Towards an Ontario Action Plan For Plug-In-Electric Vehicles (PEVs)

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Preamble

Ontario Government Policy (July 15, 2009) sets the framework and context for developing the next steps of a plan that would deliver on a vision of sustainable mobility for Ontarians and, specifically through introduction of plug-in hybrid and battery electric vehicles (PEVs). The policy is as follows[1]:

A Plan For Ontario: 1 In 20 by 2020 (Passenger electric vehicles)

- A rebate will be available for plug-in hybrid and battery electric vehicles purchased after July 1, 2010 and will provide between $4,000 and $10,000 towards the purchase of an electric vehicle depending on the vehicle's battery capacity.
- Green license plate will permit use of High-Occupancy Vehicle (HOV) lanes for a limited time (5 years starting 2010), even if there is just one person in the vehicle.
- Twenty per cent of eligible new Ontario Public Sector passenger vehicle purchases will be electric by 2020.
- Ontario will build infrastructure for charging electric vehicles through a combination of private sector companies and Ontario's existing electricity utilities.

We acknowledge that beyond PEVs, electrification of transportation also involves mass transit, ports and medium and heavy duty vehicle electrification such as trucking stops and stations for large fleets. In this report, we focus on the issues as they pertain to plug-in electric vehicles that comprise the light duty vehicles share of the transport sector.

[1] http://news.ontario.ca/mto/en/2009/07/a-plan-for-ontario-1-in-20-by-2020.html

Executive Summary

Given Ontario's generation mix, especially after coal plants are phased-out, migrating to electric vehicles in the transportation sector makes overall economic and environmental sense in the long term. We have conducted a comprehensive multi-disciplinary study to assess the implications arising from adoption of plug-in hybrid and electric vehicles (PEVs) in Ontario on a large-scale. We highlight potential concerns that need to be addressed but focus on specific measures, approaches and policy initiatives relevant to the Ontario context. We have drawn from the existing knowledge base[2] and available data worldwide for insights, but with a view to applicability for Ontario. The study goes one step beyond a road map exercise to provide some firm answers based on our analysis of the Ontario system. In addition, we have identified barriers and issues that need to be addressed, provide some recommendations and where gaps exist in the knowledge base, and suggest a path for R&D if appropriate.

The report is structured in the following main tracks:

1. *Auto Sector Developments and Needs*: In this chapter, a review is provided of the current state of the art, the evolution of key enabling technologies and some of the technological challenges and barriers for large scale implementation of PEVs in Ontario. The focus is on battery technologies and hybrid vehicle architectures and in the identification of some of the key technical, environmental, and social aspects of these technologies. Challenges in the consumer acceptance of these vehicle technologies are also identified because they will impact how fast they would be adopted or not.
2. *Electricity Sector Development and Needs*: In this chapter, a detailed review and analysis of the relevant issues and related literature associated with the impact of PEVs on Ontario's grid and electricity market are presented. All pertinent issues related to the impact of PEVs on Ontario's generation, transmission and distribution systems as well as the associated electricity market, and the effects and limitations on the adoption of PEVs in Ontario of these systems and market are discussed in detail. Thus, the chapter is divided in four main sections, each discussing respectively the interplay of PEVs and generation plants, PEVs and the

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[2] An excellent high level summary of the current status for the Canadian context is "The Electric Technology Road Map for Canada," developed by Electric Mobility Canada for Natural Resources Canada, February 2010.

transmission system, PEVs and distributions networks, and PEVs and the electricity market, in general as well as in the particular case of Ontario.

3. *Consumers, Communities and Markets*: The purpose of this chapter is to identify the "non-technical" barriers and policy issues related to the implementation of PHEVs within the Province of Ontario. A range of issues are presented, and within each, we draw upon work in other jurisdictions and begin to "bring the issue home," i.e., to identify the implications for Ontario and to recommend strategies to reduce, or ideally to eliminate, the particular barrier. Early attention to this emerging agenda that we sketch out would, we believe, serve Ontario well in the longer-term.

The report closes with the main conclusions and recommendations resulting from the analyses and discussions presented throughout the document. Particular emphasis is put on identifying the most relevant issues to Ontario that may facilitate or hinder the adoption of PEVs in the Province, from the technical, consumer, policy, regulatory and market points of view. Specific recommendations to address the gaps are made, including the identification of areas where R&D investments may be necessary in the context of Ontario to allow a smooth transition from gasoline to electrons in the Province's transportation sector. The following is a summary of the main conclusions and recommendations:

Infrastructure Issues:

- Large-scale adoption of PEVs across Ontario will certainly not happen overnight. Even with the existing incentives and continued support by key stakeholders, it will take anywhere from 3 to 5 years for PEVs to begin to assume any noteworthy share of the market and longer for a critical mass to emerge.
- Development of the necessary infrastructure needs to be targeted at specific segments in different communities and regions and over different time frames, since adoption rates will vary from one region and municipality to another.
- Detailed assessments of market potential will be required and coordination of activities amongst planning agencies, utilities and auto manufacturers based on sharing of results will be necessary to ensure the requisite infrastructure is in place when needed.

- For the 2010-2015 timeframe, charging needs can be managed with existing options without significant disruption. Beyond 2015, the planning process, further informed by emerging data on consumer acceptance, would be expected to address future needs.
- There are no significant installation and operation challenges and costs for Level 1 overnight charging.
- An upgrade to the Level 2 home garage charger could be provided either at a small cost (or as an incentive) to the first adopters. The cost of the equipment and the installation could be shared between the utility and the customer or the auto maker.
- Level 3 fast charging capability will be necessary for those customers who opt for it. The technology is under development, but this premium service option, when available, can be targeted at those willing to pay for it.
- The utility should install override controls (with customer agreement) and encourage the customer to charge at times when it is best from a utility operations perspective, based on established programs such as the Peak Saver program for demand response.
- Workplace charge stations will be necessary to develop consumer acceptance of PEVs. The cost of installation and electricity use can be recovered in a number of ways, such as including it as part of the monthly parking fees paid by individual users; payroll deductions or within the employee's benefits package.
- Public charge stations installed in high traffic zones can provide all three options for charging but at different prices. The public installations could be led by either a utility-municipality partnership or private sector entity investment.
- Region-specific or neighborhood specific "maps" of vehicle purchases and demand for charging stations need to be developed. These "maps" will aid in understanding where clusters are emerging, to minimize problems for utilities and to pin-point location of charging points.
- Even though the grid and electricity market are currently able of supporting some level of PEV charging, significant PEV penetration levels will definitely impact the grid and its associated electricity market. Thus, careful planning will be required for a successful transition to PEVs.
- Our analysis shows 10-15% penetration of PHEVs in the light-vehicle transportation sector will have a minimal effect on the grid and electricity prices, as long are charging takes place

at night (off-peak hours). This will likely be the case for some time after the introduction of PEVs in the market in the next 3-5 years.

- Vehicles should be preferably charged at night; this will even have a positive effect on grid operation by reducing the growing generation dispatch problems in Ontario at base-load conditions.
- Charging of PEVs during on-peak hours will have a significant effect on the grid that will have to be planned for, especially in highly populated areas such as the GTA where PEV concentration and early adoption may be significant.
- With wider adoption of PEVs, grid planners will not only have to consider the additional PEV-charging load for system planning but also be aware of formation of geographic "clusters" with the potential for negative impacts on the system.
- A renewed emphasis on planning, with a special focus on understanding growth of clusters, will be necessary to ensure requisite infrastructure is developed to meet the needs in the 5 to 20 year timeframe.
- The projected levels of PEV adoption would not threaten the stability of the electric grid as long as a good proportion of the chargers are "smart" and the utility has some override capability over PEV charging. Whether this becomes an impediment to consumer acceptance needs to be established through additional studies.
- To mitigate and manage the impact that high penetration and concentration of PEVs, "smart charging" strategies and technologies will have to be developed and deployed. This will facilitate the charging of vehicles at certain desired hours such as off-peak hours and/or during high wind or solar generation outputs.
- Smart charging technologies will require the availability of smart grid infrastructure that permits two-way communication among the IESO, LDCs and PEVs. Thus, smart grids need to be planned and developed considering PEV charging as an integral part of the load and the associated energy management systems in households and buildings.
- In the short term, incentives to shape the load curve could include the provision of free home and public charge spots, as well as free or cheaper electricity at off peak times to allow for a capital deferral strategy for investment in the grid.
- With high penetration of PEVs, even if all charging takes place at night, there will be upward pressure on electricity prices. If these prices are conveyed in a timely manner to the PEV

owner and/or smart charger, then optimal charging decisions can be made, thus "discouraging" charging at high-price hours while "encouraging" charging at low-price hours.

- Vehicle-to-Grid (V2G) as well as Vehicle-to-House (V2H) technologies present many potential advantages to the grid such as voltage and frequency regulation, as well as providing energy storage for wind and solar power generation. However, these technologies will not be economically feasible until several of the issues with batteries are resolved. Since battery and smart charging and grid technologies will likely improve in the long-term, R&D on technologies is needed now to be ready for deployment.
- Standards for PEV charging devices, installations and communications are currently under development by a variety of institutions. These communication standards will be very much dependent on the standards finally adopted for smart grid applications, which are currently under debate. However, the majority of Smart Grid device developers and manufactures are leaning towards the adoption of ZigBee communication profiles and WiFi technologies for home area networks.

Institutional Aspects:

- We recommend a "champion" agency should be identified and empowered to ensure the policy goals can be attained.
- To promote sustainable mobility, the planning efforts must also address social science issues such as urban land use, transportation infrastructure investment, parking and charge stations and strategies for reducing congestion such as promoting public transportation and bike lanes.
- The lead agency would work with all stakeholders to develop a clear set of regional plans for implementing the electric mobility initiatives. This would include the purchase and/or lease of vehicles, the early enablement of construction of charging stations and the creation of incentive packages in preparation for large-scale roll-out.

Consumer Issues:

- Fuel costs strongly favor PEVs with a per kilometer cost estimated to be 3 to 5 times lower than for a standard gasoline vehicle. The capital costs, however, are higher and require significant further development for full commercial feasibility.
- The up-front higher cost issue will require a policy response and a detailed consideration of the credits that may accrue through reduction of the externalities imposed by GHG emission and air pollution. These additional costs will likely decline with greater uptake.
- To overcome customers' reluctance to the higher initial capital costs for the vehicles, partnerships with financial institutions and automobile dealers need to be developed so that low-interest loans for plug-ins, based on projected lower operating costs from gas savings, are offered.
- A business strategy is needed to capture all key incentives such as vouchers for home chargers, coupons for free off-peak electricity, and other rebates, which could be bundled at the time of purchase so that the capital cost barrier is lowered to the greatest extent possible.
- There is a need to balance "consumer" and "fleet" approaches for early investment in new vehicles. A fleet-driven approach must consider what mechanisms would contribute to eventual "spillover" into a mass market. A consumer approach may wish to target high fuel consumption users to improve charging point profitability.
- Specific actions can be taken so that consumers can effectively become a part of the PEV-transition. For example, the concepts of sustainability and environmental stewardship can be made more tangible by providing visible benefits, including, for instance, preferential parking locations (similar to disabled access) or free downtown parking, access to HOV lanes and reserved airport parking.
- Education plans for consumers, municipal governments, local business and utilities should be created. These would including test drives and develop "quick lease" options for individuals and fleet consumers through effective partnership with financial institutions.

Auto Sector Challenges and Battery Issues:

- High battery costs and uncertainty in key parameters render consumers, automakers, and utilities unwilling to assume the risk of ownership. Thus, issues related to batteries have implications for all aspects of the chain.

- There is a strong need to improve battery durability with thermal issues becoming much more critical as energy and power densities are increased. The most important component of the PEV is the battery pack that influences the primary cost, range, and weight.
- One promising feature of a limited range PEV (< 100 km in an all-electric mode) is the fact that it meets the needs of most urban and sub-urban families for most of the time. For an extended trip, the range anxiety is diminished by the fact that the vehicle can be operated by in a hybrid mode supported by a "conventional" gasoline engine.
- The size of the battery back and its cost can be optimized to cater to the needs of most of the consumers. For this consumer segment, charging at home during off-peak hours with low cost electricity and without any requirements for major electrical upgrades to the home is a positive feature that would enhance acceptance.
- The low-daily-mileage characteristic of current drivers is why PEVs have potential to displace a large fraction of per-vehicle petroleum consumption. Studies are needed to provide Ontario relevant estimates of the magnitude of this petroleum displacement benefit.
- Customers with higher expectations for a vehicle to be used to drive longer distances and desire to charge as a faster rate will require batteries capable of a high recharge rate, upgrades to the home outlets and an appropriate refueling infrastructure away from home. This is a challenge that needs to be addressed through technology developments to ensure that rapid recharge does not have an unacceptable impact on battery durability and performance.
- In the present market and technology development context, the economic competitiveness of long all-electrical range vehicles (> 200 km) appears questionable, requiring a wide deployment of a rapid-recharge infrastructure. The battery in this case is expensive, and without significant incentives or additional benefits may not have great appeal to the consumer.
- More accurate life-cycle analyses are needed to better guide decision makers considering PEVs in transportation strategies. The potential of post-PEV battery repurposing for grid applications such as ancillary services and backup power require more detailed life-cycle analysis as well as demonstration projects in order to better assess the viability of these applications.

- Better, higher fidelity, modeling and in-field data for PEVs is needed. Of particular importance to fill a notable void in understanding is the need to determine the actual drive cycles of drivers in Ontario. This also included assessment of the interaction of driver habits with various PEV components.
- The challenge of the battery will continue to be the dominant considerations in realizing the vision of sustainable mobility through electrification. Besides the technical barriers that need to be overcome, especially if V2G/V2H applications are to be considered, there is a role for business models to help reduce some of the adoption barriers over time. Some of the main business models identified include: battery leasing; mobile phone-style transportation contracts; vehicle leasing; and car-clubs.
- Current battery designs and regulations result in over-design relative to an optimal case that would promote a faster adoption of PEVs. Possible solutions to address this issue include: promote early battery replacement by changing the battery design requirement; promote a strong secondary use market with applications in the utility T&D sectors; develop technical and economic research to quantify key life-cycle parameters; and allow utility rate-basing of battery purchases for key grid applications.

Acknowledgments

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CHAPTER 1 – INTRODUCTION

1. Background

The University of Waterloo, through the Waterloo Institute for Sustainable Energy (WISE), has brought together a research team to conduct a comprehensive multi-disciplinary study for the Ontario Centres of Excellence - Energy (OCE) to foster adoption and large-scale implementation of Plug-In Electric Vehicles, i.e., Plug-in Hybrids Electric Vehicles of PHEVs, Extended-Range Electric Vehicles or E-REVs, and Battery Electric Vehicles or BEVs, hereafter referred to as PEVs, in Ontario. The study has been prepared on behalf of a large number of key stakeholders in Ontario who have an interest in promoting sustainable mobility through electrification; the list of the participating stakeholders is provided in Table 1.1. A pictorial view of the key stakeholders who will either be influenced by the plan or drive the action plan for Ontario include utilities, the auto sector, government agencies, manufacturers, industry partners, consumers and financing entities is shown in Figure 1.1.

Table 1.1
Participating stakeholders on sustainable mobility through electrification in Ontario.

ORGANIZATION
AUTO21 NCE
Better Place Canada
BMO
City of Hamilton
City of Toronto Fleet Services
CrossChasm Technologies
ecamion
Electricity Distributors Association
EnerMotion Inc
Environment Canada
EverGreen Energy Corp
Fleet Challenge Ontario
Fleet Management Centre
General Motors of Canada
H2Green
Hydro One Networks Inc.
Independent Electricity System Operator (IESO)
Intellimeter Canada Inc.
LeapFrog Energy Technologies Inc
Ministry of Economic Development and Trade
Ministry of Energy and Infrastructure
Ministry of the Environment
Ministry of Transportation
Ontario Centres of Excellence
Ontario Power Authority
Ontario Power Generation Inc.
Partners + Edell
Pollution Probe
Terra Power Systems Inc.
Toronto Atmospheric Fund
Toyota Canada Inc
Veridian
Virelec Ltd
Xstrata Canada Corporation

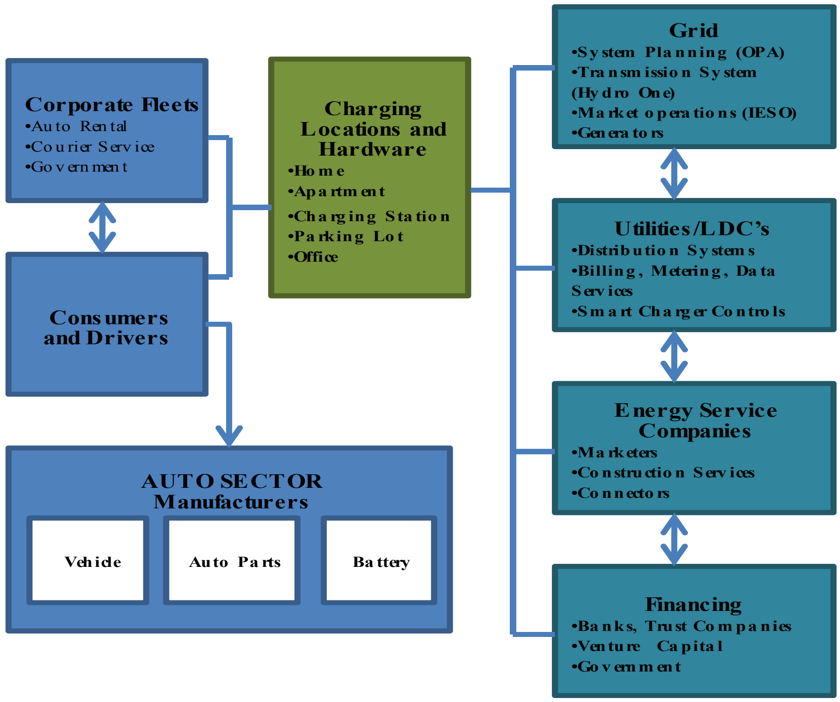


Figure 1.1. Key stakeholders of Ontario's PEV action plan.

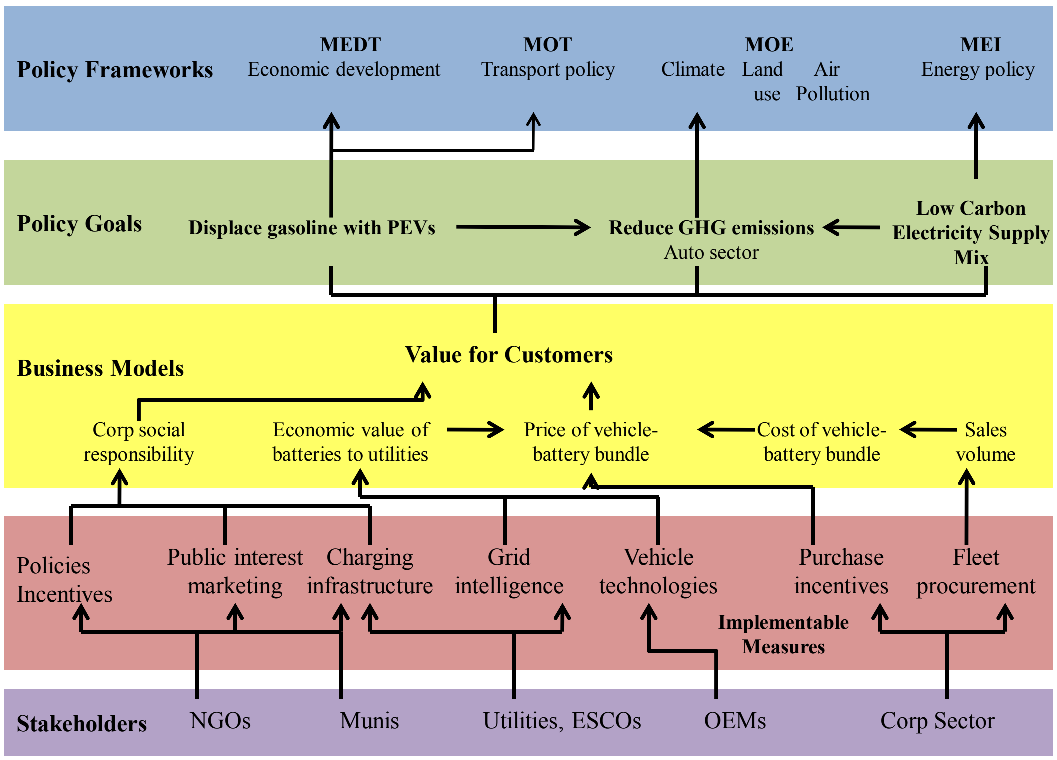
In this study, we highlight the potential and pitfalls on the way to a wider acceptance and implementation of PEVs in Ontario. We have chosen to focus on the Ontario context and specific measures and approaches and policy initiatives relevant to the Ontario context. We have drawn from the existing knowledge base and information and data available worldwide that may have a bearing on future Ontario plans. This study focuses on the Ontario context and goes one step beyond a road map exercise to provide some firm answers where the state of knowledge permits, identify barriers and issues that would need to be addressed in the future and provide recommendations to guide implementation and identify R&D needs, if appropriate. [3]

2. Ontario Context

[3] An excellent high level summary of the current status for the Canadian context is the report "The Electric Technology Road Map for Canada," developed by Electric Mobility Canada for Natural Resources Canada [4].

Figure 1.2 is intended to highlight the major players and stakeholders in Ontario and those who will influence the direction and further development of the vision to enable an emergent transformation of the transport sector and its convergence with the Ontario electricity system. It will be a dynamic interaction between development of policy goals and supporting policy frameworks. We identify the key government departments that will play a key enabling role. Furthermore, the illustration is an attempt to recognize the central role of value to customers that will contribute to success or result in failure to achieve high level goals. Under business models, it is clear that there will emerge a number of competing options to deliver on best value to the customer but the key features will remain: price of the battery and vehicle will be determined by scale and technology developments to lower cost. The economic value of PEVs to utilities as load customers, potential for load management and ultimately for storage application as secondary use are features that are new to the paradigm that is developing around large scale implementation of PEVs. The notion of corporate social responsibility that drives non-price related behaviors based on social values of environmental stewardship is shown in the illustration as an integral part of the appeal. The likely policy incentives for different stakeholders are also recognized.

Ontario Map for Plug-In Electric Vehicles (PEVs)



Adapted from the Clinton Climate Initiative

Figure 1.2. PEV map for Ontario.

3. Terms of Reference and Study Scope

Our goal in this study is to develop an action plan to address the technical challenges facing Ontario's electricity system's ability to support sustainable plug-in vehicles over the long term. A major convergence of the power and the transportation infrastructures appears feasible in the near term with the possibility of significantly reducing greenhouse gas (GHG) emissions from the new light duty vehicle fleet. This has enormous implications for Ontario's auto sector as well as the role of the power sector in shaping a future around sustainable plug-in mobility. The plan aims to address the needs of diverse stakeholders and detail concrete steps and actions required in the short term through to the medium and longer term.

3.1 Motivations and Objectives

1. The study will identify the key Ontario specific technical issues associated with meeting the electricity demands of PEVs in the Ontario market, while maintaining system reliability and price stability. Although widespread penetration of PEVs is contingent on availability, cost and consumer acceptance, their integration into the existing Ontario power system has several important technical matters that need to be understood and addressed from infrastructure, planning and regulatory perspectives.
2. The study focus is on identifying the "technological gaps" the elimination of which would enable Ontario's electricity grid to meet the expected demand of PEVs in an efficient manner, promoting reliability, electricity price stability, economic development, environmental sustainability and technological innovation.
3. The study will establish a high level summary of the current state of development and deployment activity in North America's electricity infrastructure with a view to identifying any advantages or challenges facing Ontario's electricity system in supporting this emerging vehicle technology.
4. Ontario's commitment to the implementation of smart meters and a supply mix that will be primarily non-carbon based are important advantages that could be leveraged to accelerate adoption of PEVs in Ontario. The study will identify what standards will need to be defined and what technologies will likely have to be developed to support the mass adoption of Plug-in vehicles in Ontario. The study will focus on the Ontario context but utilize all the existing (publicly) available information from external jurisdictions and also integrate specific information provided by stakeholders.
5. Convergence of the power and the transportation infrastructures has enormous implications for Ontario's auto sector as well as the role of the power sector in enabling a future in sustainable plug-in vehicle mobility. Emerging scientific and technological developments related to better electric powertrains and improved performance of batteries has changed the automotive landscape. Major auto manufacturers are committed to bringing to the market and PEVs. In the US, government, universities, utilities and the automotive industry are actively partnering to make PEVs a reality in the next 3-10 years [1, 2].
6. One of the main motivations is the fact that vehicles that can plug into the power grid for some or all of their energy needs can significantly reduce carbon emissions from the transportation sector [3], especially considering that vehicle energy storage capacity presents

unique opportunities to better integrate “intermittent” energy resources such as solar and wind power. A significant penetration of these vehicles in the market will have important positive ramifications for long term environmental sustainability as well as improving the operation of the power systems by introducing energy storage capacity for the grid. In simple terms, given the rapidly changing technologies and economics of battery and PEVs, there is the potential to use non-GHG emitting sources of electricity, particularly wind, water, solar, bio energy and nuclear, to displace gasoline cost-effectively. While it may be possible to charge PEVs without increasing peak demand or creating congestion on the system, the system implications of a constantly loaded system and its effects on the infrastructure and electricity markets would need to be assessed. Hence, the effect of these types of vehicles on generation resources, transmission and distribution of electricity, and electricity markets have to be studied in some detail to confirm their merits and to identify constraints on the electricity grid and associated markets.

7. Under certain conditions, the charging of battery vehicles could, in theory, increase the overall electricity consumption without any significant increase in the need for new infrastructure.

Given Ontario’s emerging electricity supply mix and a low GHG footprint over the next 20 years, the enabling of Plug-in vehicles and displacement of gasoline by “green” electrons would be a major Ontario contribution to GHG reductions from the transport sector. Opportunity exists to dovetail into smart grid development plans for Ontario, and also to identify and address specific "cold-weather" conditions given Ontario's climate. Whereas the economics and technical considerations at a high level appear promising, much research needs to be done to answer specific technical and system specific questions as well as identification of policy instruments required to enable such a major transformation to occur.

3.2 Report Content

The report has been divided in the main chapters described next.

3.2.1 Auto Sector Developments and Needs

In this chapter, a review is provided of the current state of the art, the evolution of key enabling technologies and some of the technological challenges and barriers for large scale implementation of PEVs in Ontario. The focus is on battery technologies and hybrid vehicle architectures and in the identification of some of the key technical, environmental, and social aspects of these technologies. Challenges in the consumer acceptance of these vehicle technologies are also identified because they will impact how fast they would be adopted or not.

First, a discussion on the energy sources for transportation is provided, concentrating on a comparison between electricity and gasoline (bio-fuels and hydrogen are also discussed in an appendix for completeness). Next, the main features and advantages of battery-based energy storage systems are discussed, providing some insight into the critical battery metrics needed to evaluate batteries for automotive applications. An comparative analysis is presented of the main types of batteries that are used or could be used in PEVs, in particular Sodium-Sulphur, Zinc-Air, lead acid, nickel-metal hydride and the now popular lithium-based batteries. The analysis of battery issues is finalized with a detailed discussion of the effects of battery energy capacity on PEV design, uptake, and charging technologies and infrastructure, including battery switching, in view of the issues associated with Ontario's cold climate.

The types of energy conversion technologies used in vehicles are presented and discussed next, highlighting the various advantages and disadvantages of hybrid architectures used in HEVs (charge sustaining) and PHEVs and E-REVs (charge depleting). A discussion is then presented on the importance of and approaches for life-cycle studies, so that the "total" GHG emissions, energy use and costs of PEVs can be adequately evaluated by customers and decisions makers to determine the "true" value of these vehicles. In this context, the use of post-PEV batteries in grid applications such as back-up power in substations and the provision of grid ancillary services is also discussed.

The chapter closes with an analysis of the technical challenges affecting consumer acceptance of PEVs due to the consumers' general inexperience with these technologies. This section concentrates on analyzing fuel and electricity consumption issues, as well as the perceived and real complications with the recharging of PEV's batteries, in view of driver behaviour and expectations. Life-cycle costing and car sharing issues are also discussed. Finally, low speed electric vehicles (LSEVs) are briefly analyzed.

