energy density (the other being weight). Thus, it is important to consider the energy densities achieved with different chemistries. Lithium iron phosphate (Valence, A123) presently delivers 100-120 Wh/kg. Electrovaya's lithium ion polymer technology delivers 180 Wh/kg. Lithium ion polymer is still an evolving technology and 200-250 Wh/kg may be achievable in the near to medium term. Discussions with industry representatives suggest that $0.50/Wh is a realistic target for large-scale commercial development of EVs. The CARB report[16] suggested that the unit price could fall to as low as $0.18/Wh. This would be for a 40-kWh battery manufactured in a facility producing 100,000 a year. The minimum unit cost falls with battery size, although not proportionately. Thus a 14-kWh battery produced under the same conditions would have a unit price as low as $0.30/Wh

A recent analysis suggests that for a compact PHEV with a 32-kilometre all-battery range, with electricity priced at $0.15/kWh and gasoline at a $1.04 per litre, the break-even cost for a 7-kWh battery would be $0.53/Wh.[17] The CARB report suggested that manufacture of such batteries in a plant producing 100,000 a year would cost $0.41/Wh. It rises less steeply than the price of gasoline and falls less steeply than the price of electricity.

The reasonable conclusion is that such PHEVs could already provide a financial advantage to owners if there were sufficient economies of scale in battery production.

Thermal effects

There are two aspects relating to temperature; first there is the operating temperature range for lithium polymer batteries and second, there is the management of the environment, both heating and cooling, inside EVs.

Lithium ion polymer batteries have served industries ranging from mining to aerospace where batteries may be exposed to a harsh operating environment. In space applications, for example, batteries may be required to operate at temperatures as low as -80°C, while in mining temperatures can be above +80˚C. Operating temperatures in Canada range from -40˚C (winter) to +65˚C (summer temperature under the engine compartment). Long periods of battery exposure to temperatures above +70˚C may cause degradation in charge capacity. In cold weather, the selfheating effect of battery operation can rapidly increase its temperature to well above the ambient level.

Another requirement is the management of heating and cooling in EVs. Vehicle heating is necessary in most Northern Hemisphere countries. Because heating-ventilating-air-conditioning (HVAC) systems are electrically powered they can reduce a vehicle's operating range. Planned solutions include more focused energy systems such as heated or air cooled seats and small, local thermal heaters.

Grid Connectivity

To the extent that vehicle batteries are charged from the grid, as in the case of PHEVs, there is interest in the extent to which this can be achieved without adding to electricity generating capacity. A recent analysis for California concluded the following: "If most PHEVs are charged after the workday, and thus after the time of peak electricity demand, … several million PHEVs could be deployed in California without requiring new generation capacity. … To ensure desirable outcomes, appropriate technologies and incentives for PHEV charging will be needed if PHEV adoption becomes mainstream."[18] The reference to 'appropriate technologies' is to "technical means to coordinate PHEV charging and electric power system operation". This could include 'smart charging'—as being studied by Pacific Gas and Electric Company[19]—which involves adjusting the charging rate for an EV according to the state of the grid power network, chiefly to reduce the rate during periods of high demand.

PG&E sees smart charging as one part, and the initial stage, of a more complex vehicle-to-grid (V2G) relationship in which each vehicle becomes a "remotely-controllable energy storage system". In Denmark's proposed Project Better Place program (see below), the plan is to store wind-generated energy in EVs' batteries during peak production, often at night, and feed it back during peak consumption.

Supercapacitors

Supercapacitors are high-energy-density capacitors—sometimes known as ultracapacitors—that act as high-capacity, short-term energy storage devices. They have also shown promise as intermediate storage devices used, for example, to buffer energy produced by regenerative braking and feed this to a battery or powertrain as required. General Motors has demonstrated a concept Saturn Vue Green vehicle that uses a lithium battery and a supercapacitor to give the vehicle an electric-only range of about 64 kilometres. This combination significantly reduces the size of the required storage system.

According to one informed observer of the Canadian scene, "Low cost continuous production of ultracaps by the method originally developed at Alcan could be Canada's best chance of a value added auto component given the lead held by others on lithium and motors".[20]

Zenn announced recently that it had invested in EEstor, a manufacturer of supercapacitors, and that it planned to use these systems in its next generation ZEVs. Zenn recently announced plans to launch in 2009 a highway capable version of its CityZenn vehicle with a top speed of 125 km/h. The company also has plans to offer drive-train kits to enable conversion of gasoline-powered vehicles to EVs.

Materials availability

Concerns have been raised about the long-term availability of lithium. A report by Meridian International Research claimed there are insufficient reserves to meet forecast demand.[21] Other reports cite massive reserves of spodumene (lithium aluminum silicate) in Chibougamau, Quebec (over 300,000 tonnes).[22] Meridian International Research claimed that processing of spodumene for production of battery-grade lithium is uneconomic, chiefly on account of its energy requirements. Today, battery-grade lithium is produced mainly from lithium chloride secured from salt lakes in the U.S., Chile, and Bolivia. The question of lithium availability requires further study (as may the availability of rare earths used in vehicle motor magnets[23]). Lithium in batteries is not consumed and is readily available for recycling at the end of the battery life.[24]

In another paper, Meridian International Research noted “Zinc production is the third or fourth highest of all metals and the only metal that can sustain large battery production in the volumes required by the global automotive industry.”[25]

Major players

The number of firms involved in advanced battery development has increased greatly during the last five years. Table 3 lists most of the major players outside China. In China, there are over 300 companies involved in the EV industry in various ways, including battery development, but only 100 or so are said to be licensed.

Table 3 Major Advanced Battery Manufacturers

Region	***Company***
Japan	▪ Toyota - Panasonic EV Energy – partnered with Matsushita Electric Industrial – plans to produce 200,000 NiMH batteries annually ▪ GS Yuasa Corp is partnered with Mitsubishi Motors Corp to develop Li-ion Nissan-NEC planned development of Li-ion including batteries for Project Better Place ▪ Automotive Energy Supply Corp is a joint venture between Nissan and NEX Corp that is developing Li-ion for Project Better Place ▪ Hitachi Vehicle Energy is developing Li-ion for GM 2nd generation hybrids ▪ Sanyo has partnered with Volkswagen Group to supply Li-ion and NiMH batteries
U.S	▪ A123 – has secured partnership with GM ▪ Altair Nanotechnologies – partnered with Impro Inc (Korea) to target local auto industry (Hyundai, Kia, Renault-Samsung, Ssangyong, GM-Daewoo) ▪ Valence – supplying Li-$FePO_4$ batteries to Tanfield Group (UK and Ford?) ▪ Johnson-Saft – Johnson Controls merger with Saft Advanced Power Solutions to provide both NiMH and next generation Li-ion for automotive sector ▪ Cobasys plans to supply NiMH to GM Chevy Malibu slowed by recall of batteries in existing Saturn Vue SUV and Chevy Malibu?
Europe	▪ Saft/Renault – in Europe Saft is partnered with Renault

	▪ Lithium Technology Corp – German manufacturer of large format Li-ion ▪ MES DEA SA, Swiss based supplies Na $NiCl_2$ Zebra battery ▪ Continental AG – with investment in Tokyo Li-ion start-up Enax is supplying hybrid drive to BMW and batteries to Mercedes
Canada	▪ Electrovaya Corp will supply its Li-Superpolymer batteries to US Phoenix Cars and also partnership agreements with Tata (India), Miljobil Grenland (Norway) and Bricklin Visionary Vehicles
Korea	▪ LG Chem – has US subsidiary, Compact Power, Troy, MI – contract with GM to provide Li-ion battery for E-Flex system (in Chevy Volt) ▪ Kokam (now div of Eagle Picher) – demonstration of lithium polymer (LiPo) in Smart EV
China	▪ BYD Auto (Div of BYD Group) plans launch of EV using $LiFePO_4$ battery by 2010 ▪ China BAK Battery developing Li-ion battery – possible outsource for North America, EU?

Three major North American players, A123, Altair Nano, and Valence have their batteries assembled in China, which brings the risk of compromised intellectual property and loss of know-how.

The way ahead

Batteries are the key to the future success of EVs. Lithium-ion batteries, specifically lithium-ion-polymer technology, is still early in its development path, with a possible doubling in present performance, with improvements in safety, longevity, and cost. Nanostructured electrodes may help satisfy needs for both high energy and high power requirements.

E. RECENT AND CURRENT MARKET TRENDS

There are signs that EVs are on the cusp of a major breakthrough, driven by some or all of the following factors:

- rising oil prices, and the insecurity of supply from regions of political and social unrest;
- major breakthroughs in enabling technologies, primarily batteries but also motors and control/drive-trains;
- the commercial success of hybrid EVs, despite questions over cost savings and CO_2 emission reductions, and its validation of the technical and economic viability of electric drive technology;
- serious interest by the major auto OEMs in all categories of EV—hybrids, plug-in and pure battery—and the emergence of over 30 start-up EV companies in the past few years;
- major investment in battery development for transport applications by more than a dozen major companies in Japan, Korea, Europe, and North America, with Chinese companies rapidly following;
- emergence of a new paradigm for public perception of the automobile – analogous to the cellular phone service business model as set out in Project Better Place (discussed below).

Industry Overview

The two elements of the landscape for the developing EV industry comprise battery developers (reviewed in Section D) and manufacturers of hybrids, plug-in hybrids and battery EVs. The latter element is considered here as three sectors: major auto industry OEMs, EV companies that have vehicles in the market or firm launch plans in 2008, EV start-ups that may have a concept vehicle but where market launch is still uncertain.

Auto Industry OEMs: the past year has seen some major advances in all of the three EV categories. The forecast in early 2007 that there will be over 50 hybrid models in the market by 2010 now needs to be refined into a projection of how these will be divided among regular HEVs, PHEVs, and BEVs. How this split will fall out and how the various players will share the EV market—estimated at $30 billion market in 2006 to rise to over $200 billion by 2015[26]—depends on many factors, some of which are discussed here.

Table 4 lists the top 20 OEMs with notes on their plans for developing HEVs, PHEVs or BEVs.

Table 4. EV Development Plans by Auto Industry OEMs

Company	***Sales 2006 million /units***	***Hybrid***	***Plug-in Hybrid***	***BEV***
Toyota	9.12	Over 1M units sold	Yes	Under development ?
General Motors	8.93	Saturn Vue BAS (Belt Alternate System(on Aura and Malibu models	Saturn Vue Green Line and Chevy Volt launch 2009	
Ford	6.27	Several models Fusion, Mercury Milan and Lincoln MKZ – use NiMH	Testing Escape with SoCal Edison – Toyota Synergy drive	
Volkswagen (Group)	5.68	Partner with BMW & Daimler to develop HEV		
Honda	3.67	No 2 in market 0.4M units sold	No interest – prefer to invest efforts in BEVs	Under development
PSA	3.36	Partner van with fuel cell range extender		Partnered Venturi for La Poste delivery vans
Nissan	3.22			Project Better Place – for Israel and Denmark
Chrysler	2.54	ENVI group started Sept 2007	Testing PHEV Sprinter van	GEM, LSV 40,000 units sold
Renault	2.49			Project Better Place – for Israel and Denmark – JV with Nissan
Hyundai	2.46	Accent hybrid I-Blue concept FCEV unveiled 2007		JV with Enova for BEV launch in Hawaii in 2009
Fiat	2.31		Fiat Multipla people mover	
Suzuki	2.30		Twin hybrid launch in Japan, NA by 2011 (supercapacitor intermediate energy storage?)	
Daimler	2.04	Smart EV		Collaboration with BMW, Continental AG
Mazda	1.40	3 models, Ibuku, Senku and RX-8		
Kia	1.38	Rio model hybrid		
BMW	1.37			Return of BEV Isetta? Partner with Daimler on battery devt
Mitsubishi	1.31			IMiEV planned launch 2008

AutoVAZ	0.77	Access via partner Renault	Access to Renault models	
Subaru	0.59			R1 Microcar available Japan – NA launch in 2009
Tata Motors	0.56	Indica and Nano versions planned		Active program to develop EVs – version of Indica and Nano?