3.2.2 Electricity Sector Development and Needs

In this chapter, a detailed review and analysis of the relevant issues and related literature associated with the impact of PEVs on Ontario's grid and electricity market are presented. All pertinent issues related to the impact of PEVs on Ontario's generation, transmission and distribution systems as well as the associated electricity market, and the effects and limitations on the adoption of PEVs in Ontario of these systems and market are discussed in detail. Thus, the chapter is divided in four main sections, each discussing respectively the interplay of PEVs and generation plants, PEVs and the transmission system, PEVs and distributions networks, and PEVs and the electricity market, in general as well as in the particular case of Ontario.

The various generation technologies relevant to the current and future electricity supply in Ontario are first discussed, identifying their main advantages and disadvantages with respect to the adoption of PEVs. A simple analysis is presented of the maximum possible PEV penetration in Ontario up to the year 2025, based on a load "levelization" approach and considering the current and future generation capacity to supply Ontario's load including PEVs. The effects of the resulting penetration on generation and associated pricing are also discussed.

The mutual effects between PEVs and the transmission grid are analyzed next. Ontario's current and future transmission capacity and the effect of PEV loads on transmission system planning are discussed in view of the fact that transmission congestion affects generation dispatch and electricity prices. Results of a study of the maximum optimal penetration of PEVs in Ontario from 2008 to 2025 for off-peak charging are presented and discussed, considering the province's generation and transmission systems current and future characteristics and limitations. The positive effects of PEVs on generation dispatch and electricity prices during off-peak hours in Ontario are also discussed.

The impact of PEVs on distribution systems and the effect that these systems may have on PEV adoption rates are also studied. Various issues are discussed in this section, in particular the effects that PEVs could have on feeder flows, loading and voltage profiles, as well as on system reliability, protections and power quality. A detailed analysis of several relevant charging issues such as charging plugs and stations is presented, highlighting the importance of smart charging strategies and technologies in the context of smart grids. The interactions between DG and PEVs with regard to energy storage and voltage and frequency regulation, for both G2V and V2G operating models, are also discussed.

The impacts of PEVs on Ontario's electricity market are discussed last, in particular how changes in load profiles due to PEV charging affect generation dispatch and related electricity prices. The impact of electricity prices may have on PEV adoption and vice versa are also analyzed in this section.

3.2.3 Consumers, Communities and Markets

The purpose of this chapter is to identify the "non-technical" barriers and policy issues related to the implementation of PHEVs within the Province of Ontario. A range of issues are presented, and within each, we draw upon work in other jurisdictions and begin to "bring the issue home," i.e., to identify the implications for Ontario and to recommend strategies to reduce, or ideally to eliminate, the particular barrier. Early attention to this emerging agenda that we sketch out would, we believe, serve Ontario well in the longer-term.

The following key barriers are described and possible solutions are proposed, from the consumer, market, policy and regulatory perspectives, since the associated main technical issues are dealt with in some detail in the previous two chapters:

- Infrastructure issues: first mover conundrum, costs and requirements.
- Consumer issues: consumer acceptance, growth of demand and consumer control.
- Utility issues: interconnectivity, regulations, standards.
- Battery issues: costs, uncertainties, replacement and life cycle management.
- Markets and business models: communications, billing and settlements.

For each of these items, the policy, regulatory and market work and initiatives being undertaken and implemented in other jurisdictions are identified and described. Possible solutions and specific actions and recommendations relevant to Ontario are also provided.

3.2.4 Conclusions and Recommendations

This closing chapter gathers the conclusions and recommendations resulting from the analyses and discussions presented in the previous three chapters. Particular emphasis is put on identifying the most relevant issues to Ontario that may facilitate or hinder the adoption of PEVs in the Province, from the technical, consumer, policy, regulatory and market points of view. Specific recommendations to address the gaps are made, including the identification of areas where R&D investments may be necessary in the context of Ontario to allow a smooth transition from gasoline to electrons in the Province's transportation sector.

4. References

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CHAPTER 2 − AUTO SECTOR DEVELOPMENTS AND NEEDS

1. Introduction

For the auto sector to contribute to a dramatic reduction in petroleum consumption, air pollution and greenhouse gas emissions (GHGs) emissions, we need to explore the strategic integration of the electricity and transportation energy sectors and to examine the potential for such reductions in ways not imagined before. Here, we focus on the electric and hybrid-electric power-trains to enable these reductions; specifically, plug-in hybrid electric vehicles (PHEVs), extended range electric vehicles (E-REVs) and battery electric vehicles (BEVs) all referred to, subsequently as PEVs. While "plug-in" electric power trains that can draw some or all of their energy from the electrical grid can reduce or eliminate the transport sector's reliance on petroleum, their GHG emissions and energy reduction potential has to be considered in light of the existing and emerging supply mix of the Ontario grid.

We review of the current state of the art, the evolution of key enabling technologies and some of the technological challenges and barriers for large scale implementation in Ontario. We focus on battery technologies and hybrid vehicle architectures and identify some of the key technical, environmental, and social aspects of these technologies. Challenges in the consumer acceptance of these vehicle technologies are also identified because they will impact on how fast they are adopted or not.

We observe that a simple assessment of fuel economy no longer provides a practical comparison framework since the diversification of transportation energy sources will, in the future, include grid-sourced electricity. A better comparison framework then is the total energy use and environmental impacts of a vehicle throughout its life-cycle. For example, a "well-to-wheels" analysis is now common, and refers to the total impact of the production, distribution, and consumption of a given fuel. This concept can also be applied to a range of variables including energy use and GHG emissions. The key issues to consider, when assessing new vehicle technologies for Ontario as shown in Figure 2.1 are:

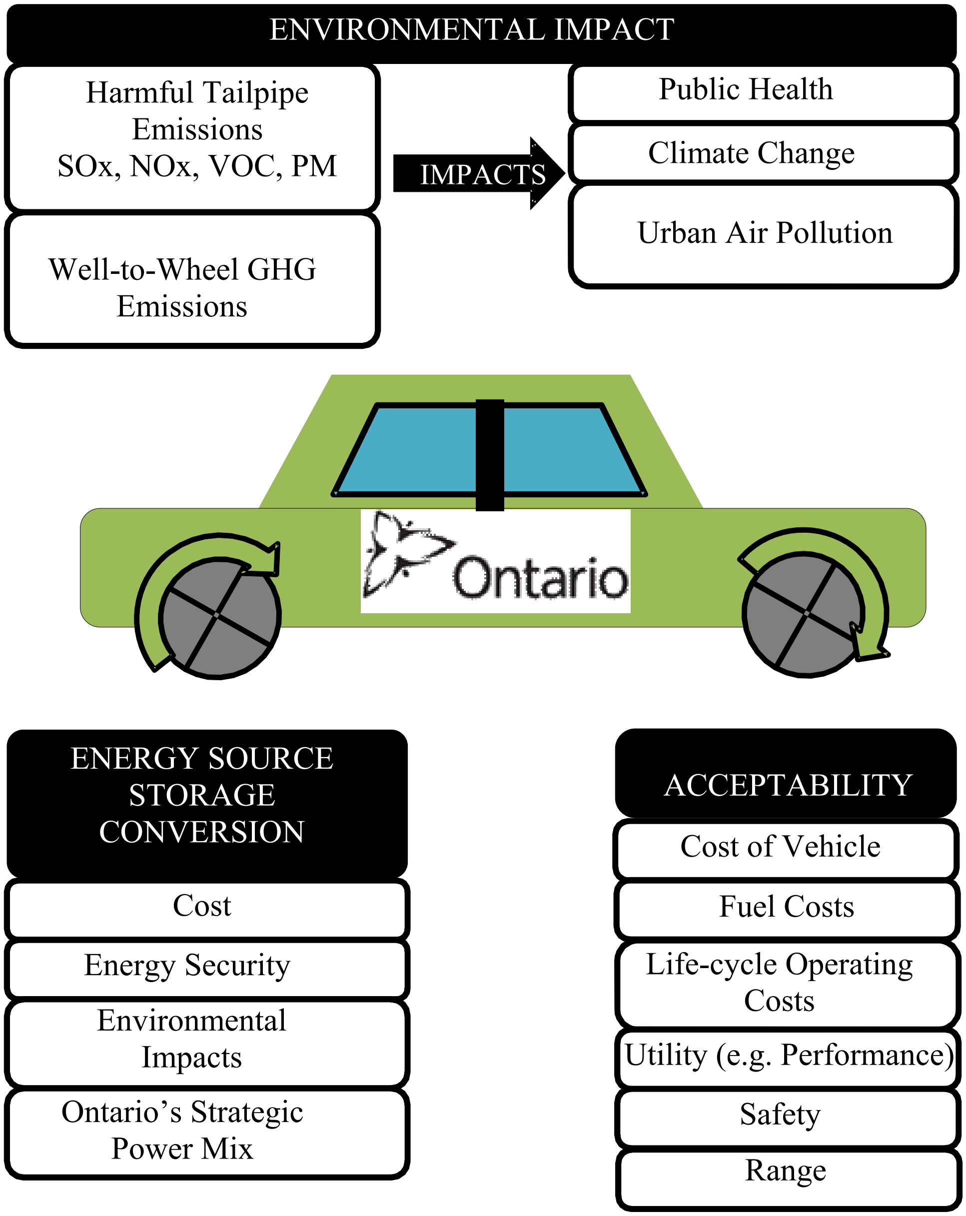

Figure 2.1. Policy factors to be considered in the assessment of new vehicle technologies

- Environmental Impact: Most critical are the well-to-wheel energy per km driven and life-cycle GHG emissions of future vehicle technologies. The location of the emissions is also an important factor.
- Energy Source: Vehicle power must be obtained from an energy source. Moving beyond gasoline, the primary energy sources for electricity would include wind, solar, nuclear, biogas or fossil fuels. Different vehicle technologies will draw energy from different sources or combinations of these sources.

- Public Acceptability: If consumers are not willing to purchase or operate vehicles based on new or alternate technologies, then the transition will be slow or will take a very long time. The policy and public acceptance issues are addressed further in Chapter 4

The above considerations cannot be treated in isolation. Development of new vehicle technologies and slow rates of fleet turnover suggests that adoption of PEVs will occur at a measured pace over time. New vehicles will likely be deployed in combination with other measures such as improvement of conventional technology and development of low-carbon fuels and fuel production pathways.

In this report, we consider the technological challenges and barriers to adoption of PEVs on a large scale. PEVs offer a good *opportunity* to reduce GHG emissions and transport-related fossil-fuel consumption, and face lower technical risk and fewer infrastructure hurdles than other future vehicle technologies. In this chapter, we provide an assessment of the positive attributes and also highlight the important challenges and barriers that exist in the auto sector on the way to adoption.

2. Transportation Energy Sources

In Ontario there are over 6,957,000 light duty vehicles, which accounts for about a third of the vehicles in Canada; in 2008, these vehicles used 25 billion kWh of energy (Figure 2.2) and 12.4 billion litres of gasoline [1]. Urban air quality requirements and the need to reduce GHG emissions are the key factors influencing the strategy to displace gasoline in Ontario's vehicles. Currently, the use of alternative fuels in the transportation sector is insignificant relative to the number of passenger vehicles that use gasoline (note that the commonly available hybrids such as the Toyota Prius and others are essentially gasoline powered vehicles, albeit with better fuel efficiency).

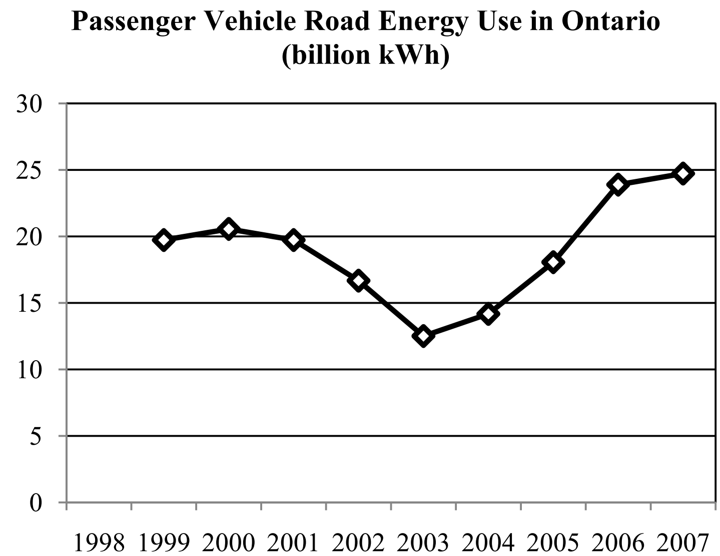

Figure 2.2. Road energy use in Ontario

Plug in vehicles offer a substantial potential for energy diversification as well as zero-emission driving for the portion of the driving duty that is in the "all-electric" mode. The quantitative impacts Province wide will depend on the level of penetration and share of the market, i.e., the number of operating PEVs in any given year; the nature of Ontario's supply mix; and the aggregate actual "all-electric" distance (km) driven. It is important to note that the gasoline internal combustion engines (ICEs) will continue to maintain a significant share of the vehicle market in the near future and it will decline over time, if, and only if, a large number of PEVs are adopted by consumers in the market place. Stress on availability of petroleum energy sources, geopolitics or other global factors that give rise to significant price increases would be a contributing factor that would hasten the adoption and growth of the market share of PEVs.

A sustained increase in petroleum prices may not be realized for a decade according to the US Energy Information Administration (EIA) [3]. Thus, it would appear that a price of gasoline in the $3-4 USD per gallon is a reasonable central scenario against which the attractiveness of PEVs can be considered; a higher price of gasoline would contribute to faster adoption, but it is not prudent to use these prices for these types of studies a central scenario based on available forecast of gasoline prices. Also, there is some potential for improvement in the fuel economy of ICEs that will extend the viability of this technology. An improvement of at least 20% in fuel economy is clearly within reach in the short term [2]. Some potential improvements include reducing vehicle weight though improved materials and design (which will benefit all vehicle technologies); development of ICE-based mild hybrid vehicles; start-stop hybridization of ICEs; electrification of the auxiliary power draws; cylinder shut down; and direct injection of fuel into spark ignition ICEs.

Driver behavior is a significant factor in determining fuel economy and this is important for all types of vehicles. It has been estimated that up to 20% improvement could be realized with simple driver behavior modifications such as less aggressive braking and acceleration; observing the speed limit; improved vehicle maintenance, including maintaining adequate tire pressure; and adoption of smaller vehicles [4].

Very few passenger vehicles today rely on grid-based electricity for energy. For example, in 2007 the US Department of Energy estimated that there were 2,961 on-road PEVs [12]. It is noted that the "hybrid vehicles" currently on the market (Toyota Prius and others) are essentially gasoline powered engines that combines a battery and electric motor onboard and does not require the vehicle to be plugged into the wall and hence does not have any grid-based electricity input. On the other hand, the emerging technology of PEVs and the next generations of powertrain architectures for vehicles depicted in Figure 2.3 use electricity stored in the battery to provide the energy to the drive-train. Practically, an electric vehicle is the simplest form of automotive design. The power train consists of a battery, power converter, and an electric motor (no engine, no transmission, no belts or pulleys – the only moving part would be the electric motor, the wheels, and cooling fluid pumps).

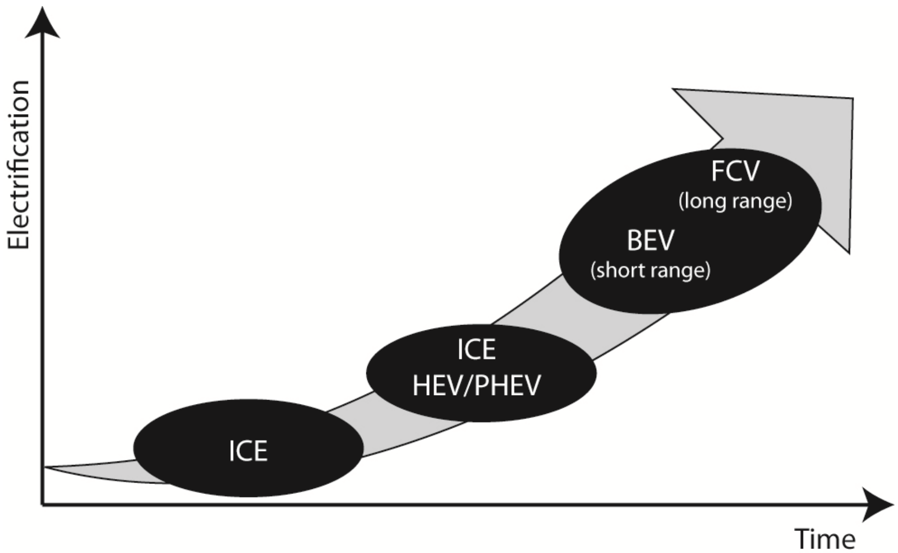

Figure 2.3. Future electrification of advanced vehicle technologies.

Electricity can be entirely produced domestically, as opposed to fossil fuels, resulting in a significant increase in energy security for nations that depend on foreign oil. In this context, the adoption of PEVs is an attractive proposition. However, as discussed in some detail in see Chapter 3, there is a significant amount of research and testing required to properly understand the potential impacts plug-in vehicles will have on the electricity grid and the upgrade costs associated with new infrastructure requirements. It also is expected that utilities may need to develop control technologies to help reduce these impacts by restricting charging times and locations for end users. The consumer acceptability of such actions will require further investigation, as discussed in detail in Chapter 4.

For a broader perspective, the role of biofuels and hydrogen as complementary technology developments are described further in the Appendix.

3. Battery-Based Energy Storage Systems

The key enabler of hybrid vehicle technologies is the on-board energy storage system (ESS) which augments the vehicle's primary power source. In some cases such as E-REVs, BEVs and fuel-cell vehicles (FCVs), the ESS may be the only power source to the wheels. Of current interest to the auto industry is the development of electricity energy carriers. One can store electric energy electrochemically in a battery, chemically as hydrogen, mechanically in a flywheel, and in electrostatic form via an ultra-capacitor. This section focuses on battery based ESSs.

In general, electric energy storage systems enable the following benefits for HEV and PHEV's [14]:

- the ability to recapture the vehicle's kinetic energy through regenerative braking that would otherwise be lost in the conversion to heat from conventional mechanical braking;
- to meet peak power demands with a faster response time;
- to reduce the size, cost, and mass of the primary power source (engine downsizing); and
- in some cases the ESS can enable a control strategy where the primary power source (ICE or fuel cell) runs in a more efficient operating zone. In this situation the ESS acts like a buffer between the power demands of the vehicle and the power delivery of the primary energy source. With these two elements now asynchronous, the power source can operate in its most efficient range regardless of the current power demand, and any excess or deficit in energy production is handled by the ESS.

BEVs will only benefit from the first item in the above list, i.e., regenerative braking.

There are a number of possible battery chemistries that can be used in an electrical energy storage system for PHEVs and BEVs. Presently, nickel metal hydride (Ni-MH) batteries are the most commonly used technology in HEVs. However, analysts expect that lithium batteries will be best suited for future PHEV applications. This is due to expected design improvements that will yield significant energy and power density advantages while costs simultaneously decrease due to production quantities.

3.1 Critical Battery Metrics

When considering various batteries for automotive applications, there are several critical performance metrics: capacity, charge/discharge rate, energy and power density, operating voltage, self-discharge, cycle life, and state-of-charge. Battery capacity is the total amount of energy that the battery can store, usually stated in kilowatt-hours or watt-hours (kWh or Wh). This, combined with the efficiency of the various powertrain components, determines the driving range of the vehicle in "all-electric" mode, and consequently the extent to which a driver can displace fossil fuels during each trip.

Battery charge/discharge rate is the power-acceptance/delivery capability of a battery, usually stated in watts or kilowatts (W or kW). The rate at which a battery charges determines battery charge time. The rate at which a battery can supply energy to the electric motor(s) determines the vehicle's acceleration and grade climbing ability in "all-electric" mode.

Chemistry-specific metrics are the energy density and power density of the battery, usually stated in kWh/kg and kW/kg, respectively. These are essentially the battery's energy capacity and discharge rate specifications divided by the battery mass. Higher values mean more performance delivered per kilogram of battery weight, leading to lighter and more energy-efficient vehicles.

Battery chemistry also determines the operating voltage of the battery, the 'self-discharge" rate (the rate at which battery capacity is lost when idle), and the cycle life (number of times the battery can be depleted and recharged). The cycle life is a function of the depth-of-discharge (DoD); typically, a larger DoD results in a lower overall cycle life.

Finally, the battery state-of-charge (SOC) refers to the amount of charge remaining in the battery (i.e. 100% SOC is fully charged, 50% SOC is half-charged, and 0% SOC is a fully depleted battery). Typically, keeping a battery at a very high or very low SOC results in lower cycle life, although newer batteries are improving in this regard.

Table 2.1 compares the relevant specifications of some major battery chemistries: nickel metal hydride, lithium ion, and lead acid. Since the total weight of a PHEV battery is governed by the energy and power density, a specific chart called the Ragone plot is used to illustrate these key metrics. Figure 2.4 shows the higher energy and power densities of lithium cells that make them an attractive choice over Ni-MH and lead acid batteries [15]. This said, the next section will discuss the characteristics of a range of possible automotive ESS battery types.

Table 2.1
Important data for Lead Acid, Ni-MH and lithium ion cells.

	Energy Density (Wh/kg)	Power Density (W/kg)	Voltage (V)	Self Discharge (%/Month)	Cycle Life @ 80% DoD	Cost ($/kWh)	Cost ($/kW)
Lead Acid	20 - 40	300	2.1	4 - 8	200	150	10
Ni-MH	40 - 60	500-1300	1.2	20	> 2500	500	20
Lithium Ion	100 - 200	800-3000	3.6	1 - 5	<2500	800	50 - 75

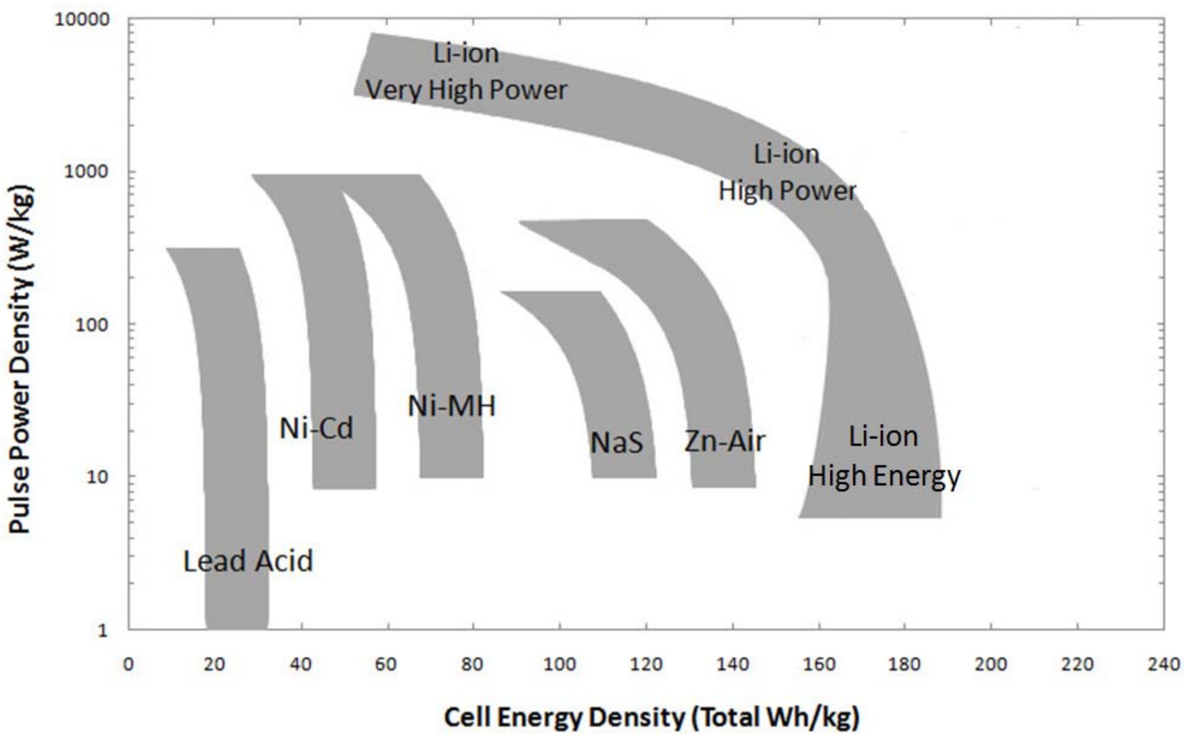

Figure 2.4. Ragone Plot of various ESS for PHEV applications.

3.2 Potential Automotive Energy Storage Systems Battery Types

3.2.1 Sodium Sulphur Batteries

There are a number of other battery technologies that have potential for automotive applications. Sodium sulphur batteries are presently in limited use in stationary systems, such as for storing energy from variably generating renewable sources like wind turbines. One benefit of using this chemistry is that the sodium anode, sulphur cathode, and aluminum oxide separator all have low material costs, however production costs are still relatively high (but decreasing). Additionally, the battery is laid in a tubular formation allowing easy access for maintenance or scrapping. The life-cycle impact of the battery is greatly reduced by the fact that all of the components of the battery are recyclable. The energy density of sodium sulphur batteries is up to 760 Wh/kg, nearly three times that of lead acid batteries [16]. The primary reason that sodium sulphur batteries are not considered viable for use in PHEVs is the extreme temperature they operate at. Cells will operate effectively at 300 to 350 ˚C, which makes thermal management very difficult when they are contained within a vehicle. The operating temperature also creates a corrosion issue, which affects durability.

3.2.2 Zinc-Air Batteries (Semi-Fuel Cells)

Zinc-air or aluminum-air batteries, or semi-fuel cells, are primarily used in experimental settings and underwater vehicles at present, although they are commercially available in limited numbers. Zinc-Air (and related Aluminum-Air, and Lithium-Air) have very high power densities, much higher than other types of batteries. The most significant issues with semi-fuel cells is that they cannot be recharged onboard the vehicle, and do not "cycle" beyond a few discharge/charge cycles.

The major components of these cells are the zinc electrode and the potassium hydroxide electrolyte, both of which are common and cheap materials that render an overall low cost per cell. In other common battery technologies ions pass from one electrode to another via the electrolyte, and the battery is re-charged by applying electricity to drive ions back to their original state. In this battery type; however, the zinc electrode simply discharges into the electrolytic solution until the electrode has been depleted, as such this chemistry is more difficult to control and not well suited for cars that are to be parked much of the time. The common method of re-charging this battery type is to install a new zinc electrode and fresh electrolyte, as such there are life-cycle and supply chain logistic issues to be overcome. This can be convenient in that the charging time can be lower than if the battery were to be charged internally, however it also increases the environmental impact as fresh materials are being consumed instead of being contained within a closed system. Not being able to recharge via electric current means that regenerative braking or other on-board ESS charging is also impossible. The distribution of zinc and recovery of electrolyte also creates a challenging logistics problem. Experimental cells have been designed that can be charged by application of current, much like other battery technologies, but these cells are not yet commercially mature. A major concern in the use of zinc-air batteries in a PEV application is the low operating power of the zinc air cell; the power may be insufficient for an electric vehicle [17]. At this time no manufacturer has successfully demonstrated that these cells can be re-charged (or "cycled") onboard the vehicle itself beyond a few cycles.

3.2.3 Lead-Acid Batteries

Lead acid batteries are used in virtually all combustion engine vehicles. Owing to years of use in this application there is a large body of literature devoted to lead acid batteries. Few major design improvements can be expected in the future for this reason. Since lead-acid batteries have a relatively low energy density (Figure 2.4), weight is an issue if they were to be used in a PHEV application; however a bipolar design would help in this regard. The lead acid battery is a very cheap technology due to low material costs and a well developed method of production.