For the first time since the California CARB initiative we are seeing serious interest in battery EVs being showed by the auto industry OEMs. At the 2008 New York auto show, Mitsubishi showed the iMiEV an all battery vehicle powered by four in-wheel hub motors. Subaru is also committing to introducing its R1 electric micro cars that are presently being fleet-tested by Tokyo Electric Power Company. However, Nissan may be the automaker in the best position to launch a mass-market electric vehicle through its alliance with Renault and their plans to sell electric cars in Israel and Denmark (see Project Better Place, below).

Market-ready EV start-ups: At the end of 2007, there were more than 30 EV start-up companies that provided hybrids, plug-in HEV conversions, LEVs or FPBEV products. In the first rank are listed groups that have EVs in the marketplace or firm launch plans, as well as substantial financial and resource support. This group includes Azure Dynamics, Bollore-Pinfarina, Commuter Cars, Dynasty Electric Vehicles, Electrovaya, Chrysler-GEM, Pininfarina-Bollore, Myers Motors, Smith Electric Vehicles, Tesla, Zenn, and Zap Motors. They are summarized in Table 5.

Table 5. Established and Start-up EV Companies

Company	*Vehicle/Type*	*Website*	*Status*
AC Propulsion	Leading EV designer control/battery systems eBox conversion	www.acpropulsion.com	Equpt suppliers Tesla, X-Box, Venturi
Azure Dynamics	Canadian manufacturer of custom HEV vehicles including taxis and buses – partnered with Ford and Fedex	www.azuredynamics.com	Several custom commercial HEVs` in market
Bollore-Pinfarina.	Bollore Blue car –produced by Pininfarina	www.pininfarina.com	Launch 2010
Commuter Cars	Tango model is concept car $39K up – to order	www.commutercars.com	2 years to launch
Dynasty Electric Vehicles	Range of BEV models –price $19,000	www.itselectric.com	Available
Think Global	Think City; original design by Ford; Li battery; LSV with predicted 175-km range	www.think.no	Planned launch in Norway, UK, and N. America during 2008.
Chrysler GEM	Earliest commercially available LSV	www.gem.com	Over 60K units sold
Cree Ltd	SAM EV - BEV 3-wheeler	www.cree.ch	Plan launch late 2008
Electrovaya Corp	Maya 100 Concept crossover SUV – plans to launch Maya 300 LSV late 2008	www.electrovaya.com	Launch 4th Q 2008
Hybrid Technologies Inc	Offering custom conversion BMW Mini and Mercedes Smart Car	www.hybridtechnologies.com	Custom orders now
Hymotion	Custom conversion of PHEVs	www.hymotion.com	Recently acquired by A123
Magna Corp	PHEV produced by Austrian Steyr Group	www.magna.com	Launch 2009?
Miles Electric Vehicles	2 LSV models plus XS500 FPBEV	www.milesev.com	Available – XS500 in 2009
Myers Motors	Single seat BEV model NmG	www.myersmotors.com	Available
Modec	UK based all-electric van	www.modec.co.uk	Available in UK
Smith Electric Vehicles	BEV 2 models, Edison All battery delivery vehicle – priced at $40K	www.smithelectricvehicles.com	Available UK, US launch in 2009?

Phoenix Cars	BEV Sport Utility Truck – partnered with Electrovaya	www.phoenixcars.com	SUT launched early 2008
Reva	LSV, Pb acid battery – price $7K to $9K	www.revaindia.com	Available India and UK
Tesla Motor	Custom sports car priced at $100K	www.teslamotor.com	Launch Q1 2008
ZAP Motors	Plans to import EVs from China – Xebra Company big on hype – short on delivery	www.zapcar.com	Xebra model problems of range and performance
Zenn Car Company	LSV sold in US market	www.zenncar.com	Available US and some Canadian provinces

Committed EV Companies: In the second tier of EV start-ups is a larger group that has a concept car and plans for market launch, or will produce specialist vehicles such as sports cars and some niche market EVs. Such companies are summarized in Table 6.

Table 6. Start-up and Committed EV Companies

Company	*Vehicle/Type*	*Website*	*Status*
Amer. Elec Vehicle	Kurrent – small golf cart design LSV cost $10,000	www.aevehicle.com	Various models to order
Canadian Electric Veh.	EV kit supplier	www.canev.com	Supply ca 1 kit/month
Elbil Norge	LSV – battery, similar to Think	www.elbilnorge.no	Available only in Norway
Fly Bo	Chinese made Smart car lookalike $13K	www.greatlakesautosales.net	Available now
Fisker Automotive	Luxury PHEV sports coupe	www.fiskerautomotive.com	Available late 2008
Gordon Murray Designs	City Commuter LSV (ex F1 Designer)	www.gordonmurraydesign.com	Tba 2009
Loremo	German 2 +2 diesel hybrid coupe	www.loremo.com	Launch tba 2009
Mindset	Swiss HEV coupe	www.mindset.com	2009
Lightning Car Company	Electric Lightning high-end sports car with a price close to $300K	www.lightningcarcompany.com	Available 2008 (date tba)
Obvio	Brazil made range of BEV micro sports car ($15-49K))	www.obvio.ind.br	Available from Zap? – proposed launch 2010
Tara	Tara Tiny – BEV competitor to Tata Nano – priced at Rps 90,000 ($2,500)	www.tarainternational.com	Available 2008?
Unicell	**Quicksider BEV delivery vehicle**	**www.unicell.com**	**Prototype being tested by Purolator**
Venture Vehicles	**Venture 1, futuristic, 3-wheel, tilting PHEV and BEV models**	**www.flytheroad.com**	**Launch tba 2009**
Venturi	**Fetish - $450 French high-end sports car**	**www.venturi.fr**	**Launch July 2009**
Velozzi	**PHEV X-prize contestant – 0 to 60 mph < 3 sec –partner IDC South Africa**	**www.velozzi.org**	**Custom order**
Wrightspeed	**X-1 Record breaking vehicle**	**www.wrightspeed.com**	**Custom – to order**
Spark Electric Vehicles	**Import range of Chinese LSVs and FPBEVs**	**www.smart-ev.com**	**Available**

Emergence of the Asian EV Industry

Table 5 and Table 6 do not address the Asian EV industries. There are at least 300 companies in China alone involved in EV development, with around 40 that are active in actual production of

The China Electric Vehicle Association (CEVA) lists over 40 companies as corporate members including manufacturers of e-bikes, scooters, cars, buses, and trucks, and their equipment suppliers. As well, CEVA lists over 60 industry experts as members. The Chinese auto industry sells 1.5 million vehicles internally (and some 10 million motorized bikes), while export levels are projected to reach two million by 2010.

EVs. Discussions with representatives of the Chinese EV industry suggest that there are no vehicles operating with lithium batteries at this time.

As with other key manufacturing sectors, the economic growth of Asia, especially the three billion populations and rapidly growing middle classes in China and India will have a major impact on the EV market. India has only a few companies actively involved in EV production. These including the Reva (also known as the G-wiz), which is sold too in London, UK, and several groups developing in electric auto-rickshaws, known as tuk-tuks. Tara International also has a concept EV, the Tara Tiny that aims to compete with the Tata Nano ICEV. It is priced at just under 100,000 rupees (about $2,450). Tara is partnered with Aucma, a leading Chinese electrical equipment supplier.

In contrast, China has embarked on a massive EV infrastructure development and is well on track to becoming the global leader in electric vehicle technology.

Project Better Place

Project Better Place (PBP) is an ambitious plan created by Silicon Valley entrepreneur Shai Agassi to create EV recharging grid networks. The PBP business model is designed to reduce oil dependence by creating a market for EVs through equipping metropolitan areas and eventually entire countries with networks of charging stations. Not only would PBP drive demand for renewable energy sources such as solar and wind it would also create a new model for selling cars and fuel. Nissan and its alliance partner Renault are PBP partners with plans to produce EVs on a commercial scale by 2011-12. The vehicle will be a battery version of the Renault Megane with an advanced lithium ion battery developed by Nissan and NEC of Japan. Apart from the CO_2 generated at the power plant—and in Israel (solar) and Denmark (wind) they would be substantially renewable, emission-free sources—the electric Megane generates zero CO_2 emissions compared to the 180 g/km for the conventional model.

In its PBP plan, Israel has committed to provide a network of 500,000 battery charging and replacement stations as well as charging points in public parking garages and along streets. Driving distances are relatively short, which alleviates the main concern associated with electric vehicles' inherently limited range. Some 90% of car owners drive less than 70 kilometres a day and the country's three largest cities are within 160 kilometres of each other; thus the issue of range vs. charging is not a barrier.

The Danish project would also involve around ½ million charging stations and 150 battery swap stations. Under the Agassi business model, EV owners would rent the battery and pay a fee based on distance driven; thus the age of the batter need not be an issue. Battery replacement should be at least as fast as filling a tank with petrol. Agassi claims discussions with over 30 countries are ongoing; Canada would not appear to be one of them.

Norway is also strongly pushing EV technology. The Think Global company is a major actor in the EV scene, as is Miljøbil Grenland, a subsidiary of Norsk Hydro (and also a partner of Canada's Electrovaya).

F. MARKET OPPORTUNITIES AND CHALLENGES

Introduction

The North American EV industry faces an impressive array of challenges and opportunities. On the positive side, there is an enormous groundswell of interest in clean, green transportation. This will reflect in a steadily increasing demand for electric vehicles. On the negative side for new market entrants, as well as threats from Asia and Europe, there is the emergence of the auto industry OEMs that are belatedly showing serious interest in both HEVs and BEVs. As Think Global's president has noted, the auto OEMs may be slow but they are not dumb. Nissan, Mitsubishi, and Fuji Heavy Industries (Subaru) have all made commitments to pure battery BEVs and Honda's CEO has said they may well skip PHEVs and move straight into BEVs. Many of the large number of planned HEVs that may ultimately end up as PHEVs. As Carlos Ghosn, Nissan's CEO, in announcing the company's plans to introduce an array of BEVs to the US market by 2012, noted, "what we are seeing is the shifts coming from the markets are more powerful than what the regulators are doing".[27]