Monitoring the state-of-charge (SOC) of lead acid batteries is simple because it is well-correlated with electrolyte density leading to accurate control systems. Shallow discharge cycles can be expected when driving under city conditions which is a strength of lead acid batteries for PEVs as these cells are durable under numerous shallow discharge cycles. Another strength of a lead acid battery is that it is very durable if the state-of-charge remains above 80 percent. On the other hand, the lead acid battery is very sensitive to the rate at which it is charged, thus life-shortening can be expected if the charge is too slow while thermal management becomes a particular challenge if the charging cycle is too aggressive. In research labs at this time there are lead-acid / ultra-capacitor hybrid power sources, but these have yet to be demonstrated feasible even at the research stage. At present lead acid batteries have a high weight to energy ratio making them unfit for use in PEVs; however, if a bipolar configuration were to be developed this weight drawback would be greatly reduced.

3.2.4 Nickel-Metal Hydride Batteries

Nickel metal hydride (Ni-MH) batteries were developed as an alternative to nickel cadmium batteries and are presently the most commonly used cell in HEVs. This alternative was developed to reduce the environmental impact, increase the energy density, and decrease the voltage depression, i.e., the loss of peak voltage capability, of the cell under conditions typically seen in PHEV use. Ni-MH batteries are often viewed as a well balanced option; in few criteria do they excel, but neither do they exhibit great difficulties. It is very unlikely that Ni-MH will greatly increase in energy or power density with future research due to the nature of the chemistry. At present these cells are relatively inexpensive in comparison to lithium cells, but they are not expected to decrease in cost due to concerns over the price of metallic nickel.

Although Ni-MH batteries are not generally seen to be the cell of choice for future PEVs they should still be examined closely due to their use as a bridge to future lithium cell usage. It should be noted that Ni-MH share thermal management challenges similar to those of lithium ion cells [18]. Another nickle based chemistry is the nickel-zinc battery (NiZn). While nickel-zinc battery systems have been around for over 100 years, the power density is still too low for vehicle application, and there continues to be durability challenges under high number of charge/discharge cycles.

3.2.5 Lithium-Based Batteries

Lithium based cells are widely seen as the cell that would work best for PEV applications. These cells are still in their infancy relative to some other cell chemistries but they show great promise for use in PEVs. There are three major types of lithium batteries: lithium metal, lithium ion, and lithium polymer.

Lithium metal batteries use a metallic lithium electrode. These electrodes have a very high energy density, mostly due to the lithium; however, this metal reacts with the organic electrolyte in the cell. The reaction forms a solid electrolyte interface and with extended use dendrites may form on the electrode surface and significantly affect battery life and efficiency. These types of cells typically show a short cycle life along with passivation effects (forms an oxide layer that does not conduct electricity) which severely limit their potential for use in PEVs.

Lithium-ion (Li-ion) batteries use an insertion compound as the electrode. A variety of different insertion compounds have been, the most important of which are titanium, iron phosphate, and manganese spinel technologies [19]. Each of these insertion compounds performs slightly differently, but they have very similar energy and power densities. Presently, lithium ion batteries are used in consumer applications with cobalt oxide as the insertion compound;

however, the use of cobalt renders the cells prohibitively expensive for the scale required in PEVs. Table 2.1 shows the current cost of lithium ion cells, but this is predicted to drop to approximately $400/kWh in the medium term making them more affordable than Ni-MH cells [20]. The anodes of these cells are made from carbon structures which exhibit high specific capacity, low costs, and are easily cycled. Lithium ion batteries are safer than lithium metal batteries because of lithium metals instability.

Lithium polymer batteries use a solid polymeric electrolyte which also acts as a separator within the cell. These batteries can use the chemistry of lithium metal or lithium ion cells. Without the need for an electrolytic solution cell weight is significantly decreased. Safety is also improved because there are no liquids that can leak from the cell. With a solid membrane the geometry of the cell surface can be altered, allowing cells with different capacities to be easily created. However, the solid polymer electrolyte offers a significant downside in that it has a much lower conductivity than traditional liquid electrolytes. This lowered conductivity means that the membranes must be made very thin to prevent large internal resistances, which serve to decrease the efficiency of the cell as well as increase the need for good thermal management.

At present there are still several challenges regarding lithium cell commercialization in vehicles, specifically their shelf life and cycle life. Due to lithium's tendency to react with the electrolyte, much energy is lost while the battery is in standby, a common occurrence in PHEVs. In addition, lithium cells require a very aggressive thermal management system because the cells can experience thermal runaway with improper control schemes. Safety concerns for lithium cells also exist due to these thermal management problems, as exampled in media reports of laptop batteries catching fire. Also, at high temperatures the electrolyte will decompose into gaseous compounds. This requires that cells be equipped with venting capability or they may rupture, spilling the electrolyte and exposing the inner circuitry. There are additional concerns with lithium chemistries due to decreased conductivities at low temperatures, raising concerns regarding discharge power performance. Furthermore, the cells cannot be charged too aggressively or else lithium plating may occur leading to irreversible capacity loss; however, the possibility of plating can be removed through proper cell design.

Given current research lithium cells are the best candidate for future use in PEVs. Most lithium analysts foresee great drops in the cost of lithium cells as the manufacturing process is further developed. This is the greatest contributor to the high cost of lithium cells aside from the lithium itself, and with widespread adoption there may be lithium supply constraints.

With cost decreases projected in mind, it can be expected that lithium cells will eventually become less expensive than the Ni-MH cells. Further, owing to cell chemistry, researchers predict that lithium cells will provide the energy and power densities requisite for use in PEVs. In a general sense, basic research on lithium-ion batteries must focus both on developing new materials (electrode and electrolyte), developing new cell structures along with their thermal control. An important trend in lithium-ion battery development is the rising importance of nano-structured electrodes which offer the opportunity to improve discharge rate (power delivery) capabilities while maintaining high energy capacity.

3.3 The Importance of Energy Capacity and Ontario's Climate

The most sensitive design variable in the electric vehicle is the energy capacity of the battery pack, which is the primary cost, range, and weight driver. This cost/range trade-off drives the difficulty in designing an electric vehicle for a mass market given current consumer cost and range expectations. While it is true that most daily trips are in the tens of km there is an expectation that consumer vehicles may be used to drive long distances and be quickly refueled as needed. For consumer acceptance, the plug-in hybrid vehicles offer an important advantage, namely, operation in the non-electric mode to complete a longer journey. Over time and with larger battery packs, which involve a cost/weight trade-off, extended operation in the all-electric mode towards a range of a few hundred km becomes feasible. This will require an infrastructure of electric refueling stations and batteries capable of rapid recharge. The demand for fast charging on the road, if it emerges quickly, is an important technical challenge that can become problematic from a consumer acceptance perspective. While batteries capable of such high-rate recharge are likely to be available, rapid recharge also severely affects the durability of the battery and the requirements on the recharging infrastructure are significant. More details regarding charging and related infrastructure are provided in Chapter 3 and 4.

One other factor is critical to consider – especially in Canada's climate – is that all battery technologies are affected by a cold environment. A cold battery will only provide limited power and capacity and operation in a cold environment may lead to durability issues. This would indicate that battery heaters, during plug-in periods, may have to be considered in the Ontario context and impacts on performance degradation the winter months.

3.4 Battery Switching

Battery switching is the process whereby the battery in PEVs is changed out or swapped at charging stations for an entirely different battery with a full SOC. The concept of battery switching stations is proposed, for example, by the company "Better Place", where the concept is to have the batteries owned by a central agency and rented by the vehicle owner. After the depleted battery is removed and replaced with a charged battery it is taken to be recharged and subsequently reused in another vehicle.

The successful acceptance of this business model or strategy will have to be assessed in light of a number of key factors such as:

- Environmental factors (e.g., snow, ice, salt, and dirt) and its role in the serviceability and ease of the battery change-out. Also, salt poses as significant safety hazard with the high voltage battery back;
- The need for a standardized battery packs access. Given the large number of different vehicles and OEMs, this is an important constraint. If the standardization cannot be imposed, then success of the concept will be unlikely because it will be restricted to one or very few vehicle types or likely, only in a "fleet" concept. A dedicated robotic change-out facility has several hurdles to overcome in a practical context.
- There is some potential that consumers will become dissatisfied with fluctuations or differences in battery pack power and capacity properties depending on their age and state of degradation. The state of degradation can severely impact vehicle range and it unlikely that consumers will accept significant variability in range with each battery change-out. This could be addressed in a battery management system that allows degraded packs to cycle to a lower state of change, but then battery pack longevity will be significantly impacted and reduced.
- Unless the proprietary technology becomes available for use by a wide number of service providers, the "battery switch" will be a challenge. The battery pack will likely weigh more than 170 kg, and will be connected to several vehicle systems including high voltage bus bars, communication and control systems, and a liquid cooling system. Thus, the "switch" is

not likely to be trivial for manual or semi-automatic replacement and will require supervision by a skilled technician and use complex equipment to be conducted safely. Mechanical and robotic support for the battery change-out tends to be very complex, making it expensive. If this translates into only few stations, it would reduce consumer acceptability. Alternatively, if the stations require a high utility factor, then busy stations lead to long wait times and again lower consumer acceptability. The level of maintenance and skilled technicians required to maintain a high degree of reliability at these change out stations is an unknown and the issue would need to be monitored.

- For safety, consumer acceptability, life-cycle cost, and the practicality of battery switching without a standardized battery pack makes this option improbable in the near future. If the barriers could be overcome, it is a highly innovative and novel concept that may gain some traction in the medium to long term future.

This issue is also discussed in the context of charging stations and their impact on the grid in Chapter 3.

4. Energy Conversion Technologies

In 2008, the US market for conventional hybrid vehicles was dominated by gasoline hybrid-electric light-duty vehicles. From Figure 2.5 nearly 2.8% of total vehicle sales in 2008 were hybrids and this is estimated to rise to over 4% in 2016. JD Power predicts a more aggressive hybrid market that will surpass 5% in 2010 and 8% in 2015 [21], [22].

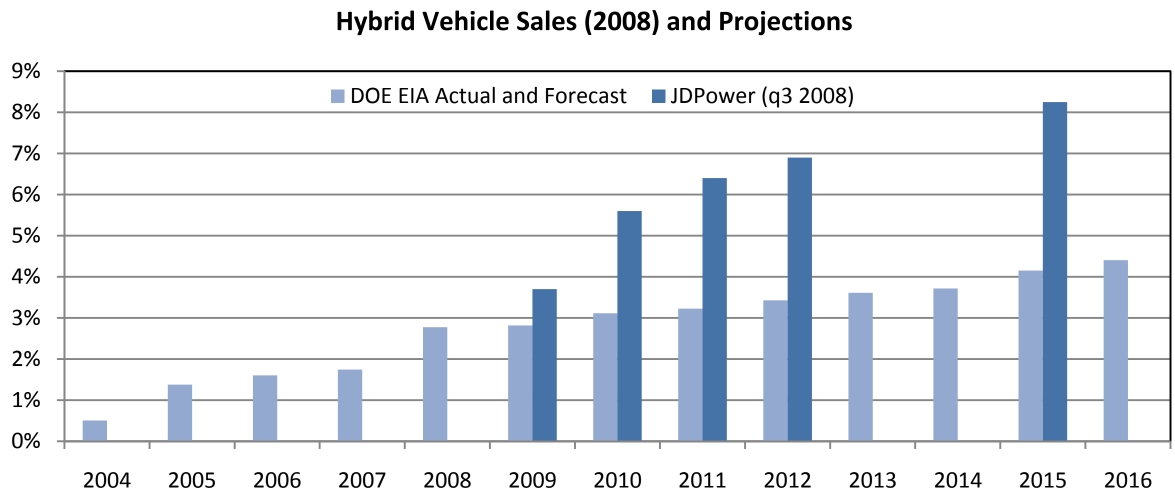

Figure 2.5. Hybrid vehicle sales

Ongoing developments in hybrid vehicles has led to a large number of designs exhibiting different advantages and disadvantages. Axen and Kurani in [23] investigated consumer awareness of hybrid vehicles finding that the majority of people think that a typical hybrid vehicle available for purchase in the last decade can run on electricity from a wall outlet. A hybrid vehicle with this characteristic is commonly referred to as a PHEV and, in contrast to people's knowledge about hybrids, is not yet commercially available at dealerships (though some companies do now specialize in PHEV conversions). Today's consumers is likely less concerned with the engineering classifications of hybrid vehicles and more concerned with the vehicle's captical cost, operating costs, functionality, and overall impacts on their lives. Nevertheless, consumers will also likely need to consider the costs and benefits of hybrid system differences, for example, the difference between the need to plug-in versus the option to plug-in. In addition, the consumer will also likely need to consider when to plug-in. As such, education on the fundamentals of new vehicle technologies will be necessary for consumers to make informed decisions that will suit their lifestyle, budgets, and environmental impact expectations.

4.1 Hybrid Architectures

The majority of hybrid vehicles that are commercially available today make use of the ICE and some form of energy storage, usually a battery or ultra capacitor. There are many different types of hybrids, ranging from mild to heavy with varying degrees of advantages; the important features of common hybrid arrangements are summarized in Table 2.2.

Table 2.2
Advantages and disadvantages of HEV, PHEV, and E-REVs

ADVANTAGES	DISADVANTAGES
Hybrid Electric Vehicles (HEV)	
• Downsized engines with the same or better vehicle performance • Engine stop/start at idle and (limited) all-electric operation • Does not always require a transmission • Enables regenerative braking • Electric launch and assist	• Vehicle cost may be higher compared to conventional vehicles • Some hybrids will exhibit little to no efficiency gains in highway driving situations, as there is no opportunity for recovering kinetic energy • Increased complexity and more components compared to conventional vehicles – likely that most powertrain maintenance will be done at the dealership
Plug-In Hybrid Electric Vehicles (PHEV)	
• In general, all PHEVs exhibit the same advantages as HEVs • Grid-connected battery enabling the displacement of gasoline and reduction of consumer operating costs (cost of electricity is less than gasoline) • Quiet all-electric operation (speed and power limited, ICE may turn on under heavy acceleration or cold temperatures)	• More expensive vehicles (attributed to the large, high capacity plug-in battery) • Charging restrictions • Utility infrastructure will be impacted
Extended-Range Electric Vehicle (E-REV)	
• Similar to PHEV except the vehicle exhibits all-electric operation under all conditions until the battery is depleted at which point the ICE turns on and acts as an HEV	• Battery and electric drive need to be sized to meet the full range of vehicle power demands (may increase cost and weight)

In general, not all hybrids exhibit the same advantages/disadvantages above but will vary depending whether they are mild (weak) hybrids or full (strong) hybrids or variations in between. Whether overall safety is a net advantage (e.g., lower emissions), disadvantage (e.g., high voltage battery), or unchanged is yet to be determined.

One important categorization of hybrid vehicles is how the battery state-of-charge (SOC) is managed. A battery that on average maintains the same SOC by constantly being charged by the prime vehicle energy source (e.g., an ICE) or by regenerative braking is called “charge-sustaining” (CS). If the battery on average can deplete and use a net amount of energy from the electrical grid, i.e., a plug-in, it is called “charge-depleting” (CD). It should be noted that once a CD vehicle battery is depleted it can normally continue to operate as a CS hybrid vehicle. A summary of the operating modes of a hybrid vehicle is presented in Table 2.3.

Table 2.3
Summary of hybrid vehicle operation modes.

Charge Sustaining (CS)	The vehicle will operate like a conventional hybrid in charge sustaining mode. In this mode only gasoline is consumed. Regenerative braking can charge the battery when possible.
Charge Depleting (CD)	The vehicle is using energy from the electrical grid. There are two possible CD modes. Once the "wall-charge" energy is expended, the vehicle enters CS mode.
Blended Mode	Vehicles can operate at lower speeds and/or with low loads on the electric motor without engine assist. However both battery and gasoline engine power are required to reach higher operational speeds or to meet higher loads (e.g., steep grade climbing). At these higher demands both electricity and gasoline will be consumed.
All-electric	Vehicles can operate at all speeds in electric mode until the battery reaches the SOC where CS mode begins. A vehicle that can operate in all-electric mode may also have the ability to operate in blended mode. In all-electric mode only electricity is consumed.

Another classification scheme is the "degree of hybridization" which can range from mild to strong. Essentially the degree of hybridization indicates the extent to which the vehicle can make use of electricity for motive power, thus improving fuel economy. For example, a "mild" hybrid may have the capability to use regenerative braking to charge the battery, and to switch off the gasoline engine while coasting in order to save fuel. A 'strong" hybrid would take this one step further by providing "all-electric" driving (no ICE) under certain operating conditions, further displacing gasoline use. The choice of the degree of hybridization is a trade-off between initial vehicle cost and fuel savings.

Although not specific to hybrid vehicles, the concept of a drive cycle is important to the discussion of vehicle performance. A drive cycle is essentially a prescribed set of maneuvers, i.e., accelerating, maintaining a given speed, braking, grade climbing, performed for a given period of time resulting in a range of demands on the vehicle power systems (e.g., torque, speed). Of course, depending on the specific demands of a given drive cycle, the energy efficiency (e.g., fuel economy) will vary. Standardized drive cycles provide a characterization of different vehicle operating conditions and allow for a reasonably fair comparison of vehicle performance.

There are a number of Society of Automotive Engineers (SAE) standards under development that are worth noting [46], as these will guide the PEV architecture and manufacturing:

- J1711: Recommended Practice For Measuring The Exhaust Emissions And Fuel Economy of Hybrid Electric Vehicles;

- J1772: SAE Electric Vehicle and Plug-in Hybrid Electric Vehicle Conductive Charge Coupler;
- J2464: Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing;
- J2836: Use Cases for Communication between Plug-in Vehicles and the Utility Grid/EVSE/customers; and
- J2894: Power Quality Requirements for Plug-in Vehicle Chargers.

4.1.1 Charge Sustaining HEV

A CS HEV blends two or more power sources together as previously discussed. Over a given drive cycle, a HEV does not use a net amount of electrical energy and does not charge from the electrical grid; the only source of power for the ESS is the engine or regenerative braking. The battery SOC swing is generally limited to a narrow range of 5-10%, which leads to longer battery life [24]. In other words, the ESS maintains a steady SOC on average, but throughout a drive cycle the SOC may vary within a predefined range to meet acceleration demands or when capturing energy through regenerative braking.

4.1.2 Charge Depleting PHEVs (PHEV, E-REV)

CD hybrid vehicles displace petroleum use with electricity use. The battery's SOC will fluctuate throughout the drive cycle for the same reasons as a CS vehicle, but on average it will deplete over the trip. A PHEV will initially operate in CD mode or a blended mode which simultaneously draws power from both the ESS and the gasoline ICE. Typically, the ESS of a PHEV is not sized to meet the full range of vehicle operating requirements, and can only operate in a CD all-electric mode to a limited speed; once the limit is exceeded the ICE necessarily turns on to assist. Once the battery SOC has reached a minimum set point the vehicle will enter CS mode and operate as a regular HEV. Typically the all-electric range is represented by "xx" in the PHEVxx name (e.g., a PHEV30/PHEV60km has 30 miles or 60 km all-electric range).

An E-REV design is only slightly different from a PHEV in that it is forced to charge deplete in all-electric mode, regardless of the vehicle operating requirements (e.g. speed, grade climbing) before the onboard ICE and generator are activated. This means that the electric motors and battery must be sized to meet all of the vehicle's technical specifications except range without assistance from the ICE. The Chevrolet Volt is an E-REV that is expected to be available in 2010. Its battery will provide an all-electric range of about 60 km based on the standard trip drive cycle, i.e., the UDDS cycle, and a fully charged (80% SOC) battery. When the battery SOC has depleted to 30% the Volt will operate as a charge sustaining series hybrid. With a 60 km all-electric range many drivers will be able to significantly reduce their gasoline consumption. SAE J1711 studies estimate that 62% of urban populations drive 60 km or less per day, and other surveys estimate the percentage is as high as 82% [25]. In the event that one needs to drive further, the Volt has the ability to extend its range to more than 600 miles (966 km) with a downsized ICE; this extended range is a key public acceptance factor.

5. Energy and the Environment

Emissions arising from electricity generation depend on the supply mix of the primary energy sources. A PEV operating in the "all-electric mode" has zero total emissions at the vehicle level (tailpipe emissions), but a complete view should also include the emission at the generation source and the overall electricity supply mix. A comprehensive study by EPRI and NRDC [26] shows the variation in emissions from different scenarios of PEV adoption and the generation mix in different jurisdictions in the US. Annual reductions in GHG emissions are significant in every scenario combination of the study. Even in areas where coal dominates, i.e., areas with high CO2 intensity of the electricity sector and low PEV penetration, the reductions are significant although less pronounced than in areas where the CO2 intensity is low, i.e., where the mix is less coal and more hydro, nuclear and gas. In the case of Ontario, there is currently a significant amount of clean energy being produced from hydroelectric and nuclear plants (51% nuclear and 23% hydro [27]), with plans for an increasing role of renewable sources of electricity in the Ontario supply mix, as per the Integrated Power System Plan (IPSP) [40] and the Green Energy Act (GEA) [41]. Based on these documents, Ontario's supply mix as of 2014 is expected to be mostly based on nuclear and renewable resources, resulting in a decline on GHG emissions from 35 MG to 5-6 into the future beyond the year 2014, as illustrated in Figure 2.6 . This makes it very attractive to promote displacement of fossil fuels use in vehicles by electricity in Ontario.

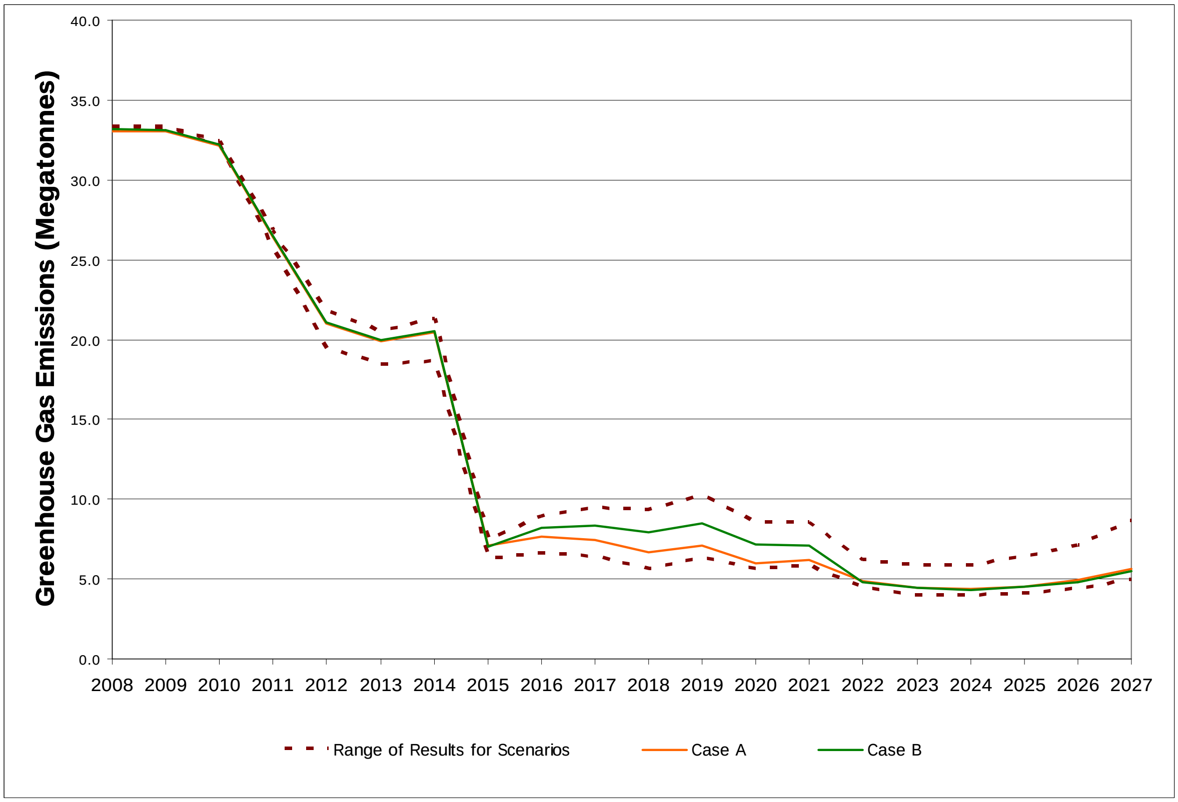

Figure 2.6. Ontario's supply mix GHG emissions [source: OPA].

As emerging vehicle technologies become more complicated and diverse, there is a need to develop objective metrics for comparison purposes. With PEVs the fuel economy parameter (miles per gallon or 100 kilometers per litre) is becoming increasingly ineffective for comparing vehicle. When comparing new and advanced vehicles, we recommend use of a broader life-cycle view of the technology and its use. Figure 2.7 illustrates life-cycle process considerations.

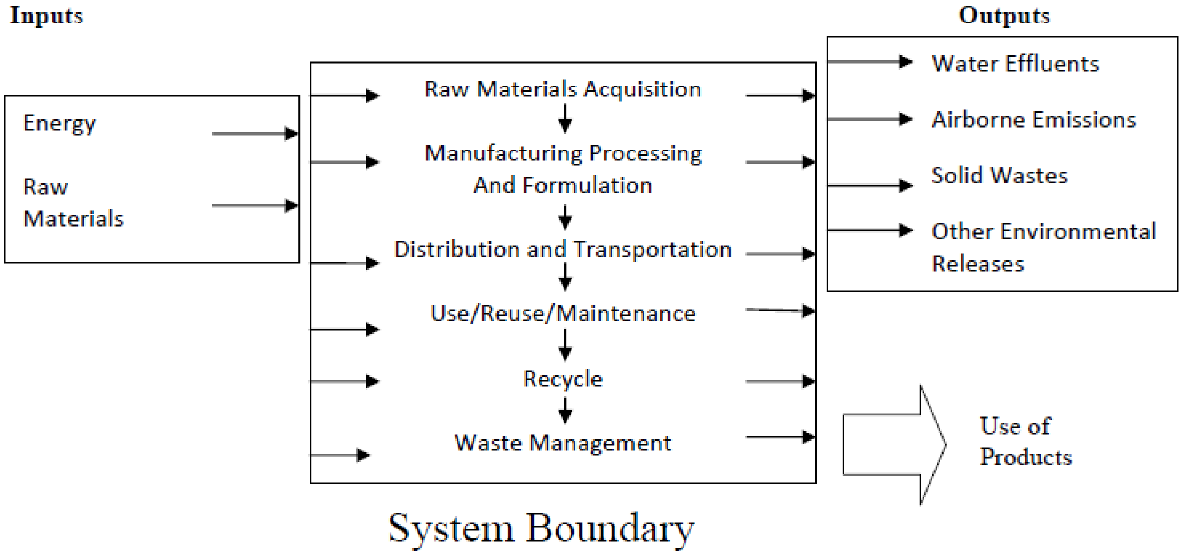

Figure 2.7. Life-cycle process considerations.

Key factors to consider in a vehicle life-cycle are the following:

- Life-cycle Total Energy and Fossil Energy Use (Wh/km): Monitors a vehicle's overall energy use and reliance on fossil-based energy.
- Life-cycle Harmful Tailpipe Emissions (g/km): These emissions − which are mainly particulate matter (PM), volatile organic compounds (VOCs), NO_x, and SO_x, − lead to regional impacts. Specifically, the degradation of public health, mainly from the particulate matter and associated smog formation. This is a point-source emission and is mainly due to the use of fossil- and bio-fuels in ICEs.
- Life-cycle Green House Gas Emissions (g/km): The impact of these emission is global, and thus one must consider the "well-to-wheel" generation of emissions associated with the production and distribution of the energy used, as well as its consumption.

Currently, in North America there are two emissions models accepted to give reasonably accurate life-cycle results and predictions over the next 10 years. Canada's version is a spreadsheet called GHGenius, the US version is called GREET. For the purposes of reporting data in the next three sub-sections below only figures from GHGenius are used since it is better suited to modelling applications in Ontario. Where applicable, the 2009 electricity mix for Ontario is used in.

5.1 Life-cycle GHG Emissions

Presented in Figure 2.8 are the life-cycle emissions for several fuels and energy carriers using as inputs average Canadian values and Ontario's current electrical mix where applicable. Most notable are the significant reductions in GHG emissions for PEVs, which will become larger as the IPSP [40] and GEA [41] are implemented due to the planned phase-out of coal plants and the significant incentives for renewable generation, thus supporting a transition to PEVs in Ontario. The associated costs are discussed in Section 5.2.