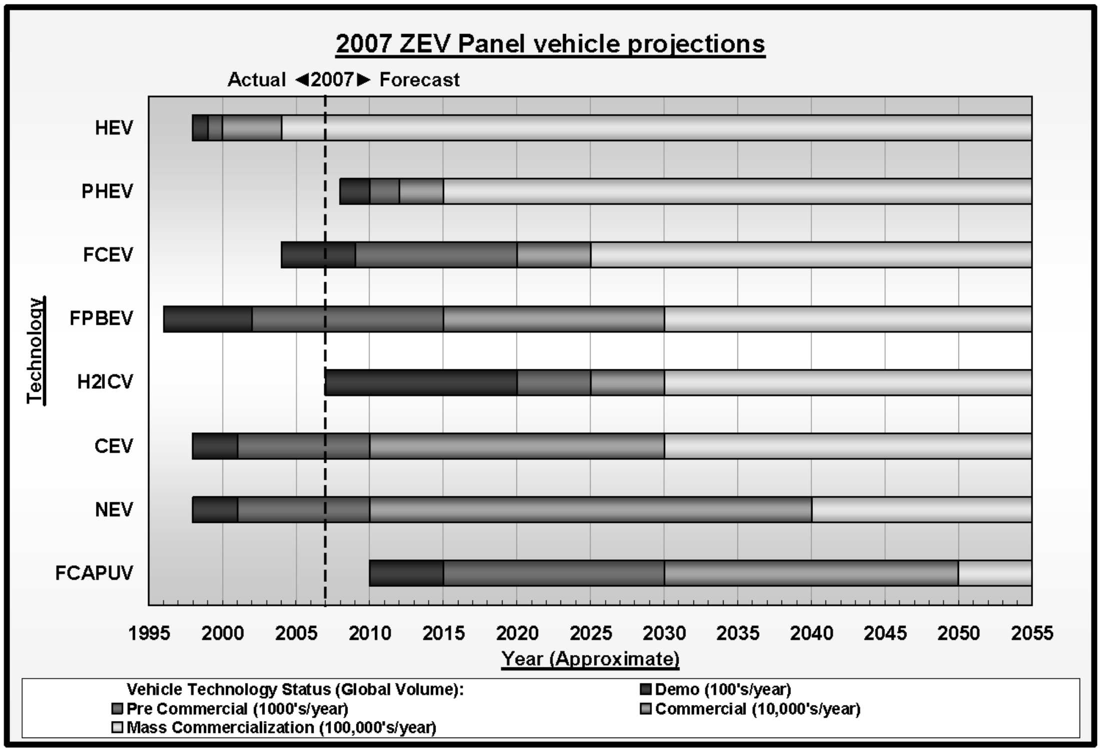
This situation can benefit the smaller EV players. First, there is the possibility of partnerships since the large OEMs are cutting back on their R&D budgets and becoming more likely to partner or purchase know-how. Second, there is a significant time window for the start-ups to grab market share while the OEMs are developing their plans.

Market forecast for main classes of EV

The CARB 2007 report defined the level of maturity for the various categories of EV to reach deployment as follows; 100s (demonstration), 1,000s (pre-commercialization), 10,000s (early commercialization) and 100,000s (mass commercialization. The figure below shows the forecast of the ARB Independent Expert Panel of prospects for various types of ZEV and PZEVs achieving the increasing levels of maturity.

Figure 3 is based on forecasts for HEVs and agrees with predictions by many industry analysts.[28] However, the timing of this report also coincided with some significant developments in both plug-in hybrid and battery EVs. Consequently, the forecast of the lead times when the PHEV and FPBEV categories reach mass commercialization is moot and the specific milestones may well be reached at earlier dates. These changes may also have a trickle-down effect on neighbourhood electric vehicles (NEVs) and City electric vehicles (CEVs).

Figure 3. Market Penetration for Major EV Categories



A major category of EVs not shown in Figure 3 is commercial electric vehicles including delivery vehicle, buses, and trucks. Smith Electric Vehicles (UK), with over 50 years experience in commercial EVs, recently launched two new vehicles, the Edison 3.5-tonne electric van and the Newton 7.5-tonne truck. Both vehicles have found strong market acceptance and Smith recently signed an agreement to share technology with Ford.

In Canada, Unicell has introduced a revolutionary new delivery vehicle, the Quicksider, presently undergoing pilot trials by Purolator. The Smith and Unicell vehicles are powered with Zebra batteries.

Carbon finance – emission credits in the transportation industry

An important financing mechanism for electric vehicles could carbon finance instruments. As the world moves towards stricter control of GHG emissions there are three ways in which such instruments facilitate the EV programs. The wider adoption of carbon tax mechanisms would make EVs more cost-competitive with ICE vehicles. There are also several areas where EV programs can qualify for emission reduction credits. These include the introduction of vehicle fleets using more energy efficient propulsion methodologies. Car rental companies and delivery/courier companies that use either hybrid or pure battery EVs could qualify for emission reduction credits based on their defined GHG reductions. The impact of taxes and credits would depend on their amounts and their method of application. Thirdly, sustainable transport solutions in developing countries can be supported by Clean Development Mechanisms.[29]

Carbon finance generally could assume an increasingly important role in funding the development of sustainable transport solutions.

The view from industry

> Hybrid technology is a very expensive way to save a small amount of fuel. The cost/benefit analysis is quite on the expensive side, but we're politically pressed to develop hybrids by the US market. If someone said that every car must be a hybrid, the car industry would be bankrupt quicker than anything else.
>
> Wolfgang Hatz, Chief engine designer for the Volkswagen Group[30]

EV World editor Bill Moore recently noted, "it took a war, a movie and oil at $100/barrel to revive the fortunes of the EV industry". Helped by some major breakthroughs in battery technology, HEVs and possibly PHEVs, as well as BEVs, now look set to meet a forthcoming market for more sustainable vehicles.

It is not clear how this market will shake out between HEVs, PHEVs, and BEVs The major OEMs have announced that over 50 new HEV models will be launched over the next 3-5 years but the big question will be how many of these will end up as PHEVs or BEVs. When Honda's CEO announced it would bypass PHEVs and move straight to BEVs, this was followed by a major press release by Carlos Ghosn on Nissan's plans to launch mass-market, BEVs worldwide. Referring to the PBP program and Israel's willingness to finance the infrastructure, Ghosn noted that "whoever puts the most incentive on the table is going to get the technology first". The Nissan business plan is to introduce close to 60 models worldwide by 2012. The EV versions would be supplied by alliance partner Renault and Nissan will provide the lithium ion battery packs. Nissan-Renault have also joined with India's Bajaj Auto with the goal of producing a $2,500 car to compete with the Tata Nano by 2011.