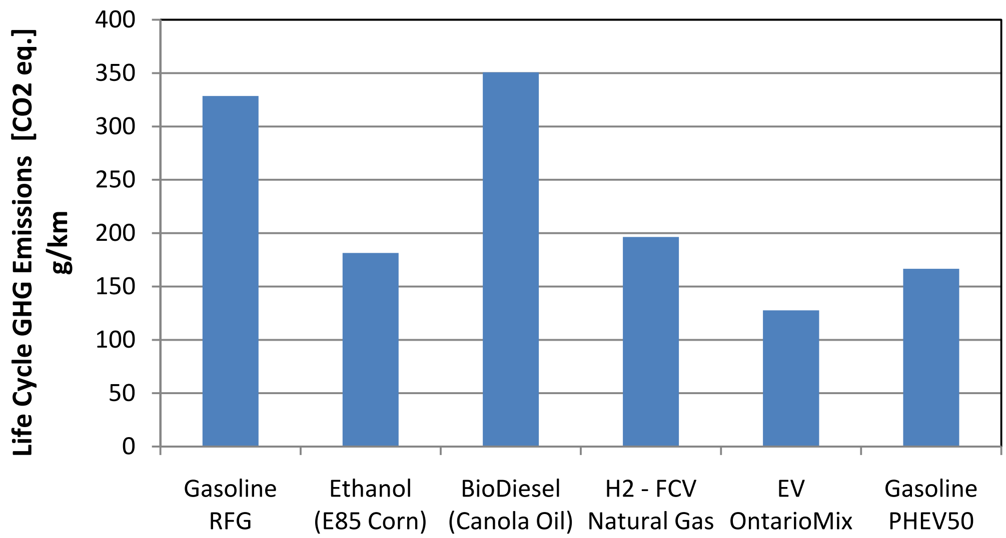

Figure 2.8. Life-cycle GHG emissions for 2009 Ontario generation mix (PHEV50 stands for PHEV50km).

5.2 Life-cycle Energy Use

Life-cycle energy use enables a comparison of significantly different energy sources and consumption technologies. When considering the life-cycle energy use of a vehicle, it is the specific amount of fossil fuel used that is often of greater importance than the total amount of energy used. This is because fossil fuels are associated with both emission concerns, with the depletion of a non-renewable energy resource concerns, and with energy security concerns. That is, it may be reasonable to displace fossil fuel energy use with other forms of energy, even at the cost of using more total energy, if it increases the sustainability of human activities. The life-cycle energy use (both total and fossil fuel) for various vehicle technologies is shown in Figure 2.9 [28].

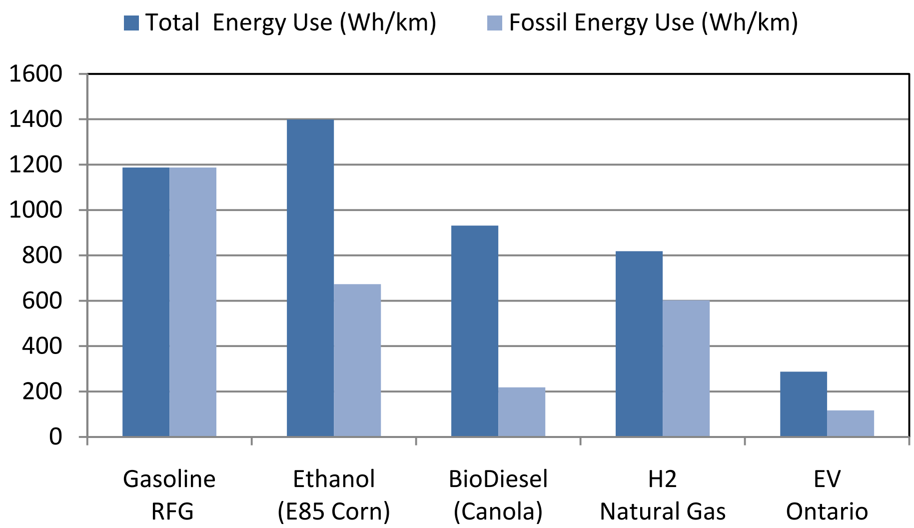

Figure 2.9. Life-cycle fossil and total energy use for 2009 Ontario generation mix.

5.3 *Life-cycle Cost of Vehicles*

In looking at PHEV life-cycle costs and driver satisfaction with life-cycle costs many factors have to be considered. A review of the current literature reveals such studies are limited in both number and scope [29-33]. The difficulty in such analyses is that it requires a large number assumption about electricity cost, fuel economy, driver behavior, km driven per year, length of ownership, capital cost, maintenance cost, and distance of each "trip". Thus a study is really only applicable to a specific driver, in a specific vehicle, with specific electricity and gasoline pricing. Naturally, stochastic analyses with future cost projections and variability could be applied in an academic analysis, and such future studies are recommended. A more detailed discussion of these costs and associated issues is presented in Section 6.2.

5.4 *Useful Value of Services to the Grid for Post-PEV Batteries*

Ancillary services such as voltage and frequency regulation are those services necessary to support the transmission of electric power from seller to purchaser while maintaining reliable operations of the interconnected transmission system. Some of these services require of a "spinning reserve", where generation reserve capacity may be called shortly after an event that causes significant deviation from the standard voltage and frequency of the grid; this service requires a payment to the generator that is ready to increase/reduce power when requested.

Historically, operators have relied on generation resources for ancillary services, with loads playing a marginal role (demand response programs are being more widely implemented nowadays to increase the load participation on some of these services). However, batteries are perfectly suited to provide voltage and frequency regulation services due to their nearly instantaneous response. Batteries are also unique in being able to provide genuine "up" and "down" regulation simultaneously, acting as both a generator (battery discharge) and a load (battery charging).

At the end-of-life in a vehicle batteries (particularly Li-ion batteries), with proper assessment of battery state of health, may be applied to other application such as back-up power or ancillary services. This requires the development of assessment methods for battery state of health (including ongoing in service state of health assessment and monitoring), and development of battery pack management and re-packaging strategies. Considering Li-ion batteries specifically, final disposal presents a number of considerations, including the reactivity of the components in Li-Ion batteries and the fact that recycling techniques based on heavy metal recovery are not applicable. Recycling of Lithium batteries cannot be achieved in conventional E-waste processing facilities.

There is a need for further analysis in Ontario into batteries as ancillary service technology, the economics of repurposing batteries, and technical issues associated with repurposing and recycling batteries. Also needed is work to develop more comprehensive life-cycle management assessments and management tools, for example, vehicle data logging and interface to utilities will need to be developed that include battery state-of-health assessments. In the end, repurposing HEV, PHEV, or BEV batteries improves their life-cycle costing.

On the recycling side more work is needed to determine the feasibility of building a Li-Ion battery recovery, management, repackaging, and Li recycling facility in Ontario (including the economics of such a facility). In general the goals of such a recycling would be as follows:

- keeping individual Li-ion cells in service in an appropriate application as long a possible with cell assessment, monitoring and repackaging protocols;
- recovery of a high percentage of the lithium from the metallic components;
- recovery of the contained cobalt, nickel or manganese for lithium transition metal oxide anode batteries;

- recovery of a high percentage of the lithium contained in the battery electrolyte;
- recovery to the maximum extent possible the other metal and plastic components contained within the battery;
- where possible the lithium and metal components should be recovered in a form where they can be used to produce battery components (either anodes or electrolyte); and
- near zero emissions of toxic materials to either waste water or the atmosphere.

6. Consumer Acceptance Technical Challenges

The introduction of PHEVs to the marketplace creates new concerns for potential buyers due to general inexperience with hybrid technologies. Fuel consumption is a major consideration for consumers today, and the ability to recharge the PHEV's batteries can be seen as an additional complication regarding vehicle's refuelling requirements. Plug-in capability creates an additional need for the vehicle owner to purchase energy, and also requires additional effort to ensure that the battery is charged. For consumers to accept PEVs it is important that they understand the charging process and how it will lead to lower overall fuel costs.

6.1 Consumer Concerns and Considerations

One concern that consumers will have is where they will be able to recharge their PHEV's battery. Recharging the battery requires the vehicle to be connected to the electrical grid. PHEVs can be recharged at the owner's home by plugging into an electrical outlet located in their garage. A specialized high voltage/high current electrical outlet may be required to meet fast charge time expectations; however, a standard electrical outlet can be used too, it is just a matter of charge times. Table 2.4 illustrates the expected charging times and other key characteristics of some basic types of electric vehicles. These issues are discussed in some detail in Chapter 3.

Table 2.4
Expected characteristics of basic PEV types [42].

Type	Range	Full-charge Time 240 V standard outlet	Full-charge Time 120 V standard outlet	Acceleration	Other features
Plug-in hybrid electric vehicle	• 40 miles on a full charge • After 40 miles, gasoline engine provides up to a 600 mile range	2 to 3 hours	7 hours	• Zero to 60 mph in 8 seconds (comparable or better than conventional cars)	• 200+ miles per gallon fuel efficiency through combined electricity and gas use
Electric city car	• 40 to 60 miles on a full charge	3 to 4 hours	10 hours	• Zero to 60 mph in 10 seconds (better than similar conventional cars)	• Low operating cost • Requires less maintenance • Fits into small parking spaces
Full-range electric car	• 100 to 200 miles on a full charge	4 to 5 hours	34 hours	• Zero to 60 mph in 6 seconds (better than similar conventional cars)	• Low operating cost • Requires less maintenance

In addition to expectations about the time it takes to charge a PHEV battery, there will also be time of day charging considerations to contend with, as discussed in great detail in Chapter 3. A full charge using a standard outlet typically takes several hours, so the ideal time for charging would either be overnight or during work hours when the vehicle is not needed. Workplace charging stations will need to be developed to provide complementary charging facilities away from home.

Another consideration for the consumer is the frequency at which the battery should be recharged. Consumers may assume that the battery's SOC is similar to a fuel gauge and that it requires recharging whenever it reaches a low level, i.e., runs out of "fuel". Since consumers are accustomed to a vehicle which stops functioning when it runs out of its gasoline, they may believe that the PHEV battery will also cause the vehicle to stop working once the charge is depleted. This is not true since the vehicle is capable of operating in a charge-sustaining mode, using the combustion engine for primary power, i.e., the traditional HEV mode, once the battery is depleted. As such, a PHEV should be charged on a nightly basis to benefit from all-electric driving; however, forgetting to recharge the battery or driving beyond the all-electric range will not cause the vehicle to stop working, but it will decrease the benefits to the consumer and the local emission benefits that derive from all-electric driving.

Consumers will be concerned about the costs associated with charging a PHEV's battery. Plugging-in to the grid at home will result in larger electrical bills for the vehicle owner. However, these increased electrical costs are offset by a large reduction in gasoline consumption, and so the consumer will experience net monetary savings. For example, in Ontario a modest cost estimate for electricity is 10 cents per kWh. If one assumes a litre of gasoline in Ontario costs one dollar CAD (on average) then a comparison of vehicle operating costs can be made. Based on a rough powertrain efficiency estimate, the cost of operating (charging) a PHEV would be approximately 3 to 5 times less than using gasoline. Given the importance of cost considerations to consumers and the importance of life-cycles to appreciating the benefits of PEVs life-cycle costing is specifically discussed in more detail in the next section.

The amount of all-electric driving/range that can be accomplished with a PHEV will be of concern to the consumer as it directly translates into the amount of gasoline they will be able to displace. A recent goal for the all-electric range for a midsize vehicle is 40 miles (64 km) assuming the vehicle begins with a fully-charged battery (e.g., the Chevy Volt). However, vehicles with 60 miles (97 km) of all-electric range currently exist and technological advances continue to increase the range of electric-only operation. As previously noted, this is not the maximum range of the PHEV or E-REV vehicle since it can continue to operate using the ICE once the battery is depleted.

6.2 Life-Cycle Costing

It is estimated that a conventional ICE car costs about 5-10 cents a mile to operate at current gasoline prices. A plug-in hybrid could run on electricity at 1-2 cents a km assuming electricity costing about 8 cents a kWh. Thus, even a rough estimate look at PHEVs reveals dramatic fuel cost benefits of at least a 3 to 5 times for a given fuel economy for the ICE vehicle, and for a give electricity price. These factors are highly variable with respect to location, time, cost of gasoline, economic conditions, and government incentives. We note that the fuel economy of ICE vehicles continues to improve, and fuel economy of gasoline powered HEVs is also offering an improvement even without the plug-in option. Also, HEV and PHEV vehicles benefit from better design features embedded through advances in technology developments (e.g., tire design, and weight) and less fuel economy negative features (e.g., roof racks).

The current gasoline based HEVs have failed to achieve claimed fuel economy ratings due to many factors and this has disappointed consumers. For starters, the standardized drive cycles used during the government mileage tests for vehicle fuel economy ratings do not reflect personal driving behavior, routes, or road conditions. For example, the test's top highway speed is 100 km/h while many drivers often exceed this velocity in highway driving.

Another factor influencing fuel economy in Canada is wintertime heating demands, which result in the engine running more often than a control strategy that simply maximizes fuel economy would provide for. The impact of wintertime heating can be quite a large decline in observed fuel efficiency. Air conditioning loads can have a similar detrimental impact on observed HEV fuel efficiency. More development is needed in electric vehicle accessories such as air conditioning and heating. As well, the control systems for electric vehicle winter driving require further development. For example, for Ontario's climate, the development of control systems to preheat vehicles with plug-in grid power prior to a winter trip is vital to conserving onboard electrical power.

Driver behavior is a key factor impacting observed HEV fuel economy. Computer control software decides when to run the engine, when to run the electric motor or recharge the battery, and how to employ regenerative braking, but this software still relies on driver input. Motorists who optimize their driving for hybrids by coasting to stops and gently accelerating get the best mileage with HEVs or PEVs. Aggressive driving can cause the fuel efficiency of hybrid vehicles to decrease by more than 30 percent. HEVs generally do come with advanced driver graphical user interfaces which serve to "teach" drivers to have better driving habits which will result in better fuel economy. Strong HEVs or PEVs get the best mileage in stop-and-go traffic but offer fewer benefits in the highway driving.

PHEVs do have the potential to match current driving habits and needs, with these vehicles expected to typically fall in the PHEV 10-60 km range. Such PHEVs are potentially well-matched to American motorists' driving habits. In particular, the distribution of distances traveled each day, based on prototypes and data collected by the National Personal Transportation Survey (NPTS) in 1995, has 50% of the days travelled being less than 48 km.

Although comprehensive studies have yet to be done, and more study is recommended, Ontario drivers likely have longer trips.

A low-daily-mileage characteristic of current drivers is why PHEVs have potential to displace a large fraction of per-vehicle petroleum consumption. Studies are needed to provide Ontario relevant estimates of the magnitude of this petroleum displacement benefit.

For fleet vehicles in Ontario, consultants such as CrossChasm Technologies in Waterloo, provide services to analyze “trip” behavior and thus can recommend the best hybrid vehicle technology for a particular application form both economic and environmental perspectives. Such work is primarily model based. Continued development of high fidelity HEV, PHEV, and BEV models is necessary for improved decision making in implementing, and more rapid prototyping of, such vehicles.

A number of studies have conducted detailed life-cycle cost analysis of HEVs. Few studies are available with respect to PHEV life-cycle costs, which is to be expected as there are no OEM PHEV vehicles offered at this time. And the few studies that do exist are in general not objective nor independent. Figure 2.10 shows some of the factors to be considered in the life-cycle costing for HEVs; for PHEVs, one would also have to include grid electricity recharge costs. The studies that do exist tend to show a breakeven point for HEVs operating on gasoline at about $1.49 per gallon to $2.65 per gallon (U.S. units retained from the published study). Therefore, HEVs are considered close to the breakeven cost of ownership at today’s gasoline prices [31]. Note that this study assumed a capital cost premium of $3,000 to $5,000 extra for an HEV. Firm pricing for PHEVs has yet to be established but if the cost premium is in the $10,000 plus range, then it will take a combination of these three factors to achieve break-even: (i) greater use of low cost electricity to displace gasoline and offset higher gasoline fuel costs, (ii) significant reduction in battery cost and (iii) during the early phase, government incentives to allow economies of scale to be fully developed. Clearly more detailed life-cycle cost analysis of vehicle ownership costs is required, as well as objective and independent academic analyses. Finally, it is important to point out that, from a policy viewpoint, the “social cost benefits” of PHEVs need to be considered, since there is the potential to reduced health costs from improved air quality.

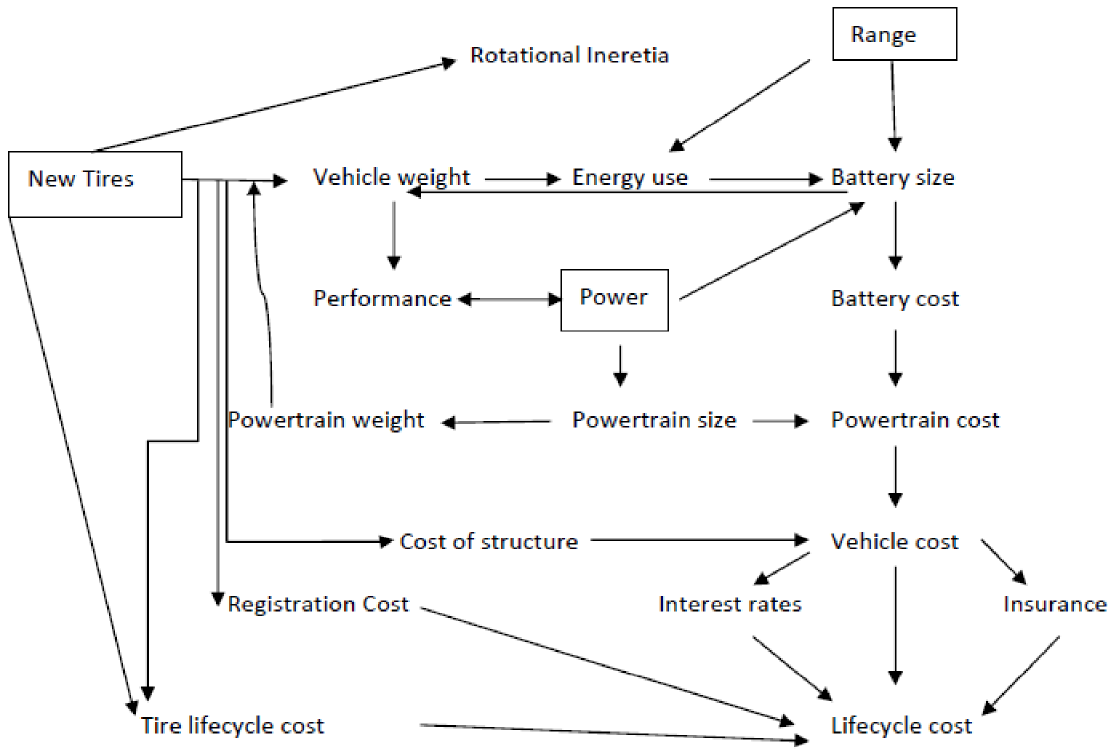

Figure 2.10. Retail and life-cycle costs for an HEV [31].

6.3 *Car Sharing*

Car sharing is a transportation concept worth noting in a discussion of PEVs. Car sharing is where individuals experience the benefits of using private vehicles without the costs and responsibilities of vehicle ownership. Instead of owning one or more vehicles, a household accesses a fleet of vehicles on an as-need basis. The impacts of car sharing can be categorized into transportation, environmental, land use, social, and economic effects. A major impact of car sharing on the transportation system is a reduction in vehicle ownership. Canadian studies and member surveys suggest that between 15% and 29% of car sharing participants sold a vehicle after joining a car sharing program, whereas 25% to 61% delayed or had forgone a vehicle purchase. Furthermore, Canadian research showed that each car sharing vehicle removes between six and twenty-three cars from the roads. A reduction in vehicle ownership, in turn, is likely to result in fewer vehicle km traveled (VKT), reduced traffic congestion and parking demand, and an increase in the use of public transportation and other transport modes such as biking and walking. As well, reduced vehicle ownership and VKT results in lower greenhouse gas (GHG) emissions. Car sharing also shows evidence of beneficial social impacts. Many households can gain or maintain vehicle access without bearing the full costs of car ownership. Low-income households and college students can also benefit from participating in car sharing [34], [35]. The notable negative to car sharing is the reduced economic activity due to fewer car sales.

PEVs slightly disrupt the car sharing model primarily due to the time they take to recharge, time a car sharing service would not be earning revenue. Advanced technology projects that integrate battery SOC information into the vehicle reservation system can help to minimize downtime for charging, but cannot avoid it entirely. For example, by knowing when it is advantageous to charge during the more expensive daytime peak hours, at designated ”charging points”, for short periods of time in order to reduce charge time later and enable sooner re-release of the car shared vehicle.

6.4 Low Speed Electric Vehicles (LSEV)

LSEV technology has taken on an accelerated pace in the past few years. There are many rules and regulations that govern the use of LSEVs in Ontario. They can be operated by any person with a valid Class A, B, C, D, E, F, or G driver’s license on roads with speed limits of 50 km/h or less on Pelee Island, within 50 m of property owned or occupied by a university or college of applied arts and technology, and between private properties by directly crossing certain public roads subject to specific equipment requirements and operating conditions. They can also be operated by any person with a valid Class A, B, C, D, E, F, or G driver’s license on public roads with speed limits of 50 km/h or less province-wide provided the LSEV meets prescribed additional equipment requirements and Canada Motor Vehicle Safety Standards (CMVSS).

As per the Ontario Ministry of Transportation classification system [36], a “low-speed vehicle” means a vehicle, other than an all-terrain vehicle or a vehicle imported temporarily for special purposes, that:

- is designed for use primarily on streets and roads where the access and use of other classes of vehicles are controlled by law or agreement;
- is powered by an electric powertrain;
- does not produce emissions;
- is designed to travel on four wheels;

- does not use fuel as an on-board source of energy;
- has a gross vehicle weight rating of less than 1,361 kg;
- has an attainable speed in 1.6 km of more than 32 km/h but not more than 40 km/h, on a paved level surface; and
- meets the Transport Canada Technical Document 500 standards for LSEVs.

This means LSEVs are required to have, at minimum, equipment such as headlamps, turn signals, parking brake, windshield, seat belt assembly, and exterior and interior mirrors. ZENN (Zero Emission, No Noise) is a 2-seat BEVbuilt by ZENN Motor Company (a Canadian company based in Toronto), and is designed to qualify as a LSEV, although the company has indicated that it will now focus only the power train. It has a range of up to 64 km, does not exceed 40 km/h, and weighs 544kg. TH!NK is a Norwegian company that offers an easily recyclable electric car with a 200 km range. It has 2 seats and 3 doors including the rear hatch [37], [38].

Although the outlook for EVs has shifted dramatically since the 1990s there continues to be regulatory challenges related to electric vehicle safety, so commercially viable LSEVs are not yet on the market. In addition, current LSEVs do not provide the consumer features, range, performance, personal comfort, safety, and reliable operation demanded by the public. If these challenges can be met there would be more rapid and wider penetration of electric vehicles. Referring back to Figure 2.3, BEVs are seen as a medium to long range future general transportation vehicle technology.

6.5 Trip Range and Its Impact on PHEV Benefits

Critical to an understanding of the environmental impact associated with PHEVs is driver behaviour. Ideally, a driver would recharge his or her vehicle each night during off-peak hours, drive the vehicle the next day only within the vehicle's "all-electric" range, and then recharge at night again. To limit all PHEVs to their all-electric range is clearly unrealistic, and so one could divide total annual PHEV use into two categories: all-electric and ICE-powered. For example, if a vehicle is used for 20,000 km each year, 12,000 km might be short trips within the all-electric range, i.e., short trips after a recharge period, with the other 8,000 km travelled using onboard fuel, which in PHEVs means making use of the gasoline ICE as a range extender. This again is a simplistic assumption, as the onboard vehicle control system will likely permit some km to be driven with a combination of electric and ICE power. Nevertheless, these two categories of PHEV operation emphasizes the concept that even for drivers that travel the same number of km each year, certain drivers will greatly benefit from a PHEV if they live close to work and only do short trips each day, while others will benefit little if they do long trips a few days each week.

The 2001 National Household Transportation Survey (NHTS) conducted by the U.S. Department of Transportation provides general driving data for U.S. drivers. In particular it provides the cumulative frequency of distances driven per trip for the U.S. population, also known as the utility factor. In 2008 Argonne National Laboratories used the utility factor for calculating the fuel economy of a national fleet of PHEVs. The Canadian Vehicular Survey (CVS) is published quarterly by Statistics Canada and is the largest set of data on the general Canadian driving population. Unfortunately only aggregate numbers, such as total km driven by the Canadian population, are published. As such, obtaining a utility factor curve for the Canadian population is difficult using the CVS. However, smaller studies have been conducted which require participants to keep travel diaries. An example is the 2006 Transportation Tomorrow Survey, conducted by the Data Management Group at the University of Toronto, which surveyed drivers in the Greater Toronto Area. Figure 2.11 contains utility factors from two sources: the 2006 Transportation Tomorrow Survey for the Greater Toronto Area and the 2001 National Household Transportation Survey for the general U.S. population [43-45].

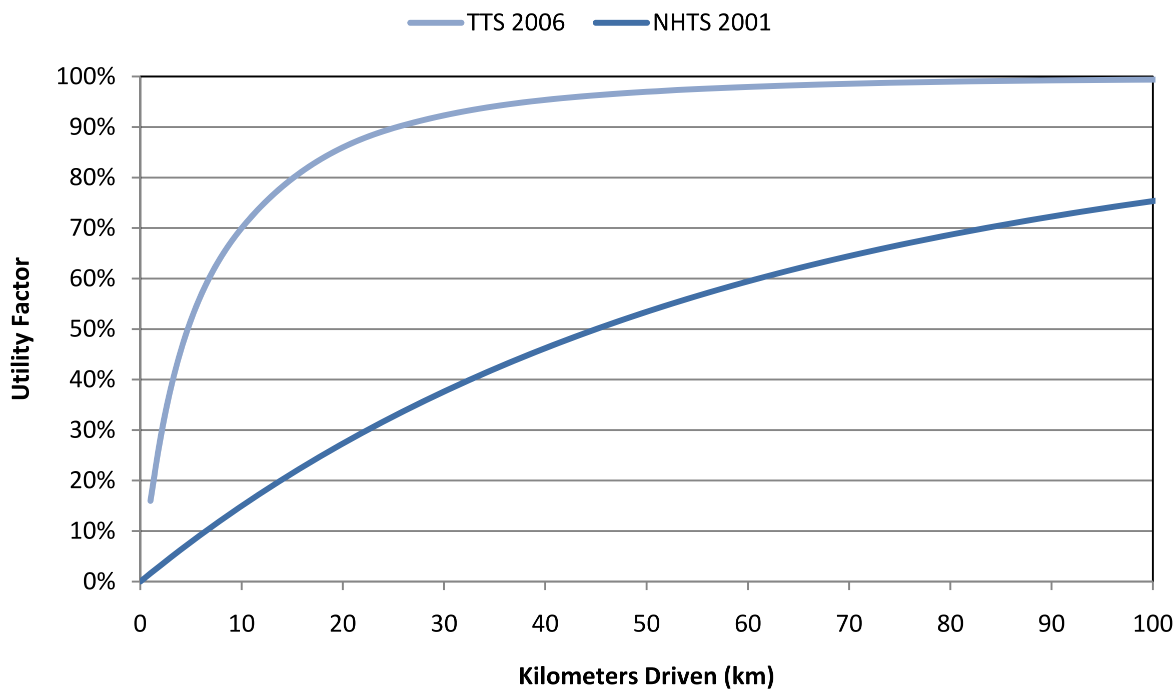

Figure 2.11. Utility factor indicates the fraction of total kilometers driven which use only electric energy [39].

Based on Figure 2.11 and the NHTS data, a PHEV with a charge depletion range of 60 km would expect to spend about 60% of the time travelling in charge depletion mode, i.e., all-electric mode, and 40% of the time in charge sustaining mode, i.e., gasoline ICE running mode. However, in sharp contrast, based on the TTS data, a PHEV with a charge depletion range of 60 km would expect to spend about 97 % of the time travelling in charge depletion mode and 3 % of the time in charge sustaining mode. The wide discrepancy between these two results clearly dictates that more work is needed to better understand the trip or utility factor profiles specific to Ontario, if the benefit of PHEVs to Ontario's fleet mix is to be well understood.