The economics of EVs is the key to success and, as VW Group engineering head Wolfgang Hatz has suggested, hybrids may be uneconomic to produce. A major problem for all EVs is that the cost of the battery still represents a high proportion of the vehicle cost. However, as battery prices come down and oil prices rise, EVs become more competitive.

One option as set out in the PBP program is a lease arrangement where the customer buys the car and leases the battery. Some indications of how this model might work were set out by Think Global's marketing director, Don Cochrane. The Think model is to sell the vehicle at a price of around $28,000 of which the battery cost is approximately $20,000. Customers would sign a contract to lease the battery at $200/month. This model is more attractive in Europe prices where, as Cochrane points out, many drivers pay $200 to fill their tank.

The question is how soon PHEVs and BEVs can secure a significant portion of the HEV market? While the automobile market is notoriously tough, there are still plenty of opportunities for smaller players and the rash of start-ups. Since OEMs typically do not produce much more than 20% of a new car in-house, there is a greater chance for outside groups to share technology. A good example is the Bollore Group, which has spent five years developing a BEV and recently signed a production/marketing agreement with Italian design house Pininfarina.

Electricity generation and provision: opportunities and challenges

In 2005, 60% of Canada's electricity was generated from renewable resources Among OECD member countries, Canada ranked fifth, behind Iceland and Norway (100%), New Zealand (65%) and Austria (63%). The OECD average was 15%. In three Canadian provinces, B.C., Manitoba, and Quebec, production from renewable resources is at or close to 100%. Almost all of Canada's current renewable generation is from hydraulic energy. There is substantial potential for much-increased generation from a wide variety of other renewable sources, notably wind and marine energy and also solar, geothermal, biomass, and other energy sources. Potentially, renewables could provide well over 100% of present electricity production.[31]

Thus, the opportunities to reduce greenhouse gas emissions through conversion to electric traction can be substantial. Making this possible in every province may require additional interconnection of provincial grids and even a cooperatively managed national grid that helps bind Canada during the 21st century as rail tracks did in the 19th century.

Also important is ensuring that vehicles can access the grid. This requires both widespread availability of charging outlets in public and private spaces and common connection standards.

Magna's next car to be powered by electricity
Leaps into environmentally friendly market with plans to build plug-in hybrid autos
Greg Keenan, Auto Industry Reporter, *Globe & Mail*, April 29, 2008

Magna International Inc. has joined the race to develop a plug-in hybrid car and plans to have a prototype on the road next year or in 2010.

Frank Stronach, founder of Canada's largest auto parts company, is looking to take advantage of the seismic shift to more environmentally friendly automotive technologies and play a key role as the industry works to design fuel-saving alternatives to the century-old internal combustion engine .

"You don't have to be a great scientist to know that we're going to be out of oil sooner or later," Mr. Stronach said.

New technologies such as hybrids offer a great market for Magna's parts and its ability to build complete vehicles, Mr. Stronach said in an interview, noting that cars with Magna-developed hybrid engines are already being tested in Europe.

That's where Magna is developing the plug-in hybrid, which runs mainly on electricity produced by batteries. That compares with current hybrids, which run mainly on gasoline supplemented by electric power generated through braking and batteries. Magna has also developed a hybrid that runs on compressed natural gas. [more]

G. MOVING FORWARD

Canada has many assets that favour development of EV technology. They include:

- Status as the world's major automotive manufacturer per capita
- Home to the world's premier grid-connected EV manufacturer (Bombardier)
- North America's major electric bus maker (New Flyer)
- North America's main domestic battery producer (Electrovaya)
- At least one prominent LSV manufacturer (Zenn).
- A high degree of urbanization and thus relatively short commutes and other intra-urban trips
- Much electric transit (half of transit journeys in five of the six largest cities are by electric traction)
- Perhaps the world's most diversified electricity supply
- Among the world's most renewable electricity supplies
- Huge opportunities for further renewable generation.

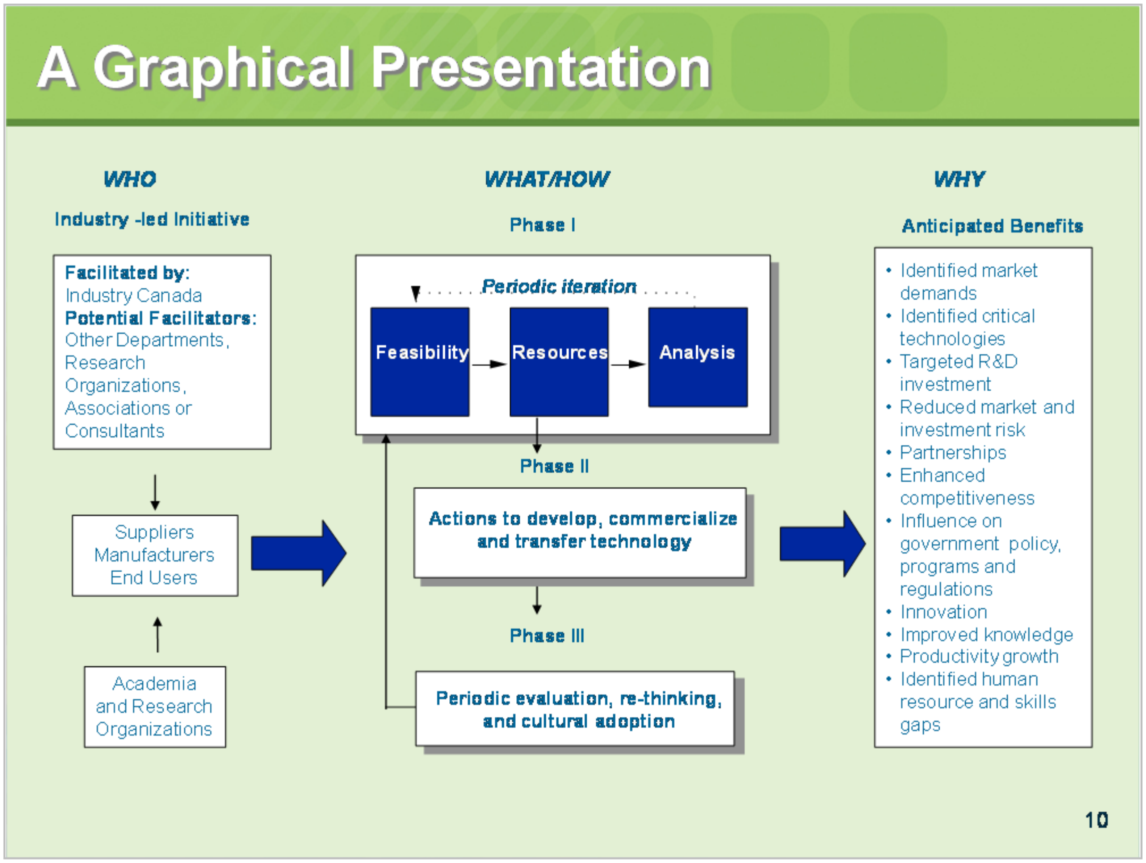
The primary requirement, perhaps essential for progress re. EVs in Canada, is for recognition by the Government of Canada of the kind provided by governments elsewhere. Below is an example of U.S. recognition of a Canadian EV enterprise.