7. Appendix

7.1 Biofuels: Ethanol and Biodiesel

Pure ethanol is not currently used in Canada as a transportation fuel but rather as a gasoline additive. Regulations will soon be enacted that will require a minimum renewable fuels content of 5% for gasoline by 2010, and 2% for diesel by 2012. Evidence of this policy can be found in gasoline today, where a maximum ethanol content (usually 10%) is often stated. This concentration does not adversely affect internal combustion engine components [5], and this blending of low levels of ethanol with gasoline (e.g., E10) have been shown to improve the emissions from gasoline ICEs [6].

E85 (85% ethanol, 15% gasoline) is a common mixture that can only be used in specially-designed “Flex Fuel” vehicles. Compared to gasoline, 42% more E85 is required by volume to travel the same distance based on the respective energy contents of the two fuels [7]. Arguably, in practice, the difference is usually smaller as E85 has a higher octane rating than gasoline and can operate in an ICE with a higher compression ratio and therefore a higher efficiency. Nevertheless, from an end-user point of view more E85 will be required to travel the same distance. Ethanol can be produced from multiple renewable resources such as corn, wheat, soy, cellulose (from wood chips, grasses, etc.). However, the benefits of ethanol are highly dependent on the feedstock and production process with estimates of the units of petroleum needed to produce a unit of ethanol ranging from less than one to greater than one. Another consideration concerning fuel ethanol are its impacts on food prices and food availability [8-10].

Biodiesel is typically made from vegetable oils or animal fats and may be mixed with commercially available diesel fuel. Blends of 20 percent biodiesel with conventional diesel fuel (referred to as B20) can generally be used in unmodified diesel engines. Blends up to 100 percent biodiesel can be used in modified diesel engines. Significant reductions in particulates and hydrocarbon emissions have been observed with biodiesel combustion with only small increases in NO_x emissions (less than 10%) [7]. Diesel engines are already well known for their high efficiencies resulting from their high compressions ratios compared to gasoline engines. Again, the environmental benefits are uncertain when using energy crops to produce bio-fuels, and there are significant impacts on food price and availability.

Life-cycle assessments performed by different agencies on the use of bio-fuels often result in conflicting results, even when considering similar fuel production pathways. Some of these differences are attributable to the analysis assumptions made, especially those regarding the impacts of NO_2 emissions and those related to agrichemical (and pesticide) movement via surface flow to local drinking water and other water sinks. Often there are significant impacts from the co-products of bio-fuel production, and the decision to neglect or include them in a life-cycle analysis can affect the outcome [5], [11].

In conclusion, E10 is and will continue to be a common fuel blend while E85 is expected to play a small role in the displacement of fossil fuels. Biodiesel is expected to play a greater and greater role in the displacement of fossil fuels, especially if alternative methods of production, such as from algae, become viable. However, biodiesel will likely only be in B5 to B20 blends simply because of raw product limitations.

7.2 Hydrogen

Hydrogen as an energy carrier can be produced from multiple energy resources such as fossil fuels, nuclear, and renewables for multiple end-uses. This has led to the development of the *hydrogen economy* concept which concentrates on the study of the economic aspects associated with the production, distribution, and utilization of hydrogen in energy conversion systems. Hydrogen is a desirable long term energy vector because it can be stored and used to generate electricity, it can be produced from a diversified range of production pathways, it represents a secure energy supply, and when used in transportation applications it results in decreased urban pollution and GHG emissions. From the electrical grid management point of view, the use of hydrogen as an energy carrier is appealing in the context of energy storage impacts on competitive electricity markets, i.e., enabling advantage to be taken of the significant price differences between peak and off-peak pricing hours (which may or may not necessarily coincide with peak and off-peak demand hours).

For transportation purposes hydrogen can be burned in an ICE, however, this mode of operation will produce NO_x emissions, a primary and necessary ingredient to the soup that creates smog. Furthermore, there is a more efficiency alternative to the ICE when hydrogen is used, and that is the fuel cell. For automotive applications a proton exchange membrane (PEM) type fuel cell is typically used, as it has the best characteristics (size, mass, operating temperatures) for automotive applications.

The transportation sector contributes significantly to GHG emissions in Canada, making up 22% of Canada's CO_2 emissions [13]. Canada's federal government has targeted a 60-70% reduction in GHG emissions, relative to 2006 levels, by 2050 [6]. A fuel cell vehicle (FCV) is one of only two transportation technologies that can achieve this goal, the other being BEVs, however, BEVs are foreseen to continue to be challenged by limited range, limited durability, and long recharge times. FCVs can truly have zero emissions on a well-to-wheels basis when fuelled with hydrogen that has been produced using renewable energy. Even when fuel cells use hydrogen made from natural gas, the GHG reductions are over 50% as compared to today's ICE vehicles. While other technologies (e.g., HEV, PHEV) will contribute to GHG reductions, the deepest cuts in fossil fuels use and GHG emissions come from the use of FCVs or BEVs. At high volumes, fuel cells offer the potential for the lowest life-cycle costs of all zero-emission technologies, and hence are expected to be the superior long term solution (see Figure 2.3).

It is worth noting that an extended-range electric vehicle (E-REV) such as the Chevy Volt is in truth still an ICE PHEV but with very strong hybridization or electrification. FCVs too are also PHEVs and may be used as the primary power plant or as the "range extender." That is, PHEV architectures are both the near and long term future for vehicle powertrains.

It is expected that HEV, PHEVs, and E-REVs will be transitioning technologies as the hydrogen economy and associated technology and infrastructure is developed and prototyped. Although this document focuses on the transition to PEVs, there is a need to consider hydrogen as an important part of integrated energy systems in the long-term, i.e., beyond 2020.

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CHAPTER 3 − ELECTRICITY SECTOR DEVELOPMENT AND NEEDS

1. Introduction

Present and future electrical infrastructures are designed to meet the highest expected demand, which occurs only a few hundred hours per year. Hence, the grid is in general underutilized and thus could generate and deliver a substantial amount of energy for energizing PEVs, i.e., Plug-in Hybrid Electric Vehicles (PHEVs) and Battery EVs (BEVs). However, the introduction of PEVs in the transport sector must consider their interaction with existing and planned electrical energy resources and infrastructures. Thus, if electricity is produced from high polluting sources, the environmental advantages of PEVs would be limited [1]. In the case of Ontario, as per the Integrated Power System Plan (IPSP) [2] and more recently the Green Energy Act (GEA) [3], most of the electricity generation by 2025 will be environmentally friendly, as coal plants are planned to be phased out by 2014. Furthermore, the development of renewable energy resources is given significant importance in the IPSP and more so in the GEA; thus, the target value of total renewable energy in 2025 is 15,700 MW in the IPSP, which is about 40% of total capacity, of which about 4,700 MW is wind power [4], whereas the estimates associated with the GEA are of 25,000 MW above 2003 levels [5]. However, the intermittent behavior of wind and solar, and their consequent low capacity factors make the development of these resources a challenging task. In this context, the integration of PEVs into Ontario’s transport sector will provide an opportunity for the better utilization of these resources and eventually add energy storage capacity for Ontario’s grid, thus facilitating the integration of these intermittent energy resources. With all this in mind, research work must be carried out for the appropriate adoption and integration of PEVs, with the objective of maximizing their benefits and minimizing the associated costs.

In view of the technical and environmental advantages of PEVs, their interactions with the grid should be analyzed in detail. Thus, several papers and reports can be found in the technical literature discussing generation, transmission and distribution system issues associated with different levels of PEV penetration in the transportation sector at various locations in Europe and North America. For example, in [6], both PHEV charging and discharging is studied in six geographic regions in the United States to examine the grid impacts for different PHEV penetration levels up to a maximum level of 50%; this study disregards the environmental impacts as well as different types of vehicles, and it assumes a unique average value for the energy requirements of all PHEVs. Based on different charging scenarios, the authors in [7] evaluate various PHEV-charging impacts on utility system operations within the Xcel Energy Colorado service territory; environmental issues are also studied, evaluating different types of emissions considering the time of charging and the marginal power plant. In [8], the impact of PHEVs on both generation supply and emission for the Virginia-Carolinas electric grid in 2018 is evaluated for different charging levels and timing, based on a gradual ramp up of PHEV market share to 25% in 2018; this analysis is also extended to all regions of the U.S., finding the marginal power plants in different regions for different charging patterns. In [9], the percentage of the U.S. light-duty vehicle that could potentially be supplied by U.S. electricity infrastructure without additional investments in generation, transmission and distribution capacities is estimated in 2007; the impact on overall emissions of criteria gases and greenhouse gases is also studied. The same authors conclude in [10] that the existent distribution system infrastructure in the Pacific Northwest would be capable of supporting an approximately 22% PHEV share of the light-duty vehicle fleet with smart-charging technologies, which basically avoid charging EVs at peak hours. In [11], the transition to grid-charged vehicles in Ontario is discussed; motivated by the notion of efficient utilization of the existing infrastructure and the concept of integrated energy systems, an optimization planning model that takes into account the grid and the transportation sector as one integrated system is presented and discussed, determining that the maximum level of PHEV's penetration into Ontario's transport sector without impacting the existent and planned generation and transmission systems would be approximately 6%, based on the proposed constrained planning framework and taking into account the environmental benefits of PHEVs. Smart demand management of power systems integrated with PHEVs is studied in [12] for an urban area with a relatively small number of PHEVs; a smart agent-based demand management scheme is proposed based on nonlinear pricing to assure proper distribution of the available energy to PHEV customers. The issue of PHEV charging strategies and their impacts on generation expansion planning is studied in [13]; this study identifies the future required generation infrastructure based on an assumed high penetration of PHEVs. Finally, in [14], the societal benefits of vehicle-to-grid (V2G) and vehicle-to-home (V2H) power are discussed, based on additional revenue streams for cleaner vehicles such as the provision of some ancillary services in electricity markets, decreased grid congestion, lower electric system costs, and storage and backup capacity for renewable electricity.

Utilities throughout the US and Canada as well as EPRI are currently carrying out studies and developing demonstration projects to better understand a variety issues associated with PEVs and their interactions with the grid. For example, EPRI has undertaken various projects to conduct a comprehensive evaluation of PHEV benefits and grid impacts (e.g. [31]), and is currently concentrating on the study of the loading impact of these vehicles on distribution system operations using real distribution circuits and measured data [15]. Canadian utilities are also performing a variety of PHEV grid impact studies in association with the Centre for Energy Advancement through Technological Innovation (CEATI), with various utilities, namely, Hydro Quebec, Manitoba Hydro and BC Hydro, reporting very recently at a web-seminar some of their findings. Hydro One is as well in the process of setting up a "sandbox" in the Owen Sound area where a variety of new Smart Grid technologies will be implemented and tested to determine their advantages and disadvantages; an important part of this initiative is the integration and study of a fleet of PHEV bucket-trucks as part of the Smart Grid technology mix. Also, Burlington Hydro has recently launched its GridSmartCity™ initiative as the first step in the evolution toward an intelligent community distribution grid; key features of this initiative are the introduction of light duty PHEVs onto the electrical grid for performance and potential impact evaluation, and using PEV batteries as a storage for supplemental power to reduce peak loads and enable renewable generation technologies such as wind and solar.

Based on a thorough review of the state-of-the-art, the main goal of this section of the report is to identify and discuss the main issues associated with the expected interactions between Ontario's electricity network and market and PEVs, in view of the characteristics and limitations of PEVs as well as the generation, transmission and distribution system infrastructure. Therefore, it is important to first discuss briefly the main characteristics and issues of Ontario's grid and its electricity market, present and planned.

1.1 Overview of Ontario's Grid and Electricity Market

Ontario's transmission system, controlled by the Independent Electricity System Operator (IESO), includes all transmission lines at voltage levels equal to or greater than 50 kV located within the Ontario control area, and includes all distribution systems and loads in Ontario [16].

The total length of transmission lines is nearly 31,000 km, mostly owned and operated by Hydro One, which is wholly owned by the government of Ontario. The installed generation capacity within Ontario's control area amounts to 31,000 MW, with a peak system demand of 27,000 MW. The Ontario system interconnects with Michigan, Minnesota, New York, Manitoba, and Quebec, importing up to 4,000 MW of electricity into the province. The IESO-controlled grid is divided into several transmission zones as illustrated in Figure 3.1. The average demands in each one of these zones are depicted in Figure 3.2 for a couple of years; note the significant electricity demand in the Toronto zone, which is to be expected given the GTA population, where both demand and population will play a significant role with respect to the impact of PEVs on the grid, as well as the capability of the grid to supply the PEV electricity demand in this zone.

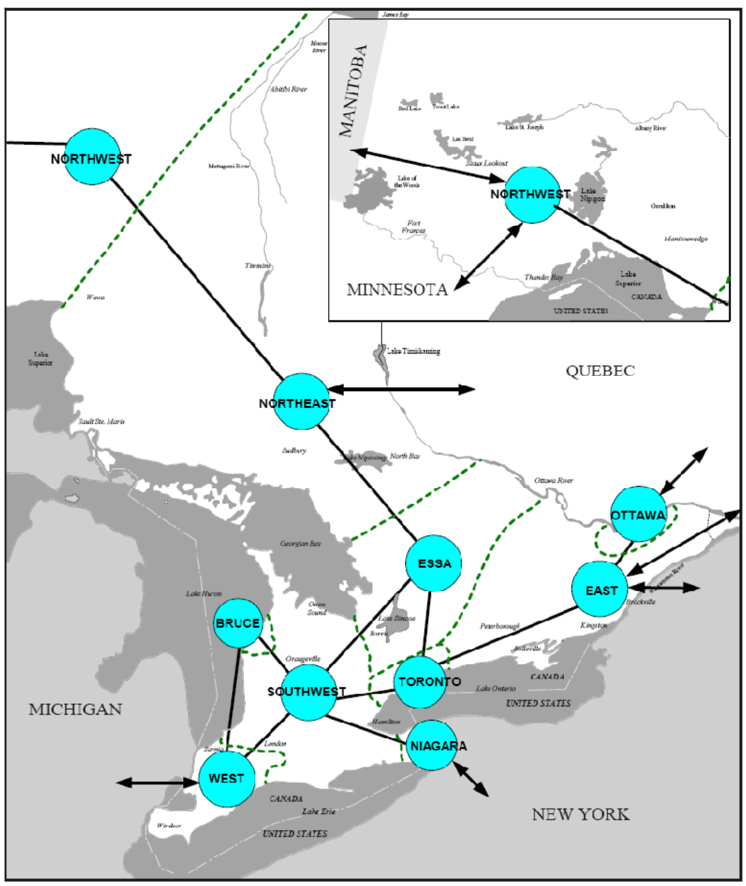


Figure 3.1. Ontario's transmission zones [source: IESO].

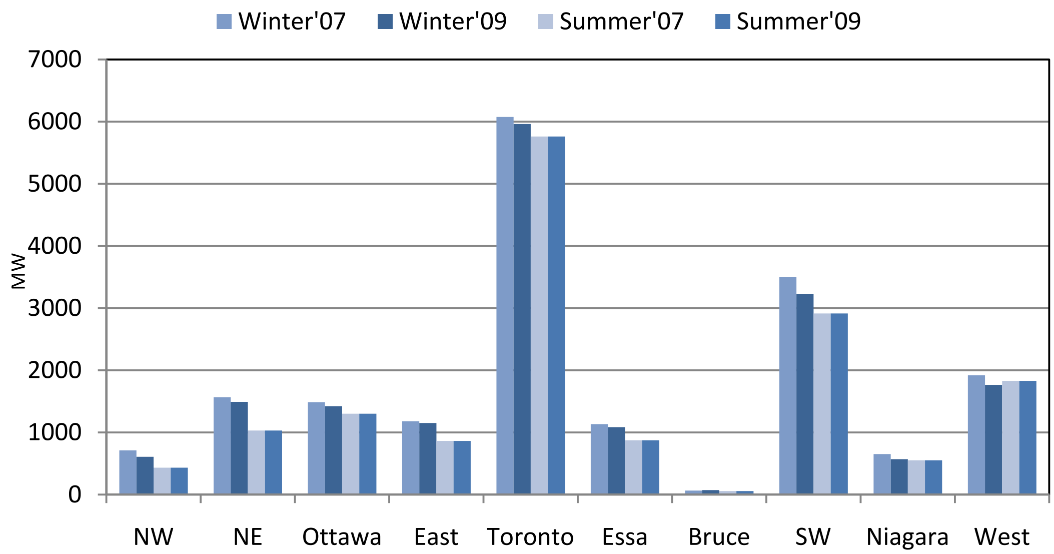


Figure 3.2. Average demands by season for 2007 and 2009.

The current generation available capacity with respect to maximum demand for Ontario is depicted in Figure 3.3, whereas the generation capacity and the corresponding energy supplied by the different energy sources are depicted in Figures 3.4 and 3.5, respectively. Typically, nuclear, coal and large hydroelectric facilities run continuously to supply the base load, whereas fossil-fuel generators (mostly gas) and small hydro generally run during the day to supply peak demand. There are more than 20 different companies that own and operate power generators in Ontario, with the largest being Ontario Power Generation (OPG), which is wholly owned by the government of Ontario and controls 70% of the generation in the province.

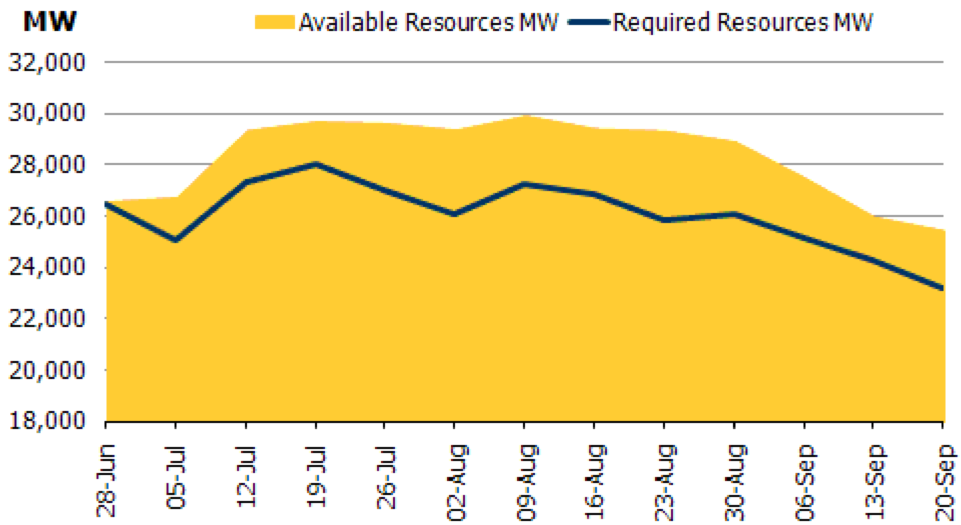


Figure 3.3. Summer 2009 supply outlook for Ontario [source: IESO].

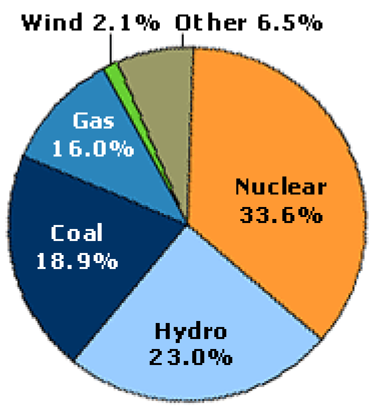


Figure 3.4. Ontario's 2009 installed generation capacity [source: IESO].

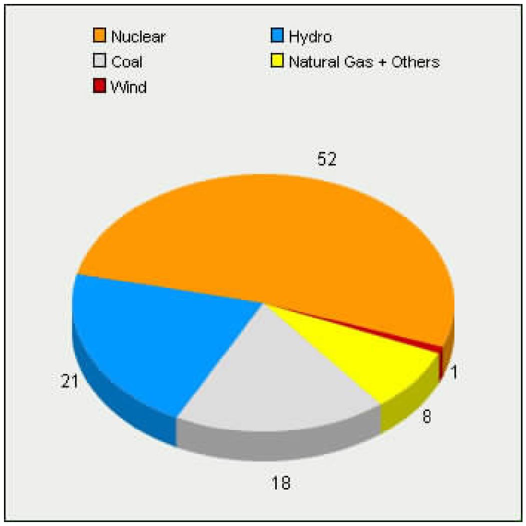


Figure 3.5. Electrical energy supply in Ontario in 2009 [source: Ministry of Energy].

The Ontario wholesale competitive electricity market opened on May 1, 2002. This market consists of a real-time physical market for energy and operating reserves, and a Financial Transmission Rights (FTR) market, and is regulated by the Ontario Energy Board (OEB). The Electricity Act of 2004 renamed the IMO as the IESO and its core responsibility is to operate the Ontario wholesale electricity market [17].

The supply and demand side entities within the province having direct connection to the transmission network must participate in the Ontario electricity market. These entities consist of generation companies, large industrial loads, and local distribution companies (LDCs). Other parties with physical assets which are connected to the distribution network, referred to as "embedded" facilities, can choose to either participate in the market or buy/sell power through contracts with power retailers. There are, however, other market participants without a physical connection, such as power traders, or boundary entities who import/export power to/from Ontario, which may participate in the physical or financial markets. There are 91 LDCs throughout the province that purchase electricity through the IESO on behalf of all its customers, which can be wholesale rate customers (industrial and commercial users that consume more than 250,000 kWh/year) and pay the wholesale price, and fixed rate customers (residential and certain users such as schools and hospitals) which account for close to half of the electricity consumption in the province.

1.2 Ontario's Plans

Until the introduction of the GEA, the IPSP constituted Ontario's basic expansion plan for the electricity grid up to the year 2025. This plan is currently under revision to meet the GEA requirements for more aggressive adoption and integration of renewable generation sources as well as demand reduction programs. In the absence of a revised and detailed plan at the moment, the analyses and discussion presented hereafter are based on the IPSP and other IESO's and Ontario Power Authority's (OPA's) public documents, which have been properly summarized in [11].

The IPSP and other OPA documents ascertain the generation and transmission plans to supply the expected system demand in Ontario up to 2025. Based on the zonal peak demand forecasts from 2007 to 2015, the forecasted load increase rates for base- and peak-load annual growth rates, respectively, and Ontario's average base-load demand in 2007, the average values of annual peak demand growth rates shown in Table 3.1 are defined in [11]. These rates can be reasonably assumed to be valid for the 2008-2025 period considered in this report, and yield the peak- and base-load demands illustrated in Figure 3.6. (It should be noted that the demand in 2009 was lower than forecasted−e.g. 24,380 MW actual peak demand versus a forecasted 25,634 MW−which can be mainly attributed to the economic recession.)

Table 3.1
Estimated percent of zonal annual growth rate in Ontario.

	Bruce	West	SW	Niagara	Toronto	East	Ottawa	Essa	NE	NW
Peak-load	0.78	1.14	1.28	0.41	0.77	0.71	1.42	1.17	-0.33	0.10
Base-load	1.03	1.52	1.70	0.54	1.03	0.94	1.89	1.55	-0.44	0.14

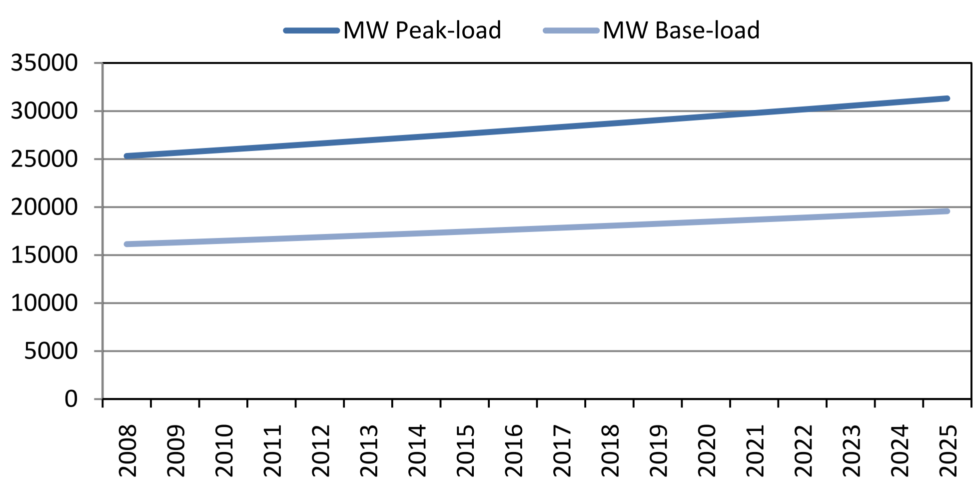


Figure 3.6. Peak- and base-load demand in Ontario.

As previously mentioned, the IESO divides Ontario's system into 10 zones; based on this representation, a 10-bus simplified model of Ontario's transmission grid corresponding to Figure 3.1 is proposed in [11] for PHEV impact studies. This model considers the main grid load and generation centers and transmission corridors, and corresponds to mostly the 500 kV network with a 230 kV interconnection between NE and NW. Based on the existing and planned projects as per the OPA, Table 3.2 illustrates the expected transmission capacity enhancements for this simplified model.

Table 3.2
Estimated main transmission corridor enhancements [11]

Year	Corridor	Current MW	Planned MW
2012	Bruce-SW	2560	4560
2012	SW-Toronto	3212	5212
2013	NE-NW	350	550
2015	Bruce-West	1940	2440
2017	Toronto-Essa	2000	2500
2017	Essa-NE	1900	2400

Based on the IPSP and a variety of information provided by the OPA and the IESO, a zonal pattern of generation capacity between 2008 and 2025 in Ontario is proposed in [11]. This pattern concentrates on base-load supply, since to avoid affecting the peak-load demand, PEVs are considered (and should) be charged during off-peak hours, and preferably during base-load hours, i.e., 12-7am as per IESO definitions. Considering this assumption, the total effective generation capacity available in each Ontario zone to supply the base-load in the 2008-2025 utilized throughout this report is depicted in Figure 3.7. The mix of base-load generation resources illustrated in this figure include nuclear, wind, some hydro (units with limited dispatch capability and small scale units less than 10 MW), Combined Heat and Power (CHP), Conservation and Demand Management (CDM), and coal, as shown in Table 3.3. It should be mentioned that the contribution of gas-fired generation to base-load energy has been disregarded, as well as some CHP facilities which are under long-term Non-Utility Generation (NUG) power purchase agreements; also, the new nuclear units which are planned to be in service in 2018 are assumed to be located in the Toronto zone. However, we understand that the OPA is updating its plans, particularly as it relates to the role of gas generation and CHP in the system.

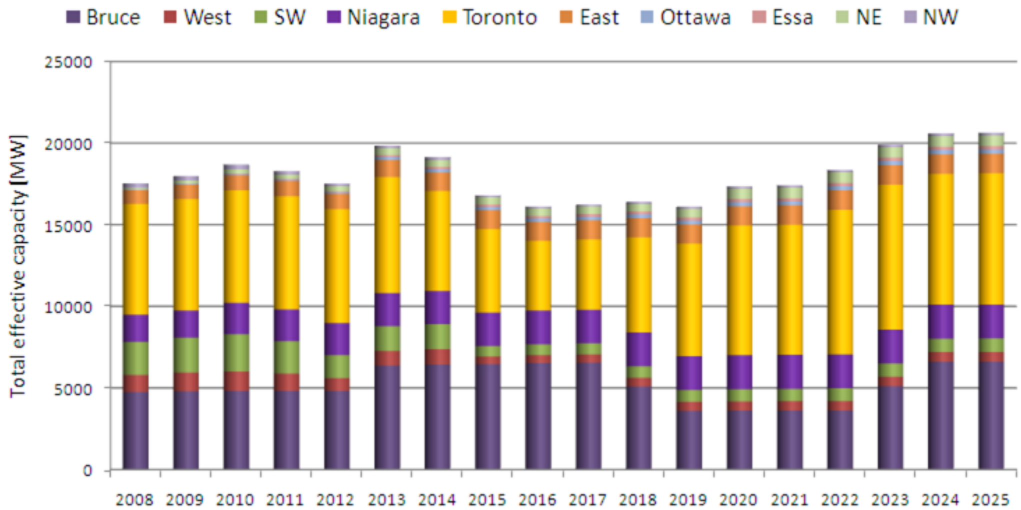


Figure 3.7. Zonal effective generation capacity in Ontario contributing to base load energy [11].