Julie Rios, Director of Energy Initiatives, U.S. Postal Service, talks to President Bush about the Postal Service's 30 zero emissions electric trucks, which deliver mail in New York City. Energy Secretary Samuel W. Bodman looks on. The trucks were supplied by Azure Dynamics. (PRNewsFoto/U.S. Postal Service)

A second requirement, perhaps associated with the first requirement, is for a Canadian Electric Vehicle Technology Institute that could bring together and foster research and development in EV technology and nurturing of the necessary skills and analyses.

An essential step too is development of a Technology Road Map (TRM) for the EV industry. This requires collaboration among partners with common innovation goals. The objective is to grow the Canadian industry through increasing its competitiveness. Roadmaps involve planning, industry-led ownership (of the TRM) and a collaborative approach. Deliverables will be a process flow document that sets out the who, how and why of the TRM process, which should be driven by industry (see Figure 4[32]). Canada carried out a similar move in promoting the hydrogen fuel cell industry and built up Ballard Corporation as a world-class player. An initiative to support EV manufacturers, possibly a consortium of them, could help Canada secure a world-class presence in the EV industry.

Figure 4. Activities needed to prepare a TRM framework



The following are some key tasks that might be considered for inclusion in the work plan of a TRM process:

- Identify all stakeholders: firms, agencies (federal, provincial, and local), industry associations, NGOs.
- Identify potential centres of excellence, e.g., Auto 21, The Centre for Sustainable Transportation (University of Winnipeg), GM of Canada's Centre of Excellence (Ontario Institute of Technology).
- Identify and locate core competencies in electrochemical and electrical engineering, automotive, including fuel cells, batteries, electrical power engineering.
- Facilitate closer collaboration among the various organizations promoting sustainable transportation; these include the Vancouver and Ottawa chapters of the Electric Vehicle Society of Canada, a private-member society, and Electric Mobility Canada, an industry association with some private members.
- Assess ways of increasing support for EV R&D.
- Explore necessary legislative and other changes required to ensure adequate domestic markets for all types of EVs.
- Define future markets relevant to a Canadian EV industry.

H. GLOSSARY OF TERMS

BEV	Battery powered electric vehicle
BBD	Billion barrels per day – a measure of crude oil production
CEV	City electric vehicle
C-Rate	Expresses the performance of a battery during discharge – for example a battery with a 10amp hour (Ah) capacity discharging at 1C will discharge in 1 hour, at a C/3 rate it will discharge in 3 hours
EM	Electric motors
EV	Electric vehicle (generic term for all electric powered vehicles, but most commonly referred to pure battery vehicles, BEVs, or ZEVs)
FCEV	Fuel cell electric vehicle
FPBEV	Full performance battery electric vehicle – one capable of operating on all highways
GHG	Greenhouse gases, most commonly referring to carbon dioxide
HEV	Hybrid electric vehicle, most commonly comprising a gasoline
ICE	Internal combustion engine
KW/h	Kilowatt hour – indication of battery capacity
Li-Poly	Lithium ion polymer battery/ chemistry
LSV	Low speed electric vehicle
NEV	Neighbourhood electric vehicle sometimes referred to as a City EV, low-speed EV or a quadricycle;
NiMH	Nickel metal hydride battery/ chemistry
NOx	Oxides of nitrogen, formed as pollutants in combustion of gasoline (often along with particulate emissions known as SOx and NOx)
OEM	Original equipment manufacturer, i.e. major established automobile industry companies (top 20l)
PHEV	Plug-in hybrid electric vehicle – a HEV that is able to charge the battery via mains power supply
PZEV	Partial zero emission vehicle (category of low emission vehicle)
SOx	Oxides of sulphur, typically formed as pollutant in combustion of gasoline
TCO2E	Tons CO_2 equivalent
Wh/kg	Watt hours per kilogram – a measure of the charge capacity carried by a battery.
ZEV	Zero emission electric vehicle

I. STEERING COMMITTEE

Bibeau,Eric	University of Manitoba
Bundy, Ken	Canadian Auto Workers Union (CAW)
Clifford, Ian	Zenn Motor Company
Cormier, Al	Electric Mobility Canada
Das Gupta, Gitanjali	Electrovaya
Elwood, Mike	Azure Dynamics
Lavallée, Pierre	Centre d'expérimentation des véhicules électriques du Québec (CEVEQ)

Martin, Roger	Unicell
Molinski, Tom	Manitoba Hydro
Odell, Tom	General Motors
Oliver, Bob	Pollution Probe
Pattee, Wyman	Ford of Canada
Roy, Serge	Hydro-Québec
Shearman, Tim	Canadian Automobile Association (CAA)
Viola, Serge	Purolator Courier
Wu, Walter	Delaware Power Systems

J. FEDERAL SECRETARIAT

Beck, Nick	Natural Resources Canada
MacIntyre, Ian	Natural Resources Canada
Marrone, John	Natural Resources Canada
Olsen, Cheri-Ann	Natural Resources Canada
Thibodeau, Charles	Natural Resources Canada
Zhang, Merrina	Transport Canada

K. END NOTES

1 Vancouver has just renewed its fleet of 228 trolley buses. The future of Edmonton's fleet of 98 trolley buses is in doubt. Twelve Canadian other cities had and have discontinued trolley bus services. Most services ended during the period 1965-1975. Those in Hamilton and Toronto continued until 1992-1993.

2 The analyses include two books published in 2008: *Transport Revolutions: Moving People and Freight without Oil* by Canadian authors Richard Gilbert and Anthony Perl (Earthscan) and *Plugged In: The End of the Oil Age* by Belgium-based UK author Gary Kendall (WWF–World Wide Fund for Nature).

3 Information about the Avicenne market EV survey is at http://www.reportbuyer.com/automotive/misc_automotive/hybrid_electric_vehicle_market_2005_2015.html.

4 Information about the Research and Markets EV survey is at http://www.researchandmarkets.com/reportinfo.asp?report_id=336156&t=d&cat_id.

5 Information about the Research and Markets EV survey is at http://www.researchandmarkets.com/reportinfo.asp?report_id=336156&t=d&cat_id.

6 The Freedonia EV survey is detailed at http://www.freedoniagroup.com/DocumentDetails.aspx?ReferrerId=FG-01&studyid=2108.

7 The MarketResearch.com Web site is at http://www.marketresearch.com/browse.asp?categoryid=873&g=1.

8 The Freedonia US battery survey is detailed at http://www.freedoniagroup.com/DocumentDetails.aspx?DocumentId=46888.

9 The Freedonia China battery survey is detailed at http://www.freedoniagroup.com/DocumentDetails.aspx?DocumentId=46887.

10 The Freedonia world battery survey is detailed at http://www.freedoniagroup.com/DocumentDetails.aspx?DocumentId=46827

11 U.S. Department of Energy, *USABC – Electric Vehicle Battery Test Procedures Manual*, Revision 2, l996. Available at http://avt.inel.gov/battery/pdf/usabc_manual_rev2.pdf.

[12] Table 1 is Table 3-2 of Kalhammer, FR et al, *Status and Prospects for Zero Emissions Vehicle Technology: Report of the ARB Independent Expert Panel*. State of California Air Resources Board, Sacramento, CA, April 2007. Available at http://www.arb.ca.gov/msprog/zevprog/zevreview/zev_panel_report.pdf.

[13] Table 2 is Table 3-1 of the source detailed in Note 12.

[14] Figure 2 is Figure 3-1 of the source detailed in Note 12.

[15] *Preliminary Analysis of eVionyx Ni-Zn Battery and Zn-Air Fuel Cell*, Electric Mobility Canada, St. Jérôme, Québec, December 2006.

[16] The CARB report is detailed in Note 12.

[17] Lemoine, DM, et al. An innovation and policy agenda for commercially competitive plug-in hybrid electric vehicles, *Environment Research Letters*, 3 (January-March 2008) doi:10.1088/1748-9326/3/1/014003. Available at http://www.iop.org/EJ/article/1748-9326/3/1/014003/erl8_1_014003.html.

[18] See the source detailed in Note 17.

[19] For PG&E's strategy for smart charging and V2G see http://www.pge.com/about/news/mediarelations/newsreleases/q3_2007/070912.shtml.

[20] E-mail from Nigel Fitzpatrick to Richard Gilbert, June 13, 2008.

[21] Tahil, W, *The trouble with lithium: Implications of future PHEV production for lithium demand*. Meridian Research International, Martainville, France, 2007. Available at http://www.reveo.com/us/node/332.

[22] E.g., *Canadian Minerals Yearbook*, Natural Resources Canada, Ottawa, Ontario, 2005, pp. 31.1-31.4. Available at http://www.nrcan.gc.ca/mms/cmy/content/2005/35.pdf.

[23] See *From the ground up—A miner's view of the rare metals*. Presentation by Avalon Ventures Ltd. at http://www.avalonventures.com/_resources/Barcelona_presentation.pdf.

[24] What is claimed to be the only plant in the world that can recover lithium from all sizes of battery is located in Canada: that of Toxco, in Trail, B.C. See http://www.toxco.com/processes.html.

[25] Tahil, W, *The zinc-air battery and the zinc economy: a virtuous circle*. Meridian Research International, Martainville, France, 2007. Available at http://www.reveo.com/us/node/332.

[26] The estimate of market growth is in the source detailed in Note 5 and associated text.

[27] The quotation from the speech of Carlos Ghosn is at http://www.nytimes.com/2008/05/13/business/13auto.html?_r=1&partner=rssuserland&emc=rss&oref=slogin.

[28] Figure 3 is the unnumbered figure on Page 12 of the source detailed in Note 12.

[29] For information about Clean Development Mechanisms, see http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php.

[30] The quotation from an interview with Wolfgang Hatz is at http://plugsandcars.blogspot.com/2007/11/from-fahrvegngen-and-fuhgedaboutit-v.html.

[31] See Tampier, M, 'Renewable energy: Opportunities in power generation'. Paper given at the National Energy Board's Energy Futures Workshop, January 2008. Available at http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/nrgyftr/cnslttnrnd3/martin_tampier.pdf.

[32] Figure 4 is from Industry Canada's Web site at http://strategis.ic.gc.ca/trm.