Table 3.3
Zonal effective generation MW capacity in Ontario contributing to base load energy

Year	Nuclear	Wind	Hydro	CHP	CDM	Coal	Total
2008	11365	142	2488	31	373	3143	17541
2009	11365	294	2496	178	508	3143	17983
2010	11365	494	2507	414	763	3143	18686
2011	11365	579	2530	414	890	2500	18278
2012	11365	615	2573	414	1016	1500	17483
2013	12865	754	2588	1000	1143	1500	19850
2014	11835	927	2598	1000	1270	1500	19131
2015	10800	964	2624	1000	1395	0	16783
2016	9919	1065	2635	1000	1481	0	16101
2017	9919	1102	2645	1000	1567	0	16233
2018	9919	1183	2648	1000	1653	0	16403
2019	9449	1280	2648	1000	1734	0	16111
2020	10479	1406	2658	1000	1807	0	17349
2021	10479	1406	2661	1000	1866	0	17412
2022	11360	1406	2661	1000	1923	0	18350
2023	12860	1406	2661	1000	1978	0	19905
2024	13479	1406	2669	1000	2035	0	20588
2025	13479	1406	2669	1000	2078	0	20631

Comparing the total effective generation capacity in Ontario (Figure 3.7) with the expected base-load (Figure 3.6) shows that there is a capacity deficit to supply base-load power from 2016 to 2021. This is mainly due to the retirement of coal plants and refurbishments of both Bruce B and Pickering B nuclear units. The possible supply alternatives for covering this power deficit include power imports from neighboring grids, contributions from further CDM savings, renewable and CHP resources in excess of planned levels, and contributions from intermediate-load resources such as combined cycle gas turbines. Since there are strong tie lines with New York and Michigan, and an Ontario-Quebec HVDC interconnection is scheduled to be operational by 2010, the base-load deficit is assumed here to be supplied by power imports. It should be noted that exports have also been considered in the studies presented here, as there is surplus capacity during some base-load periods in the Bruce and Niagara zones.

1.3 Content Overview

Based on this brief review of some of the relevant issues and related literature associated with the impact of PEVs on the grid, Ontario's grid and electricity market, and the main generation and transmission expansion plans to supply Ontario's base-load demand up to the year 2025, the next sections discuss in more detail all pertinent issues related to the impact of PEVs on Ontario's generation, transmission and distribution systems, and the effects of these systems and their limitations on the adoption of PEVs in Ontario. Thus, Section 2 briefly discusses the various generation technologies relevant to the current and future electricity supply in Ontario to identify their main advantages and disadvantages with respect to the adoption of PEVs; an analysis of the maximum possible penetration of PEVs considering Ontario's present and future generation capacity to supply the required system load, and the effect of the resulting penetration on generation and associated pricing in the province is also discussed.

In Section 3, based on Ontario's current and future transmission system characteristics, the expected impacts of PEV on the transmission grid and vice versa are discussed in some detail. A detailed analysis is presented of the maximum PEV penetration that Ontario's generation and transmission system can support at off-peak load conditions in the 2008-2025 time span, based on a simplified grid model.

The impact of PEVs on distribution systems, which are probably the parts of the grid most significantly and directly affected by PEVs, and the effect that these systems may have on PEV adoption are discussed in Section 4. The probable effects that charging PEVs could have on feeder flows, loading and voltage profiles, as well as on system reliability, protections and power quality are discussed in some detail. Various charging issues are considered in these discussions, in particular the stochastic nature of PEV charging, possible PEV concentration on certain feeders, smart chargers and charging stations. The possible interplay between distributed generation (DG), i.e., “small” generation units that sit at the distribution system level, and PEVs, especially with regard to energy storage and voltage and frequency regulation, is also discussed, for both the G2V and V2G/V2H operating modes. Finally, metering and retail pricing issues such as connection charges and PEV location and identification are commented upon as well.

In Section 5, we analyze the mutual effects between PEVs and Ontario's electricity market. Thus, issues such as changes in load profiles due to PEV charging and their effect on generation dispatch and associated electricity prices, as well as the impact electricity prices may have on PEV adoption are discussed in this section.

Finally, Section 6 summarizes and highlights the main issues analyzed and discussed in this chapter and provides concluding remarks, concentrating on clearly identifying relevant gaps and barriers for PEV adoption in the context of the generation, transmission and distribution systems that makeup Ontario’s power grid. Recommendations to address and/or mitigate these gaps and barriers are presented in this last section as well.

2. Generation

Until somewhat recently, Ontario's electricity supply mix comprised coal-fired power plants, nuclear with hydro and gas on the margin.. This is changing with Ontario’s government decision to phase out coal, invest in nuclear power and aggressively support the deployment of CDM and renewable sources, as reflected in the IPSP and the GEA, affecting positive and noticeable changes in the generation mix in the short span of a few years. There is strong policy support in Ontario to provide a platform for fully integrating PEVs into the transportation sector. There will be consequential impacts and an increase on system demand can be expected, which in turn will affect the plans to change the generation capacity and mix in the province.

In this section, various power generation technologies and their relationship to PEVs are analyzed from the point of view of the impact that PEVs will have on generation capacity, as well as the effect that generation capacity and technologies will have on the adoption of PEVs in Ontario. In this context, the use of renewable energy technologies to charge PEVs (G2V), and the use of energy generated by PEVs to supply power back to the grid/home (V2G/V2H) are also discussed.

2.1 Generation Technologies Relevant to Ontario and PEVs

Ontario's current and future generation sources to supply it system load basically includes nuclear, coal, hydro, gas and wind power, with coal to be phased out by 2014 and CDM being added to the mix. With the implementation of the GEA, this mix will include more renewable generation resources, such as wind, hydro, biomass, geothermal and solar as discussed in [18]. These generation technologies, in order of its impact on Greenhouse Gases (GHG), and their relationship to PEVs are discussed next.

2.1.1 Coal

Hydrocarbons or fossil fuels (oil, coal, and natural gas) represent 80% of the world's total primary energy supply (including all hydrocarbons plus nuclear and all renewable energy combined). At the same time, hydrocarbons account for 80% of the global GHG production and most of the localized air pollutants which, depending on their concentrations, can impair human health. Coal is an important part of this hydrocarbon mix and currently accounts for 25% of the world's total primary energy supply and 40.9% of the world's electricity generation, and represents 59% of the remaining available energy from the world's hydrocarbon reserves. Its share of world primary energy use is expected to rise to 26% of total energy and 41.5% of electricity production by 2030. In a typical coal-fired thermal plant, coal is used to heat water that in turn creates steam, which is then piped at high pressure to a turbine-generator system, causing it to rotate and thus produce electricity. This steam-based electric generation system is also used with other fuel sources, including oil, gas, geothermal, biomass and thermal-solar systems.

Coal-fired electricity generation by 2007 represented about 25% of Ontario's total capacity of roughly 30,000 MW, by 2009 this figure has come down to about 18%, and is on track to be phased out by 2014. Given its characteristics, coal-fired plants have been used to supply base-load, and thus play a role in the charging of PEVs; hence, the adoption of PEVs should consider this fact to minimize GHG emissions from coal-based generation. Furthermore, the aforementioned dip in the supply of base-load power from 2016 to 2021, in part due to the retirement of coal plants, should also be taken into account when considering the adoption of XVEs, as demonstrated in the penetration analyses studies presented in Section 2.2.

2.1.2 Gas

Natural gas, along with oil and coal, is a fossil fuel that is found in underground reservoirs, and is a limited resource like other fossil fuels. The combustion of natural gas produces only a fraction of the nitrogen oxide and carbon dioxide emissions of oil and coal, and also results in essentially no particulate matter or sulfur dioxide emissions. Therefore, natural gas is an attractive "transition" fuel as the energy supply moves away from polluting sources such as coal towards cleaner, renewable technologies. However, it does produce CO_2 and hence it does contribute to GHG emissions. In Ontario, natural gas is used to supply about 10% of the electricity demand.

Natural gas can be used as a fuel in conventional steam boiler generators like other fossil fuels. However, technologies directly using natural gas in the combustion process are more efficient. Combustion turbines are basically jet engines in which the natural gas is burned, creating superheated gas which is then pressurized in pipes and used to drive the turbine; these are referred as Simple Cycle Gas Turbines (SCGT). Combined cycle technology couples combustion turbines with steam-based generation technologies to boost the overall efficiency by using the heat coming out of the combustion turbine to generate steam and drive a turbine-generator system; these are referred as Combined Cycle Gas Turbines (CCGT). State-of-the-art combined cycle plants reduce fossil fuel use by as much as 40%, increasing the plant efficiency from about 40% to 50-60%. Finally, Combined Heat and Power (CHP), also referred as cogeneration, produces both electricity via a combustion turbine and useable thermal energy from the turbine's exhaust for thermal processes other than generation of electricity.

Natural gas as a fuel for electricity generation has a number of attractive features in competitive markets, as it requires relatively smaller capital outlays; it can be sited and built more quickly, often closer to consumers; and it is relatively clean. Given their characteristics, gas-fired plants are typically used to supply intermediate (CCGT) and peak loads (CCGT and SCGT). Therefore, these technologies are not expected to play a major role in PEV charging.

2.1.3 Nuclear

Nuclear power is now considered an option for reducing carbon emissions (e.g. http://casenergy.org/). Nuclear power refers to nuclear technologies designed to extract usable energy from atomic nuclei via controlled nuclear reactions, mostly through nuclear fission, which is a nuclear reaction in which the nucleus of an atom splits into smaller parts, often producing free neutrons and lighter nuclei that may eventually produce photons (gamma rays). Fission of heavy elements is an exothermic reaction which can release large amounts of energy both as electromagnetic radiation and as kinetic energy of the fragments, heating the bulk material in the nuclear reactor where fission takes place. All utility-scale nuclear reactors heat water to produce steam, which is then converted into mechanical work for the purpose of generating electricity or ship propulsion. In France, the share of electricity energy supply from nuclear power is over 80%. In Ontario, nuclear electricity generation from three main sites (Bruce, Pickering and Darlington) supplied about 50% of the energy demand back in 1997; in 2003, this went down to about 40% due to the decommissioning of some nuclear reactors; and by 2009 it was back up to over 50%. The Ontario government has made a commitment to maintain if not increase nuclear power generation in the province. In fact, in the IPSP, nuclear power plays a significant role in the electricity supply plans for Ontario, considering various possible expansion options for the different nuclear sites in the province.

Given the slow time response characteristics of nuclear power plants, these are used to supply base-load demand. This combined with the continued, significant share that nuclear power will have of base-load power, will make nuclear energy one of the main sources for PEV charging in Ontario. This will result in low GHG emissions to supply the PEVs' energy demands, even before the total decommissioning of coal-fired plants.

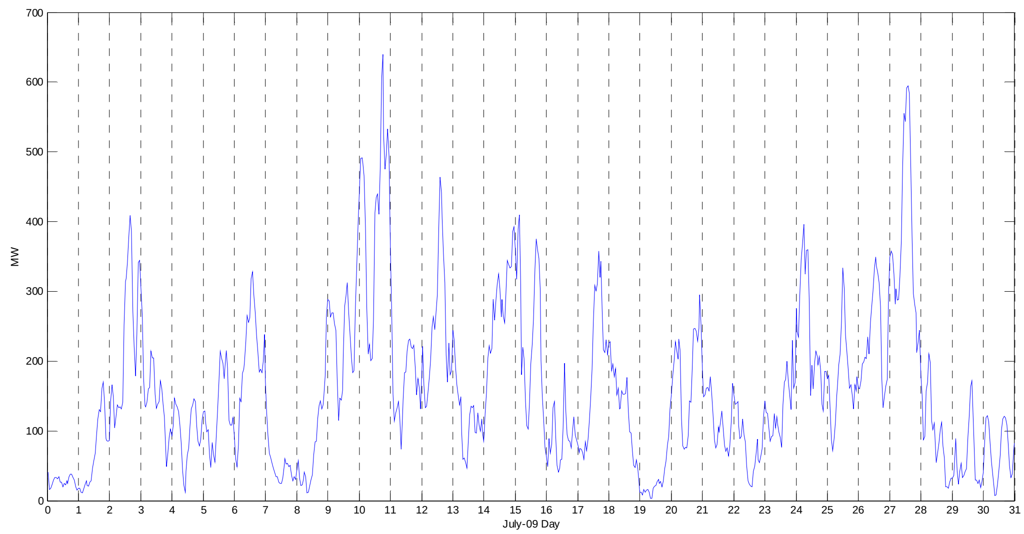
2.1.4 Hydro

In hydropower stations, the energy contained in falling water is used to generate electricity and is a renewable, relatively non-polluting electrical energy source. It is Canada's largest source of electric power generation, with a share of over 60% of the electricity supply coming from hydroelectric dams. It is the most widely used form of renewable energy. The power generated in large hydropower stations comes from synchronous generators attached to turbines that spin as a result of water rushing through them; the amount of potential energy in water is directly proportional to the head. Pumped storage of hydroelectricity has a limited role in the Ontario system but the potential for an increased role is under review by the OPA. Pumped storage produces electricity to supply peak demand by moving water between reservoirs at different elevations, so that at times of low electrical demand, excess generation capacity is used to pump water into the higher reservoir, and at peak demand, water is released back into the lower reservoir through a turbine. Hydroelectric plants with no reservoir capacity are called run-of-the-river plants, since it is not possible to store water in this case. Ontario currently has over 70 hydroelectric generating stations supplying over 20% of the electrical energy demand; however, there are only a few rivers left in the province where new stations can be built. Therefore, the hydropower share of the energy supply will steadily decrease as other sources of energy are developed. This is shown in Table 3.3, in which the share of the base load supply from 2008 to 2025 goes slightly down from about 14% to below 13%. Therefore, the role of hydropower in the charging of PEVs will be limited.

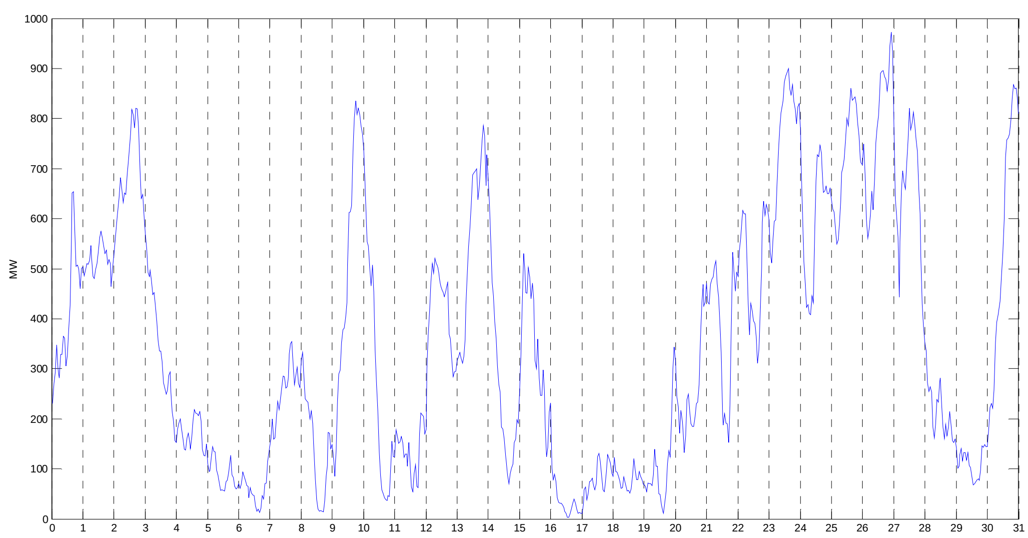
2.1.5 Wind

Wind power is the fastest growing source of electrical energy in the world, with Denmark, Germany and Spain leading in the development, deployment and utilization of wind resources. In these countries, wind power has been mainly used to offset emissions from and reduced dependency on fossil fuel-fired power plants; however, due to wind variability (see Figure 3.8), it cannot fully replace this type of generation, since it requires the backup of dispatchable power plants (although with improvements in wind-power output forecasting, there is now a wind-power dispatch center in Spain). Once considered prohibitively expensive, subsidies of various kinds have allowed the development of this technology, to the point that the cost of wind power has dropped remarkably during the past two decades because of economies-of-scale, larger turbines, and experience on how to build, install and operate wind turbines more effectively and efficiently. It took Germany seven years to install its first 2,000 MW of wind capacity, but it took less than a year in 2003 to install an additional 2,645 MW, and in Spain, the installation of the first 2,000 MW was done within four years using today's larger, more productive wind turbines. As of June 2009, the wind installed capacity in Ontario is 1083.6 MW (about 3% of the installed capacity), with a peak output of near 1000 MW being reached in July 27, 2009 (see Figure 3.8). An additional 491.7 MW of wind power is scheduled to come online by 2012 [19], and much more are expected with the Feed-in Tariff (FIT) program triggered by the GEA (13.5 cents/kWh on-shore wind and 19.0 cents/kWh for off-shore wind) [20].

Although, as it can be observed in Figure 3.8, wind-power outputs increase during the winter months, there is no discernable pattern between base-load periods and the rest of the day (the average power output during base-load periods for 2009 was 268 MW, whereas for the rest of the day it was 275 MW). Based on the variability of the wind depicted in Figure 3.8, wind power cannot be considered a base source of energy for PEVs. However, it is clear that the larger its share of the energy supply, the better for the system as a whole, and even better if PEVs form part of this load, as the associated batteries can be considered, loosely, to provide de-facto energy storage for the variable wind power.



(a)



(b)

Figure 3.8. Ontario's wind-power generation in (a) a recent summer month and (b) a recent winter month. The installed capacity as of June 2009 is 1083.6 MW.

2.1.6 Solar

In general, ultraviolet (UV) rays from solar energy can be used in solar-thermal systems to provide hot water or space heating through heat absorption mechanisms, as well as generate electricity in areas of high solar radiation through steam-based mechanisms. It can also be used to generate direct current (dc) power in photo-voltaic (PV) systems to charge batteries and power electrical equipment through power electronic converters that transform dc power into standard alternate current (ac) power. The efficiency of PV conversion has been steadily improving, which together with improvements to power converters has led to the development of a variety of PV-solar-based residential applications such as energy storage systems and lighting systems. However, the costs of these systems still constitute a barrier for the wider adoption of these technologies for large power applications. To incentivize the adoption and integration of these technologies, the OPA in Ontario is offering through the FIT program from about 44 cents/kWh to over 80 cents/kWh for PV-solar systems below 10 MW [20].

As of June 2009, the PV-solar installed capacity in Ontario was 2 MW [21]; however, towards the end of 2009, beginning of 2010, Opti-Solar started operating a 40 MW (to increase to 60-90 MW) PV-solar farm in Sarnia. Although this can be considered an exception that is not likely to be widely replicated, the FIT program will probably increase the deployment of PV solar generation throughout the province, especially small systems. From this, plus the fact that PEVs would preferably be charged at based loading conditions, i.e., at night, when solar power is not a factor, it can be readily conclude that solar will likely not play a significant role in PEV charging.

It should be mentioned that the possibility of integrating PV-solar-based on-board-chargers in PEVs has been considered, at least at the research level (e.g. solar vehicles). Furthermore, we can anticipate an emerging trend for solar based charging stations for PEVs that can make a partial contribution to the PEVs' demand for electricity (e.g. [32]).

2.1.7 Bio-Energy

That energy "stored" in plants can be extracted in a number of ways: by burning crops to create heat, converting them into bio-fuels, or digesting them anaerobically to create biogas (similar to natural gas). Figure 3.9 shows possible sources, technologies and applications of bio-energy.

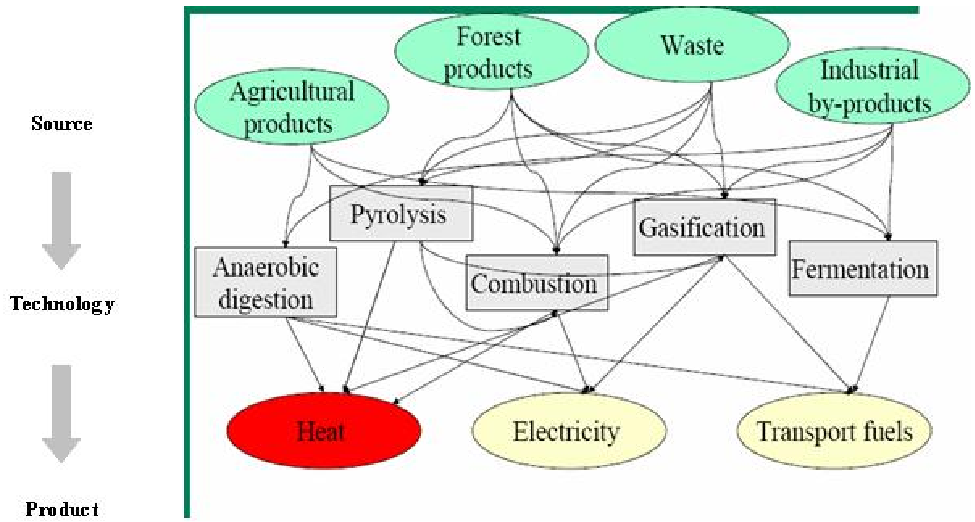


Figure 3.9. Biomass: sources, technologies and products.

With the FIT program providing incentives for biogas (19.5 cents/kWh for units of less than 100kW to 10.4 cents/kWh for plants over 10MW) and biomass (13.8 cents/kWh for plants below 10MW and 13.0 cents/kWh for bigger plants) generation [20], the role of bio-energy in the generation of electricity in Ontario is expected to increase with respect to the current 11.3 MW [21]. However, compared to other forms of renewable generation, it is expected to play a minor role in PEV charging.

2.2 Maximum Penetration of PEVs and Effect on Generation

In order to determine the impact of PEVs on Ontario's grid and vice versa, one needs to determine the equivalent loading that the charging of these vehicles will represent for the system. Thus, it is assumed in this report that light vehicles (sedans, SUVs, vans and pickup trucks with a gross weight below 4.5 tons) constitute the bulk of the transportation sector, given their numbers and prevalence in the sector. In [11], based on a detailed population analysis and the per capita number of vehicles in Ontario, the number of light vehicles for each zone and year in the 2008-2025 period in Ontario depicted in Figure 3.10 was obtained. Observe that the number of light vehicles is expected to increase from 7.1 million in 2009 to approximately 8.6 million in 2025, and that the majority is located in the GTA.

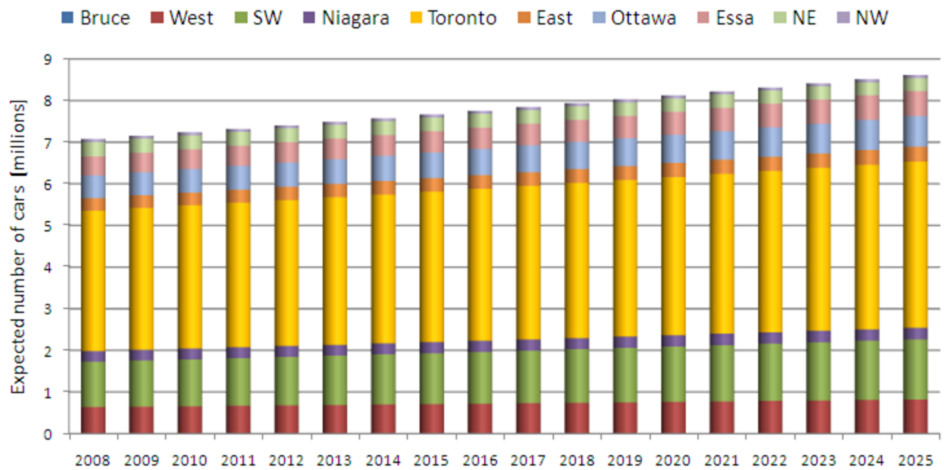


Figure 3.10. Expected number of light vehicles in Ontario during the planning period.

Following [11], a PHEV with a 30 km all electric daily trip (referred here as PHEV30km, but more commonly referred to as PHEV20 in the literature) was assumed, given that this type of vehicle would likely be popular among consumers, due to its possible lower overall costs, plus the fact that the vehicle can be "quickly" charged using a standard wall plug; besides, note that this distance corresponds to 60% of the average 50 km daily drive per light vehicle in North America, including Ontario. Due to life cycle considerations, at most 70% of the battery's energy was assumed to be used in charge depleting mode; hence, a 70 % maximum allowable depth of discharge was considered. Finally, a 1.4 kW connection (a standard 120 V/15 A plug) was assumed for battery charging, with an 85% charging efficiency. For example, Toyota's Prius plug-in with a 60kW electric motor and approximately 3.5 kWh charging demand would cover 23.4 km on battery power alone and is expected to be fully charged in less than 4 hours from a standard plug, whereas the more expensive Chevrolet Volt with a 111 kW motor and approximately 8kWh charging demand would cover 64 km (PHEV60km or PHEV40) and is expected to need about 8 hours of charging from a standard plug.

From the aforementioned assumptions, the energy demands shown in Table 3.4 can be obtained. This table yields a 1.2 kW average load per PHEV30km assuming 8 hours of uniform charging; larger powers would be obtained for shorter times due to higher charging currents. It is interesting to mention that a PHEV60km with the same size motor as a PHEV30km would basically demand double the average power.

Table 3.4
Charging requirements for different types of PHEV30km.

Vehicle type	Market Share [%]	Specific energy [kWh/km]	Required Useable energy [kWh]	Required battery size [kWh]	Charging time [hour]	Total energy demand [kWh]
Compact sedan	29	0.16	4.8	6.86	4.03	5.65
Mid-size sedan	29	0.19	5.7	8.14	4.79	6.71
Mid-size SUV	4	0.24	7.2	10.29	6.05	8.47
Full-size SUV	4	0.29	8.7	12.43	7.13	10.24
Van	16	0.29	8.7	12.43	7.13	10.24
Pickup truck	18	0.29	8.7	12.43	7.13	10.24

Based on the average load of PHEV30km under the previously stated assumption and the expected growth of base and peak loads, as discussed in Section 3.2 (Figure 3.6), one can readily conclude, as per simple "back of the envelope" calculations based on the grid potential to supply peak load during base-load hours ("valley filling"), that the grid could in theory charge almost all light vehicles in Ontario, as illustrated in Figure 3.11. This figure shows that, assuming an immediate adoption of PHEVs by consumers, the grid has the theoretical potential to supply the charging demands of over 90% of the light vehicles in Ontario for the next 16 years. If the more reasonable PHEV staggered penetration rates depicted in Figure 3.12 are assumed, by 2025, the electrical demand of nearly 100% of the light vehicles could in theory be supplied by Ontario's grid. Furthermore, since by 2015 all coal plants are expected to be retired, the generation mix would be such that most of the required energy for charging these PHEVs would be for the most part "clean," thus significantly reducing overall GHG emissions. Note that if a PHEV60km with similar electric drive characteristics were to be considered, the theoretical grid potential for charging PHEVs would be basically reduced by half.

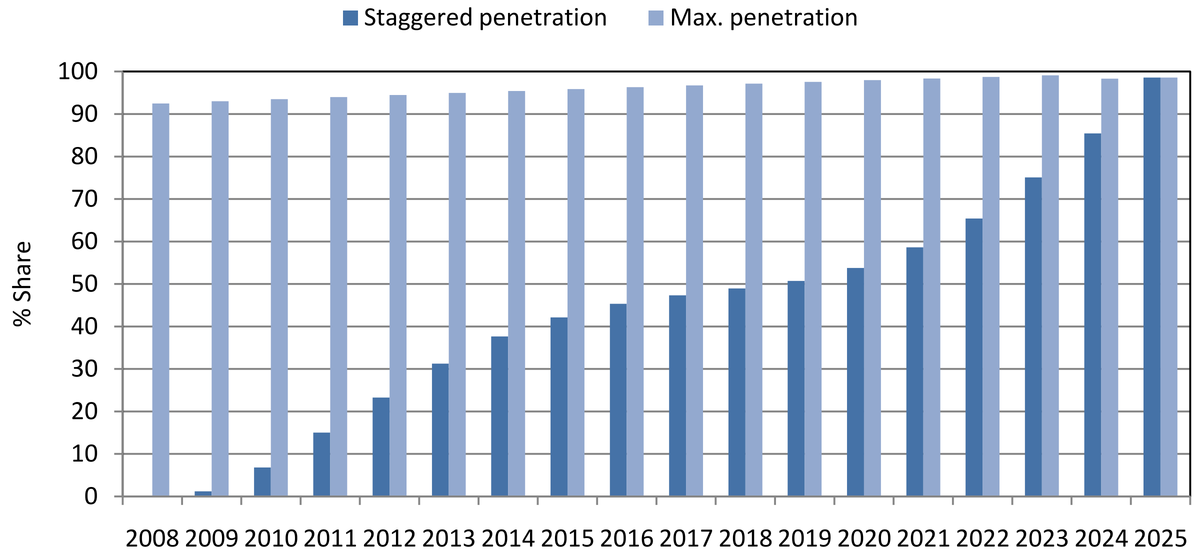


Figure 3.11. Maximum PHEV30km share of the light-vehicle fleet in Ontario assuming a "valley filing" charging approach (peak load charging at base-load hours).

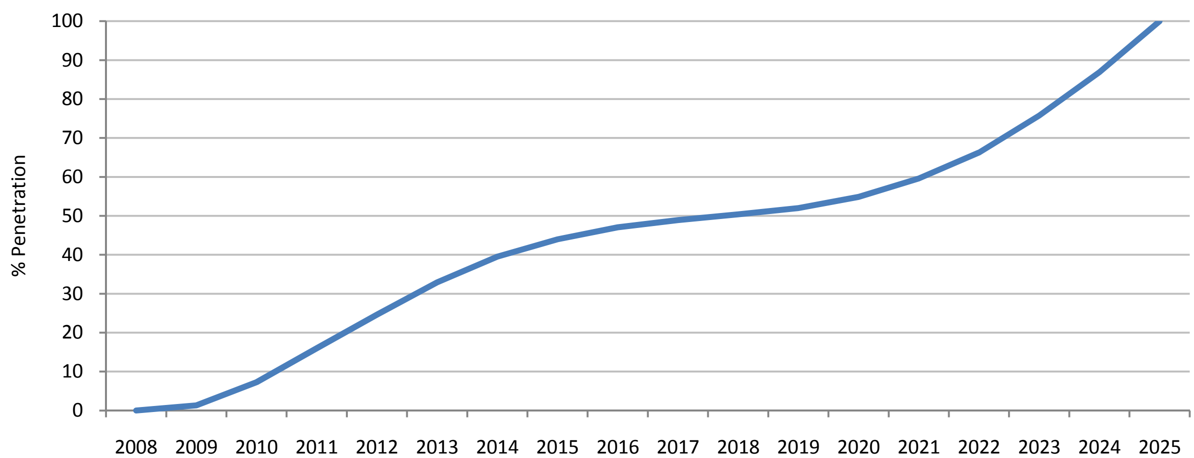


Figure 3.12. Assumed PEV adoption rates.

The "valley filing" or load "levelizing" approach shows, at a high level, that Ontario's grid has a significant potential for PHEV charging. However, this does not provide an understanding of the impacts on the system at a detailed enough level for the system operator or the planner. There are several important issues that need to be taken into consideration. First, if the system were to be operated at either peak-load or near peak-load conditions all the time, what are the life cycle cost and reliability implications for equipment performance? Would equipment at generation, transmission and distribution system levels fail more often requiring early replacement given the increased rate of utilization? The implications of this kind of PEV charging for grid reliability and increased grid operation and maintenance costs need to be evaluated. Second, grid congestion and power quality issues such as voltage regulation would certainly become an issue, as it is already the case at peak loading conditions, thus also affecting system operation and associated costs. Finally, electricity wholesale prices would increase as illustrated by the Hourly Ontario Energy Price (HOEP) analysis depicted in Figure 3.13, where it is shown that the HOEP at peak-load hours is much higher than at base-load conditions (over 100%) and than the overall average (over 50%), with quite significant spikes at certain times (over 1,000% sometimes). Therefore, to determine Ontario's actual grid potential for charging PEVs, more detailed analyses are required that consider the various issues briefly highlighted here, as well as a variety of other issues discussed next.

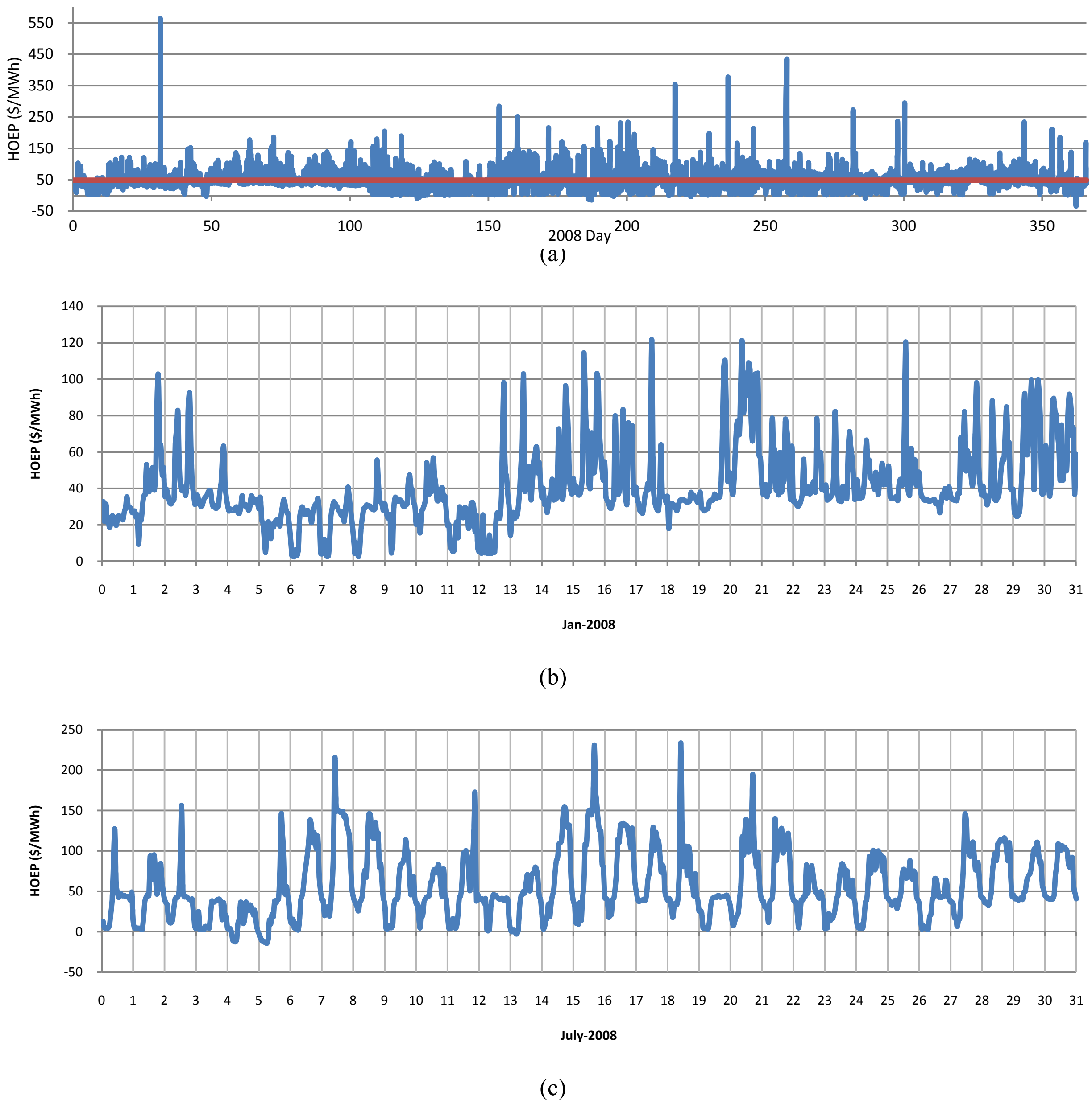


Figure 3.13. HOEP in 2008: (a) year, (b) January (winter), and (c) July (summer).
Averages: 48.83 $/MWh (4.88 cents/kWh) for the year; 29.77 $/MWh for base load;
61.94 $/MWh for peak load.

2.3 PEVs as Energy Storage

The use of PEVs as energy storage is associated with the use of batteries to store generated electrical energy, especially from intermittent sources such as wind and solar, for utilization in terms of mobility or electrical energy itself. It is clear from the discussions in Section 2.1 that at the generation level, the use of PEVs as energy storage presents many challenges that make it infeasible in practice, given the need to "coordinate" PEV charging with generation. However, at the DG level, it could present some advantages due to the closeness of PEVs to local, smaller generating units, as discussed in more detail below.

Several recent studies such as [12]-[15] show that PEVs may profitably provide power to the grid/home when they are parked and connected to an electrical outlet; this is typically referred to as V2G/V2H power. In these studies, the economic potential of V2G/V2H from PEVs is analyzed to provide power for base load and peak load, as well as electric grid services known as ancillary services, considering energy storage of renewable energy sources. These particular issues are discussed in more detail in Section 4.3. The main issues with PEV as energy storage are:

- Battery charging and cost issues, which are discussed in detail in Chapter 2, make energy storage and V2G/V2H a costly proposition. Therefore, for the foreseeable future, PEV batteries would likely be mainly used for transportation purposes. However, as battery technologies improve, using PEVs as electric energy storage systems is likely to become more feasible.
- To effectively use PEVs as storage for variable renewable generation sources, i.e., wind and solar, there is a need to coordinate these generation facilities with PEV charging. Due to unpredictability (especially wind) and timing (especially solar) issues, this seems unfeasible, unless the generating sources are "directly" connected to the charging station, as in the case of solar charging stations. These issues are discussed in some detail in Section 4.3.
- The use of PEVs to provide ancillary services such as voltage and frequency regulation is a possibility, exploiting the PEV power electronics converter capabilities and the relatively small amounts of energy needed to provide such services, especially voltage regulation. However, since the main charging of PEVs would likely take place at night, the need for frequency regulation services might be limited. These issues are discussed in some detail in Section 4.3.

3. Transmission System

3.1 Ontario's Transmission System Overview

As briefly discussed in Section 3.1, Ontario's transmission system comprises a 500 kV transmission network, a 230 kV transmission network and several 115 kV transmission networks. In Figure 3.14, a geographic depiction of Ontario's internal transmission zones, major transmission interfaces, and transmission interconnection points and corridors with other jurisdictions are provided. The main transmission flows associated with the system security limits (congestion paths) for these interfaces and interconnections are also shown.

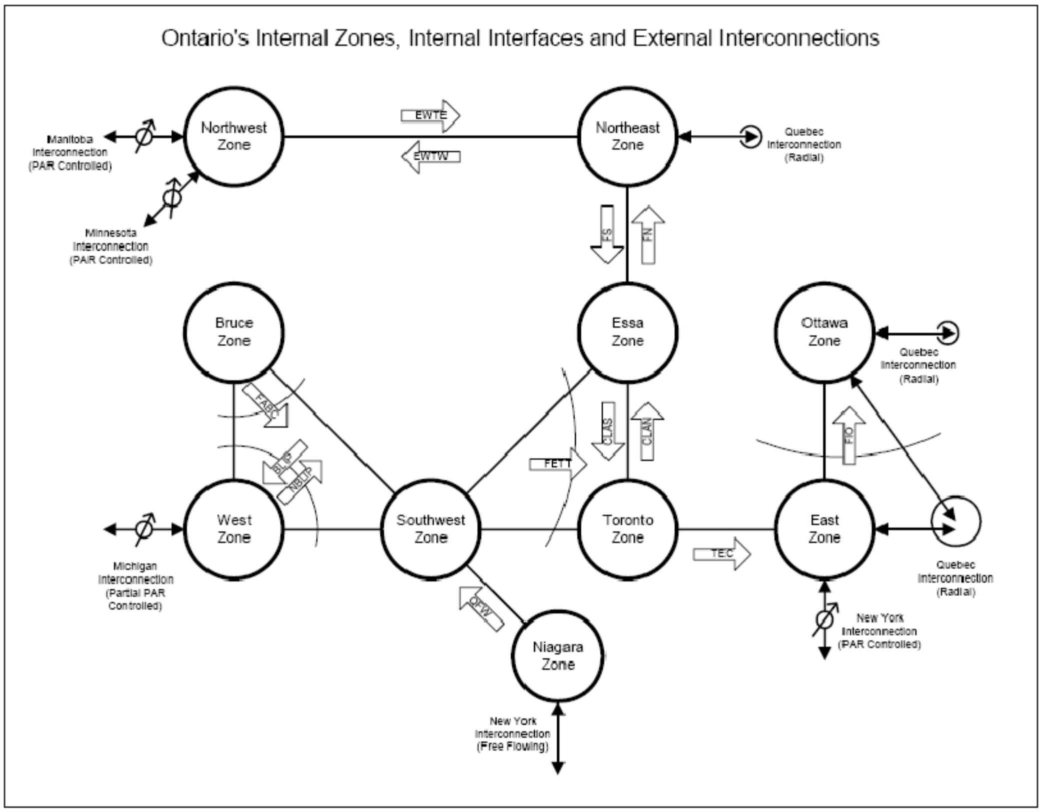


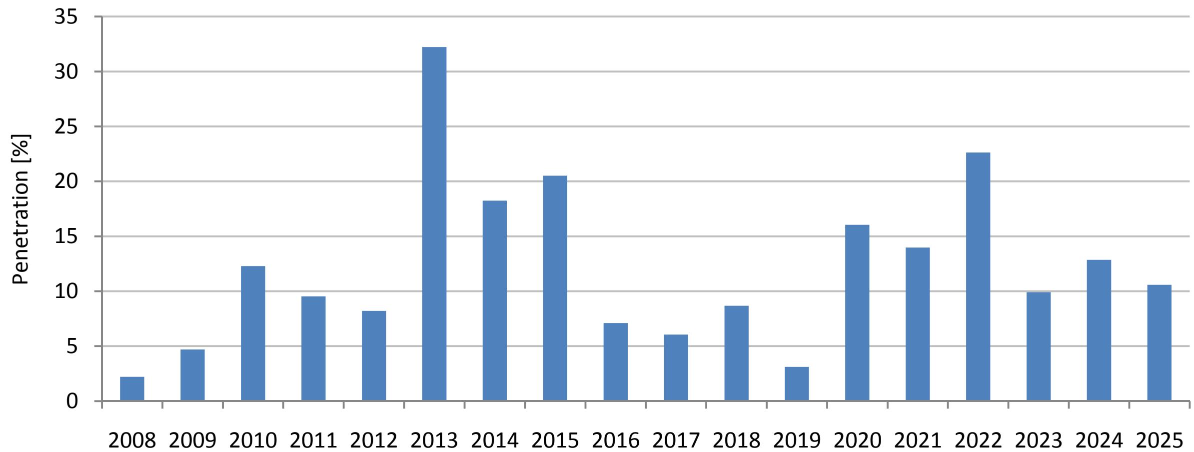
Figure 3.14. Ontario's zones, interfaces and interconnections [source: IESO].

It is important to understand the ramifications of adding load from PEVs onto the transmission system. Depending on when and where the vehicles are plugged in, they could cause local or regional congestion on the transmission grid, which would increase the utilization of existing capacity and may even require the addition of new transmission lines. For example, a large concentration of PEVs in the GTA area, which is likely in the case of wide adoption of these vehicles in Ontario, will likely exacerbate the congestion of the transmission corridors feeding that area shown in Figure 3.14. Furthermore, usage patterns of local distribution grids will change, and some lines or substations may become overloaded sooner than expected. Also, the type of generation used to meet the demand for recharging PHEVs will depend not only on the timing of recharging, as previously discussed, but on the region of the province where these PEVs are located. These issues are discussed in more detail next.

3.2 PEV Impact

As discussed in Section 2.2, to determine the maximum potential of the grid for PEV charging, it is not enough to simply consider the grid capacity to service peak load during base-load time periods, since, as just mentioned, the characteristics and limitations of base-load generation units and the transmission system must be taken into account. Thus, in [11], an optimization model of Ontario's grid at base-load conditions was developed to determine the maximum potential of the grid for PEV recharging during based-load time periods. This model allows determining the maximum PEV penetration in the light-vehicle transportation sector while considering generation capacity and the corresponding units' and demand location, which are directly associated with the transmission system capacity to service the demand as depicted in Figure 3.14. The model strives to minimize the effect that PEV charging would have on electricity prices and system operation (system reliability and security and associated issues such as dispatch and costs), while accounting for the main base-load generation and transmission system constraints.

The results are depicted in Figure 3.15. These figures show the maximum percentage penetration levels of PHEV30km – which is likely to be the more popular vehicle as previously discussed – in the light-vehicle fleet for an immediate adoption of these vehicles by consumers, and for the more "realistic" staggered adoption depicted in Figure 3.12. Observe the significant influence that the generation and transmission system constraints have on the optimal penetration levels, particularly for the case of immediate PHVE adoption, which is due mainly to the retirement coal plants and the availability of nuclear power in certain years. It is interesting to notice that these penetration levels are well below (about 10 times less) those depicted in Figure 3.11 for a simple valley filling approach.



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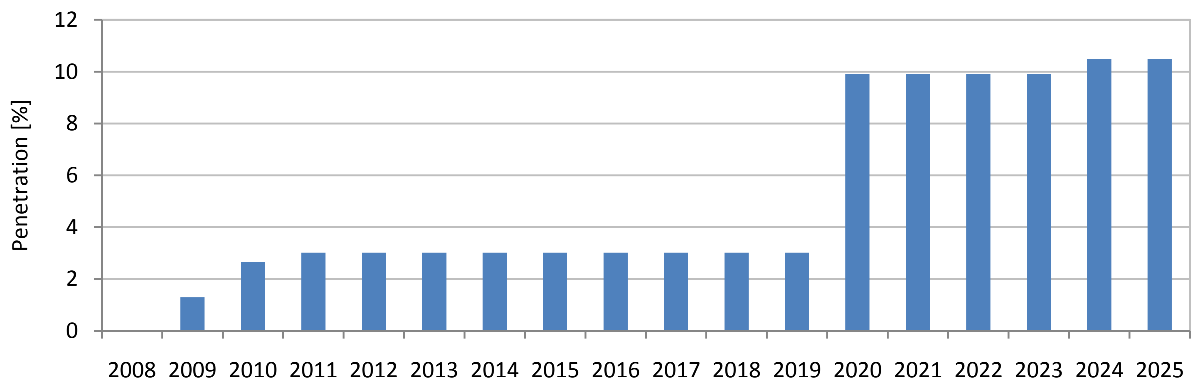

(b)

Figure 3.15. PHEV30km optimal penetration at base-load conditions with (a) immediate PHEV adoption and (b) with staggered adoption as per Fig 2.5.

In [25], the authors analyze the use of the aggregated load associated with PEV charging during off-peak conditions at night to "levelize" the load and hence contribute to lowering the need for down-regulation services during these periods. This load "levelization" presents some significant advantages for grids in which nuclear energy plays a significant role like in Ontario, since in these systems, very low demand at off-peak hours can lead to the need for shutting down generators, but since nuclear power plants cannot be simply shutdown, thermal-based and hydro plants supplying base load are forced off line, either by direct operator intervention or market bidding mechanisms. In Ontario, this particular situation is reflected in very low and even negative HOEP values during some base-load hours, as shown in Figure 3.13 (a); this has been aggravated by the reduction in electricity demand associated with the recession, as demonstrated by the HOEP statistics in 2007-2009, which show that HOPE had negative values only 1 hour in 2007, 38 hours in 2008, and 355 hours in 2009. Therefore, increasing base loading with PEV charging will certainly help to avoid these problems, making PEVs a welcome additional demand during off-peak hours.

3.3 Long-term Expansion Issues Vis-à-vis PEV Penetration

The importance of power transmission grids- the backbone of any country's economy is higher than ever. These transmission networks are getting older, are confronted with complex market liberalization processes and have to host increasing amounts of renewable energy sources. Furthermore, in order to address the challenges of energy security and climate change, transmission grids need to become more interconnected and "smart" by seamlessly integrating a wide range of users (generators, consumers and/or other grids).

Existing transmission planning methods commonly use a worst-case scenario approach. A power flow analysis is carried out for a small number of cases selected by experienced network planners. With increased uncertainty and the many assumptions necessary for analysis, the need to include renewable generation and other forms of energy consumption and storage is becoming essential and a probabilistic approach to deal with such uncertainties is needed.

A new report [46] on transmission network planning highlights that a radical change in coordinated network planning and operation is needed to accommodate market liberalization and increasing integration of renewable power sources. In the context of Europe, the report identifies that the key issues involved in achieving a reliable and effective grid are integrated strategic planning and cross-border coordination. EPRI in [47] also highlights planning's central role to accommodate high levels of variable generation from renewable resources – which may also consider V2G/V2H operation of PEVs. At the 25th Canadian Wind Energy Association conference in February 2009, the then Minister of Energy and Infrastructure, George Smitherman, announced a key plan to upgrade the Province's aging transmission grid so that certain parts of the province would be able to deliver their green energy production. The plan includes proceeding with 20 new transmission projects across the Province that are essentially transmission upgrades designed to support areas with high green energy potential, including regions in the north, east and southwest.

The most stressed region in Ontario in terms of electric power load balance and transmission line congestion has been identified as the GTA region. Existing supply capabilities are being strained by the fast demand growth rate. A reduction in local generation (closure of Lakeview coal-fired plant in 2005) has also compounded the problem. This area, accounting for 40% of Ontario's peak load, relies heavily on its transmission system to supply power from outside the area. As per the IPSP [2], some new committed gas-fired generation facilities are expected in this region, which will increase the internal GTA generation. Therefore, in such a situation, if planned conservation targets for the GTA are not met, the impact could be significant. Since the concentration of increased load from PEVs in the Ontario system can be expected to be located in the GTA region, this region needs to be prepared to meet such additional load.

The proper planning of the grid considering the effect of penetration of PEVs into the system must take into account the interests of all stakeholders, who must first be identified. For the power industry, the ability of the current system to accommodate the additional load of the PEVs can pose a challenge if we assume certain charging scenarios. For example, study [22] shows that, in 2020, with a 25% penetration in 13 US regions, 160 new power plants will be required if every PEV owner plugs in the vehicle in the early evening, i.e., around 5 PM when electric demand is still near the daily peak. On the other hand, in [9], it has been argued that existing electricity generation and transmission capacity is sufficient to accommodate increased demand associated with PEVs, provided that recharging occurs during off-peak hours. Furthermore, in [24], a study considering the integration of 4 million PHEVs into the California power grid (a 25% penetration) shows that the additional load arising from charging this number of vehicles at base-load time periods can be accommodated by the existing power system without requiring installation of new generation sources. It has also been suggested in [23] that with Smart Grid technology, utilities may stagger charging times, offer consumers lower rates for off-peak electricity and can virtually eliminate the need for new power plants. These studies coincide with our previously presented arguments and analyses for Ontario that clearly demonstrate the need for charging PEVs during off-peak hours. Therefore, planning studies should clearly take these issues into consideration.

The discussions on the impact on the grid requirements due to PEV penetration so far has predominantly concentrated on technical and commercialization feasibility of these cars, while disregarding any potential constraints on the grid imposed by increased electricity demand. In reality it might prove extremely difficult to force consumers to charge their cars during some specified period of time, particularly if it is not convenient for them. Thus, further analysis is needed for researchers to understand the effects of PEVs on electricity demand and grid performance if customers plug in when convenient for them rather than for utilities.

4. Distribution Systems

Given the nature and physical characteristics of PEVs, their integration into the grid is envisaged to be at the distribution voltage level. The basic idea is that each PEV be plugged into the grid to charge up the battery, and hence, when aggregated in sizeable numbers, this would constitute a new load that the electricity system, and particularly the distribution network, must supply. However, PEVs can be much more than just a simple load given that bi-directional power transfers are possible. The integration would eventually allow the deployment of PEVs as a generation resource (V2G/V2H) as well as a storage device for certain periods of time when such deployment aids the system operator to maintain reliable operations in a more economic manner. Therefore, PEVs have the potential of becoming active players in grid operations and thus play an important role in improving the reliability, economics and environmental attributes of system operations. Such benefits include the provision of capacity and energy based ancillary services, the reduction of the need for peaking generation units and load "levelization".

This section concentrates on the study of the relevant issues associated with PEV charging at the distributions system level. Thus, the effect of PEV loads on the distribution feeders and transformers, voltage regulation, power quality and protections are discussed in some detail, for both G2V and V2G/V2H operation modes and considering possible direct interactions with DG. The characteristics and issues of PEV charging are also presented and analyzed, including a detailed discussion on charging plugs and stations as well as the stochastic nature and concentration of PEV charging. Finally, "smart" charging strategies and technologies and metering and retail pricing issues are discussed in the context of Smart Grids and Ontario's electricity markets.

4.1 PEV Impact

4.1.1 Feeders and voltages

Given that the PEVs are envisaged to be connected at the distribution level, it is pertinent that the distribution feeder flows will be affected by the way the PEVs are operated and used by the customers. The feeder loading/unloading will depend on the time of charging/discharging and also location of the customer on the grid. For example, if a charging (G2V) operation is taking place during peak load hours, and the customer is located at the remote end of a feeder section, it is evident that the entire feeder section load will be increased. On the other hand if the PEV is operating in V2G mode during the same period, the feeder section loading will be reduced because of the counter-flow produced. The optimal scheduling of PEVs for G2V or V2G mode operations can be coordinated by taking into account grid impact studies; however, more often, customers are guided by electricity market prices and other economic factors rather than grid impact. Therefore, the grid operator needs to work out the feeder impact a priori and determine the extent of PEV penetration that can be absorbed by it without reinforcement needs. The grid impact will be more prominent in radial distribution feeders both in case of feeder overloading due to G2V operation and feeder unloading due to counter-flows arising from V2G operation.

An associated effect of feeder loading/unloading because of PEV operation in G2V/V2G modes is the consequent effect on system bus voltage profile and the need for reactive power support. It can be expected that in G2V mode of operation, the bus voltages at the remote feeder ends will be impacted and will require voltage support from capacitor banks or similar reactive power compensation equipment, due to the reactive power feeder "losses" incurred. The distribution company's main challenge is to determine the optimal capacitor switching decisions or transformer tap operation. The utility may even consider a longer-term perspective and examine the needs for reactive power support over the next 3-5 years and plan accordingly to determine new buses where capacitor banks may be installed. Also, a complex issue that may arise in this context is the formulation of the network charge component that is fair and rational to the PEV customers.

4.1.2 Power quality

Another important issue in PEV integration is the amount of harmonic current caused by the nonlinear charger loads and how it affects the rating of the supply transformer. In general, in order to analyze the effect of current harmonics on sizing of transformers, there is a need to first characterize the load. Samples of the charging current at various times during the charge cycle need to be analyzed for harmonic content. Thereafter, effects of multiple chargers connected in a system on the supply transformer can be examined. A possible hypothesis is that the varying topologies and controls from multiple chargers would produce harmonics of different phases, which would have a cancellation effect, lowering the expected harmonic distortion from the strict arithmetic sum of magnitudes that is obtained by taking an average of all THD percentages present in the system. There is a need to undertake more research on this subject focusing on harmonic current analysis for charging cycles of different PEVs.

In [48], a 480 V single-phase charger is analyzed for harmonic content at various points in the charging profile and the harmonic current magnitudes and phases are modeled as random variables based on the obtained distribution from the collected data. The Total Harmonic Distortion (THD) from the charger at random points in the charge profile is obtained and compared by neglecting and considering the phase of harmonic currents. It is concluded that for an accurate estimate of the harmonic current injection from a charger, the phase shift of the harmonic current need to be considered. However, since only one charger class is considered, the results are not generic enough.

In [49], the effects of battery chargers on the electric power grid are discussed. The authors focus on harmonic effects and their impact on life of power transformers at the distribution level. A study is conducted to relate various charge times of the day and THD of the chargers with transformer life. It is observed that commercial chargers showed THD values as high as 60 or 70%; however, in order to have a "reasonable" increase in transformer life, the THD should be limited to 25 to 30% for each charger.

4.2 PEV Loads

4.2.1 Stochastic nature and concentration

The stochastic nature of PHEV loads and lack of historical data about their patterns of variation makes it difficult, if not impossible, to forecast the penetration and local concentration levels of these loads. This can lead to over-sizing of public charging stations and the related distribution system capacity (to leave a conservative safety margin) or overloading the undersized system (compromising safety and reliability). The existing historical traffic flow data has to be combined with new forecasting methods (to be developed), to help size the charging systems and the corresponding distribution systems safely and reliably. This is especially important during the period of transition from conventional vehicles to PHEVs to BEVs, where everything is uncertain and patterns of use and growth are totally unknown, due to their strong dependence on societal behaviors and governmental policies.

Even though daytime distribution of plug-ins can be stochastic, the nighttime load introduced by plug-ins due to overnight recharging can follow a more deterministic pattern of concentration and penetration that, to a great extent, is dictated by the demographics of average household income and personal education level. During the transition period, when plug-in vehicles are more expensive than conventional vehicles, the distribution of plug-ins in the society can be uneven. The early adopters are expected to be the wealthy and the educated, i.e., those enjoying rather high income and education, and living in areas with high property value. The distribution will be very much location-, income- and education-dependent. As the price of plug-ins falls, the distribution is expected to become more uniform. Since home recharging is expected to be the most common method to be adopted by plug-in vehicle owners, during the transition period, residential areas identified by private households owned by high-income families and individuals (e.g., those with annual incomes higher than 80,000) are candidates for high concentration of plug-ins asking for reinforcement of distribution systems or making off-peak charging agreements with the utilities. For example, in the city of Toronto, in 2005, 30% of the private households made $80,000 or more [33], and 37% of residents had a bachelor's degree or higher and 10% had a Master's degree and higher [34]; therefore, from a correlation between the high-income and highly-educated population groups, the population of Toronto would likely be early adopters leading to areas in the city with high probability of high penetration and concentration of plug-ins.

As an example on how the growth in plug-in vehicle charging load can be accommodated by the utility distribution system, the system of Waterloo North Hydro (WNH) was looked at. From conversations with WNH Stations & Planning Engineering Supervisor, the utility distribution system has a feeder capacity limit of 600A at different voltage levels, with the daytime summertime operating limit set at 300A and up to 500A at night, depending on the weather conditions that affect air conditioner usage; these loading limits are for reliability purposes to make sure that in a single fault customers will not be left without power. The extra capacity available at night can be used for recharging of plug-ins in residential areas and industrial sites which do not have night shifts. The system capacity is increased in steps of 25% of the total capacity every 10 years via installation of new substations. This is meant to cover the new residences, as well as new commercial and industrial sites. If the rate of growth of free capacity matches the rate of growth with respect to time of penetration of plug-ins, and if smart systems manage the time of use (e.g., off-peak charging at home), the grid-integration of PEVs is likely to be smooth. Presently, lack of control of utilities over customer-owned DG based on renewable sources of energy does not allow for coordination of generation from renewables to support plug-in recharging. Future distribution system infrastructure enhancements, featuring enhancements such as smart switching capabilities and facilitates congestion clearing maneuvers, will permit higher penetration of plug-ins. In terms of location, urban areas are more suitable than rural areas for integration of plug-ins due to the flexibilities built in the utility distribution systems in urban areas.

4.2.2 Charging issues

The interfacing of onboard battery chargers with the grid can have adverse effects on the power quality at the point of common coupling with the distribution system, in the forms of harmonic pollution and voltage sags/swells. Since the onboard chargers are made by different manufacturers that may compromise quality for cost to keep their competitive edge, the charging stations (both home-based and public) have to be equipped with power factor correction, active filtering, power quality control and protection systems. The design and sizing of these systems are issues that are yet to be addressed.

In [29], four different charging scenarios for PHEVs have been considered to carry out studies on the effect of integration of this emerging load into the grid. These modes are:

- Uncontrolled Charging in which vehicle charging takes place only at home, starting upon arrival and ending upon departure. This is based on the natural behavior of most car drivers and can lead to higher load peaks in the early evening hours, overloading the house feeder, and uneconomical utilization of energy.
- Delayed Charging that features shifting of the charging load by the car owners or a timer to off-peak, low-cost hours (late evening and overnight) and taking advantage of incentives by the utilities based on the time-of-use.
- Off-Peak Charging in which individual or group charging is managed by the utility through a demand-side management protocol. This is only possible if the car owners already have or

are willing to sign an agreement with the utility to control their consumption. Even though the initial cost is higher in this scheme, the long-term benefit for the custom end system will pay back in a reasonable time.

- Continuous Charging in which vehicles charge whenever they stop and park. This needs distributed charging infrastructure. The initial cost is high, but provides maximum support for more-electric transportation.

During the transition from conventional vehicle domination to full-electric vehicle era, a combination of the scenarios described above will result in a charging load of stochastic nature, that can jeopardize the security and reliability of electric power if oversized feeders and carefully-designed protection systems are not in place.

Due to unavailability of public charging stations in the near future, and due to the expectation that many PEVs' charging can be done overnight, the bulk of PEVs are expected to be charged at home. The most convenient way for the car owners seems to be plugging in their vehicles as soon as they get home, which can be as early as 5 pm, i.e., during on-peak hours. Since most car owners will most probably delay making off-peak charging agreements with their local utilities (unless penalties force them or incentives motivate them), the dominant charging mode seems will be uncontrolled charging, which could add considerable load that is coincident with periods of high demand, and thus add to peak-capacity requirements. This can be obviously avoided with delayed and off-peak charging modes, which can be readily accomplish with the use of simple a timer to delay charging until later at night when the demand and thus electricity prices are lower, thus benefiting both the car owner and the utility, while making the charging load more deterministic.

The penetration level of PEVs' charging load on the grid is currently very low compared to the system capacity and is expected to increase gradually. Due to lack of infrastructure for public charging, daytime charging will be very limited for a while and therefore the daytime peak demand will not be worsened by the PEV proliferation. However, due to more probable pattern of plugging-in upon arrival at home, the evening peak demand will coincide with peak charging load of plug-in vehicles. As previously mentioned, delayed off-peak charging will improve the situation and will avoid need for capacity enhancement. Off-peak charging administered by the local utilities will also ensure efficient use of existing installed capacity based on the preferred fuel type, having cost and environmental impacts in mind while satisfying the plug-in vehicles load. In this context, it should be noted that one main advantage of PEVs over HEVs is the possibility of using electricity when it is less in demand and thus less expensive, generated from a mix of high-efficiency and environmentally-friendly sources and processes, including renewable energy sources; this can be realized if the charging is coordinated by the utility. Overnight, off-peak charging can effectively use the existing generation capacity as well as existent transmission and distribution infrastructures.

In [35], some of the hurdles in the way of large-scale penetration of PEVs are identified. One issue is the built-in electricity infrastructure of North-American homes. Thus, for a BEV car, where electricity is the only source of energy, home charging will need a 220 V wiring, since charging from a standard 110 V plug will not be practical due to the long time that it takes to charge the batteries. For example, for a medium-sized Hatchback Leaf, which can carry 5 passengers for 160 km (100 miles) on one charge of its Li-I batteries, it takes 18 hours of heavy charging from a 110 V outlet; in this case, the charging cannot be completed at home and will require out-of-home charging as well. Furthermore, the battery pack is leased at $150 per month, offsetting the advantage of charging from the electricity as an inexpensive fuel.

Plug-ins, at the present stage of maturity of battery technology, are most appropriate for short range (20-30 kilometers), where the batteries can be fully charged at home, at a rate that can be accommodated by the home wiring and can prolong the battery lifetime (trickle charging). According to [35], the PEVs with a longer range cannot all be fully charged at home overnight at off-peak rate; thus, the recharging should be completed during the day, which can happen to coincide with the peak-rate hours, unless a smart charger can guarantee an efficient charging regime. According to Southern California Edison, with peak rate of 33 cents/kWh and off-peak rate of 7 cents/kWh, charging at peak rate is like buying gas at $3.63 a gallon instead of 77 cents/gallon during off-peak hours.

According to [35], in areas where higher concentrations of plug-ins are expected, dealing with the extra load of charging could be a problem. Infrastructure will likely have to be beefed up, new transformers will have to be installed, and more maintenance costs will likely go up due to longer operation times for power plants at night and missing the down-time hours for maintenance. Al of this will indirectly translate into higher cost of electricity. Plug-ins will be beneficial where it is cheap to produce electricity at night, but there is no guarantee that high concentration of plug-ins will match the locations where extra cheap electricity can be produced. Producing low-cost extra electricity at night in locations where this is possible, and sending the power through grid to locations where concentration is higher, will increase cost and reduce reliability. The benefits from plug-ins in terms of off-peak night charging are location-dependent.

If traditional fossil fuel-based power plants are to support the increase in demand due to high penetration of plug-ins, environmental issues will deteriorate. Even though it is good to use these plants during the time periods where demand is low (e.g., overnight), maintenance time will be reduced resulting in possible economical losses. The best approach will be to introduce plug-ins together with renewable sources of energy coordinated via smart grid. In this regime, plug-ins will act as loads, storage and small portable generation units. Charging and discharging of plug-ins have to be scheduled and executed in a smart way to avoid congestion, while taking into account the comfort and preference of car owners.

In [35] it is argued that it takes more than 15-20 years for a new idea to capture 10% of the established market and another 10-15 years to become mainstream, i.e., own 90% of the market. If proliferation of PEVs is to follow the same trend, it will take a while for plug-ins to dominate the market. This long process should give enough time to utilities to learn to deal with the recharging demands of PEV, developing and deploying systems and mechanisms for this purpose.

4.2.3 Charging stations

As we transition away from conventional vehicles to sustainable electric mobility through fully-electric vehicles or plug-in hybrid electric vehicles, the availability, compatibility and reliability of charging stations become increasing important. According to Richard Lowenthal, CEO of the US company Coulomb Technologies, a pioneer in design and marketing of charging stations, the potential demand is huge, as the number of cars in the US exceeds the number of garages by 5 times and each plug-in vehicle would need two charging stations, one at home overnight and one at work in daytime [30]. Even though the technology of ac charging units is well-established, the networking technology enabling smart features and the connector technology have a lot of room for development. According to Mr. Lowenthal, “2009 is the year of the emergence of smart electric vehicle charging infrastructure”.

Steve Specker, President and CEO of EPRI, at Plug-In 2008 Electric Vehicle Conference and Exhibition, in San Jose, California, US, described the three main infrastructure goals of EPRI for the next three decades as: Generation De-Carbonization, Smart Grid, and Transportation Electrification. PEVs will heavily depend on the bulk electricity generated in a de-carbonized way, and will constitute a key player in smart grids. The charging of vehicle batteries will be scheduled based on the electricity price forecast communicated between the grid and vehicle; the vehicle battery will be used as part of distributed storage scheme and will return electricity to the grid when the demand is high.

The networking technology built in the smart charging stations will enable the following otherwise-impossible features:

- identification of the subscribers,
- electronic billing,
- search for available charging stations,
- notification of vehicle owner of completion of charging,
- and adjustment of charging expenses based on the time of use and market price

Successful large-scale launch of PEVs requires collaboration and coordination among the car manufacturing sector, the charging station providers and operators, and the provincial and federal governments. The most serious and bold step towards large-scale implementation of charging stations has been taken by Better Place, which is a company launched in 2007 with US$200 million of venture capital funding with the mandate of building electric-vehicle networks powered by renewable energy to give consumers an affordable, sustainable alternative for personal mobility. The company has already partnered with various regional and federal governments to build networks in Israel, Denmark, Australia, California and Hawaii. Better Place will activate networks on a country-by-country basis with initial deployments beginning in 2010 [36]. The business model Better Place is pursuing is based on installing a network of charge spots and battery exchange (swap) stations. Better Place commits itself to install and operate the network of charging infrastructure, while auto manufacturers make electric cars for that use battery type and location that matches specifications of Better Place charge spots and battery swap stations. Better Place powers the network from renewable energy sources, with a promise of zero emission, and its charge spots will be installed in parking spaces at home, at work, and at retail locations, enabling the car owners to top off their electric cars. When travelling over distances that cannot be supported by one charge, drivers can pull into battery exchange stations where their depleted batteries get swapped with a freshly-charged one by a robotic mechanism in a few minutes. The idea is to give consumers subscription to a sustainable transportation service in which the batteries are not owned by the customers to make owning an electric car affordable and convenient. This scheme needs standardization of type and place of batteries in the vehicle so that different vehicle models can be serviced very quickly by a standard station; up to now, Renault-Nissan Alliance has agreed to manufacture a model that fits the specifications set by Better Place. The billing is based on vehicle identification and prior service agreement between car owner and Better Place, which sells the customers the requested miles of driving. Fixed rates apply to the miles the vehicle is signed up for; beyond that, the rate will be variable. In early 2009, Better Place announced a partnership with the government of Ontario to help bring an electric car network to Ontario, which is regarded as one of North America's largest car producing regions. Better Place is partnering with Bullfrog Power, which is supposed to provide the renewable energy needed to power the Better Place network.

Three possible levels of charging have been identified [37]:

- *Level 1*: Charging uses a standard electrical outlet (120 V, single-phase, 12-16 A maximum continuous current, grounded in North America, and equipped with 15-20A over-current protection). It uses a standard 3-prong plug with a ground-fault circuit interrupter located in the power supply cable within 12 inches of the plug. Although 3-prong standard electrical outlets are available almost everywhere, Level 1 charging is not the preferred means of charging for two reasons: (1) Depending on the battery type and capacity, it can take 8-30 hours to fully recharge an EV; and (2) Several studies conclude that for some battery systems, Level 1 charging can shorten battery life and reduce performance, even though trickle charging is known to result in deeper charging and prolong battery life in other battery systems.
- *Level 2*: Charging employs a permanently wired and fastened charging facility sited at a fixed location. It uses a 240-V, single-phase ac supply, with 32-70 maximum continuous current capacity, and 40A over-current protection. It requires grounding, ground fault protection for safety of users, a no-load make/break interlock to prevent vehicle start-up during charging,

and a safety breakaway for the cable and connector. Depending on the battery type and capacity, Level 2 can recharge an EV in 2-6 hours.

- *Level 3*: Charging, which is still under development, takes place with fast-fill chargers that are expected to recharge 50% of an EV's battery capacity in 10 minutes or less. Level 3 systems will rely on an off-board charger equipped with an ac-to-dc converter. However, there are some drawbacks associated with charging at this level: The high power involved in Level 3 charging (480-volt, three-phase, 160A) is beyond the capacity of most utility transformers that serve residential areas and even some that serve commercial areas. Therefore, utility distribution system upgrades may be required to accommodate this level of charging.

Nissan is planning to produce thousands of electric vehicles in 2010 supported by a network of charging stations [38]. The company is working with Ecotality to bring close to 5,000 Nissan Leaf electric cars and more than 11,000 chargers to Arizona, California, Oregon, Washington and Tennessee. The US Department of Energy has granted Ecotality close to $100 million in support of electric vehicle project. The first Leafs are expected to arrive in the showrooms in December 2010 and, by then, the charging infrastructure should be ready. Nissan and Ecotality have the ambitious plan of installing 220 V chargers in customers' homes and creating public charging stations in a few cities and along the highways connecting those cities. Nissan is investing $1 billion in Tennessee to build Li-I battery packs for the Leaf and the car itself (beginning in 2012). The US Department of Energy has loaned Nissan $1.6 billion to help finance the project. Until the factory in Tennessee comes on line with the planned production of 150,000 Leafs per year, the batteries and cars will be built in Japan. Tennessee is promised to get 2,190 of the 220 V Level 2 chargers that will recharge a dead battery in eight hours. Ecotality and Nissan also will install 50 of the 480 V Level 3 quick-chargers that reportedly can do the job in as little as 20 minutes.

One of the problems facing proliferation of charging stations is the approvals involved in getting permission to install chargers in car owners' homes; it may take a couple of months, depending on the location. Nissan believes municipalities might choose to install charging stations in public parking garages and other locations. It seems stores such as Walmart and Costco have shown interest in talking about possibility of having chargers installed in their customer parking lots.

Ecotality and Nissan have started sharing with the public real-time information on the location of their charging stations and collecting feedback on where the interest in these stations would be strong. The Nissan Leaf is said to consume about 4 cents/mile and about 90 cents to charge it at off-peak times.

4.2.4 Standards

Standards are being developed for PEV charging devices, communications and installations, with EPRI playing a leading role [42]. Standards for devices are being developed by, for example, the Society of Automotive Engineers (SAE) for vehicles, and Underwriters Laboratories (UL) and the Canadian Standards Association (CSA) for the charging stations. For example, SAE standard J1772 "Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler" defines the standard plug/connector for electric vehicles for Level 1 and Level 2 charging in North America [43]. Installation standards for PEV charging are being defined in the CSA Canadian Electrical Code and the US National Electrical Code.

Communication standards are also under development. As per the aforementioned discussions, PEV charging will require smart chargers that are readily integrated into Smart Grids infrastructures, with two-way communication capabilities to allow information exchange between the vehicle (user) and the grid (LDC). Therefore, Smart Grid communication standards and technologies for home area networks (HAN) are being considered and will play a significant role in the design and development of PEV charging interfaces. Although these standards do not exist as of yet, ZigBee Smart Energy/Home Automation Profiles and Wi-Fi HAN technologies are being widely adopted by developers and manufacturers of smart appliances and home automation equipment [44], [45]; in fact, the ZigBee and WiFi Alliances have very recently announced an agreement to collaborate on wireless HAN for Smart Grid applications. The ZigBee Smart Energy Profile has been designed for energy management applications based on wireless HANs for energy management, allowing LDCs and customers to directly communicate with smart appliances. On the other hand, ZigBee's Home Automation Profile is becoming the standard for the control of a variety of wireless devices in home and small office automation applications. Low power WiFi has also emerged as another popular HAN technology among smart device developers and manufacturers, as it offers simple installation and network management, plus IP addressability and seamless integration into existing and popular WiFi home networks.

On the vehicle side, ZigBee is being considered as the protocol to be used for PEV charging communication applications. Thus, SAE J2847 is a technical information reference document currently under development which provides the basis for the use and support of the Smart Energy Profile in vehicle applications, and SAE J2836 is a recommended practices document providing the automotive standards for vehicle to utility communications based on the Smart Energy Profile [43].

4.3 PEV Grid Support (V2G)

In many studies, electricity generation and transportation have been identified as the major sources of greenhouse gas (GHG) emissions on the planet. Integration of renewable sources of energy in the grid and including renewables in the energy mix have received a lot of attention in recent years. Governments, even though originally reluctant and skeptical in accepting the benefits of wide-spread integration of renewables in the grid due to high initial costs and interference with the existing grid, have realized that the long-term environmental, political and societal benefits offset the short-term costs and hardships that can be resolved by advanced technologies and enforcing proper policies. Facilitating integration of plug-in vehicles in the grid is another effort worth pursuing due to its long-term benefits, including reduction in costs and emissions. PEVs can act as distributed loads (G2V), sources (V2G/V2H) and energy storage systems for the grid. Unfortunately, both renewables and plug-in vehicles have stochastic behaviors, making them difficult to manage. Within a smart grid, with multi-agent structure and communications among components of the system, the managements of distributed loads, sources and energy storage systems will be possible. This has to be the goal towards which the electricity and transportation industries should move and be supported by governments. The goal should be a system that allows simultaneous and coordinated operation of renewables and plug-in vehicles at high penetration levels. Even though obvious, recent studies show that integration of plug-in vehicles will add to the load on the grid. However, if the growth in plug-in vehicle load goes hand-in-hand with growth in installed renewables capacity, the extra load on the system could be supplied by renewables. This takes the burden of additional load off the shoulders of existing installed generation and allows for low-cost and emission-free supply of plug-in vehicles energy demand.

Plug-in vehicles constitute a distributed mobile energy storage/generation network allowing for bidirectional power flow transactions between the PEV and the grid. For full-scale implementation of the V2G/V2H concept, all vehicles with plug-in capability must plug-in when they are parked, whether or not they need recharging (this is like getting connected to the internet whenever possible). The vehicle and plugging interface will decide on recharging or V2G/V2H operation depending on the grid/home needs and vehicle's battery state-of-charge (SOC), and the preferred departure SOC set by the car owner. The majority of vehicles are on the road for a short period of the time in a day; the rest of time they are parked, either at home or at workplace. This means that a large number of PEVs are likely to be available for interaction with the grid. Even though the status (moving or parking) of individual vehicles is random, those parked and participating in an agreement with the utility can be easily identified as the targets for V2G/G2V transactions. The battery charge or discharge will take place based on the car owners' set preferences, battery state-of-charge, and grid requirements.

In [39] and [40], the authors report that in the US and Japan, at any time during peak traffic periods, more than 20% of vehicles are parked. The pattern should be similar in Canada and Ontario. This shows that in other times of the day, including peak-load, there will be more cars parked. Therefore, the large number of PEVs plugged in has the potential to make bidirectional transactions (V2G and G2V) with the grid.

In [41], the authors have developed suitable models of electric vehicles with different types of controls in order to conduct detailed hour-by-hour overall system analyses on the impact of V2G on the national energy system of Denmark. The model is run assuming full electric vehicles. The study includes wind energy and combined heat and power (CHP) generation. The analysis shows that EVs with overnight charging, especially those with increased intelligence including V2G/V2H management, will improve the efficiency of the electric power system, will lower CO2 emissions and will improve the ability to integrate wind power. The study conservatively assumes that 20% of the EVs are parked and plugged in at any time. The ability to participate in the grid voltage and frequency control has been regarded as the most important advantage of V2G over simple EVs. The model presented does not use this capability and assumed 100% SOC requirement in the morning before departure, which places a burden on the operating power plants overnight. A smart controller can schedule charging based on preference of car driver for SOC at the time of departure in the morning. In this scheme, the batteries are not fully charged overnight and some room is left to absorb energy during daytime whenever there is surplus power in the grid. The study shows that despite the conservative assumptions made on the number of parked vehicles, an EV fleet with some built-in intelligence (e.g., just-enough night charging and able to intelligently participate in V2G transactions) appears to have the potential to help in the development pf low-carbon national energy systems. Intelligent EVs can help minimize excess electricity generation and greenhouse gas emissions. V2G, along with some end-use heat storage and management, constitute a carbon-free and far lower-cost alternative to expansion of fossil-fuel generators or to building dedicated centralized storage. Given the potential advantages of V2G and G2V, in the same way that governments encourage generation from renewables by offering incentives in the form of special tariffs for the energy produced from renewables, incentives can be offered to encourage the appropriate participation of PEVs in V2G/G2V transactions with the utility.

The Micro-FIT program has been introduced by the OPA as an extension to the FIT Program for renewable energy generation [51]. It encourages the development of micro-scale renewable energy projects in the province, up to 10 kW in capacity, typically by residential customers. The project owners are paid a fixed price for the power produced over a period of 20 years. Currently this program includes biogas (16 cents/kWh), biomass (13.8 cents/kWh), landfill gas (11.1 cents/kWh), solar PV (80.2 cents/kWh), water power (13.1 cents/kWh) and wind (13.5 cents/kWh). There is a substantial interest in the micro-FIT program, encouraging several distribution level customers to participate in this initiative. Hence, a program somewhat similar to the micro-FIT program for V2G customers to appropriately recognize their energy storage contributions to the grid would provide an additional incentive to existent and potential PEV owners.

Independent System Operators (ISOs) or Regional Transmission Operators (RTOs) such as the IESO need to consider new grid integration and regulation issues associated with PEVs, especially with respect to the use of the energy stored in the batteries of PEVs to support various categories of ancillary services, Demand Response (DR) and integration of renewable technologies. In this context, there is a need for ISOs, RTOs, market operators and regulators to identify the products and services that PEVs could provide under existing market and reliability structures within ISO/RTO markets. The following are aspects that need to be considered with PEVs being possible providers of services for power system operations:

- Develop recommendations for market products, DR and other energy opportunities, as well as consider power system reliability impacts from these services.
- Identify the requirements for technologies, communications, security and protocols, constraints, prices and accountable parties, i.e., vendors, regulatory and standards agencies, and/or ISO/RTOs, in implementing such products and services from PEV providers or aggregators.
- Define performance, operability and observability requirements and recommendations for PEVs as ancillary service providers.
- Define the role and/or requirements for ISO/RTOs as integrators of PEV products and services.
- Recommendations appropriate for ISO/RTOs to formulate consistent policies/standards, and how the products and services would play across interconnected electricity markets.

In light of the above, there is a need to provide specific recommendations on market implementation issues for PEV participation in the provision of ancillary services, which impact system reliability, such as:

- Market design and operational requirements for such services.
- Recommendations for operational and market infrastructure development considering V2G, DR and renewable energy sources and their integration with energy management systems and pricing algorithms, dispatch programs, etc.
- Need for detailed modeling and analyses to demonstrate feasibility of recommendations and time lines.
- Address cyber security, field safety, vehicle plug-and-play requirements, while adhering to the respective ISO grid codes.

4.3.1 Energy storage and integration with Distributed Generation (DG)

PEVs depend strongly (PHEV) or solely (BEV) on electricity. This will increase electricity demand and depending on the rate or penetration and broader consumer acceptance would likely result in the need for expansion of generation, transmission and distribution infrastructure. Knowing that electricity infrastructure expansion is very costly and will contribute more to GHG emissions, wide-spread use of plug-in vehicles will not reduce overall cost and emissions unless electricity is produced in more economical and environmentally-friendly manner. Ideally, additional power needed for charging plug-in vehicles should be produced from renewable sources of energy. Success of plug-ins with V2G/V2H capability in reduction of cost and emissions depends on the level of penetration of renewables in the energy mix and coordinated optimal control of plug-ins and renewable energy sources. Wireless communications between the plug-in vehicles and the utility within a multi-agent smart grid is required to manage the use of participating vehicles in V2G/V2H and G2V schemes based on real-time electricity pricing information while maintaining a state-of-charge level in the car battery for the time of departure according to the car owners' preference. Without integration of renewables, harmful emissions will not be eliminated; instead, they will be simply shifted from the transportation sector to the power generation sector.

One idea is to install renewable DG at the public charging stations and complement it with an energy storage system. In this way, bulk energy can be stored during the off-peak hours, when electricity demand is low and the price of electricity is low. Then, during peak hours, the stored energy can be used to charge the plug-in vehicles. This is an extension to the off-peak overnight charging at home and makes it possible to charge the vehicles travelling beyond their battery only-based driving range.

4.3.2 Voltage/frequency regulation

Integration of a large number of plug-in vehicles with a variable charging patterns in the grid can result in issues with voltage and frequency regulation. Whether the existing installed capacity has the inertia and speed of response required to keep the voltage and frequency stabilized in the presence of a large fleet of plug-in vehicles, or voltage and frequency control have to be modified, is something that has to be studied. An alternative to putting the burden of voltage and frequency control on the grid is to make each charging station (home-based or public) try to regulate the voltage and frequency in an autonomous manner. In this way, the interface of the charging station with the grid is not simply a diode rectifier. Instead, a bidirectional switch-mode converter makes the interface with the gird, making it possible for the charging station to respond to transients. The voltage and frequency control droop characteristics of charging stations have to be carefully designed based on the ratings of the stations. Since the transactions between the grid and plug-in vehicles are mainly of active power nature, frequency control seems to be more critical in large charging stations. In public charging stations, where bulk energy storage and renewable DGs can be incorporated, there is a better possibility of voltage and frequency control. In a smart grid environment, where the sources, load and energy storage systems are communicating with one another, all the existing resources for frequency and voltage control can be utilized. It seems successful high-penetration of plug-in vehicles and renewable energy sources for sensible economical and societal benefits can only be realized in smart grid environment.

In [54], the results of a study on the impacts of penetration of PEV on a distribution network are reported. In this study, the IEEE 34-node test feeder has been connected to a 3-phase 160-kVA transformer on the Belgium national grid. With zero penetration of plug-ins, the maximum load on the 400 V, 220 A line is 120 kVA. The transformer rating is supposed to satisfy a few percent growth in the load over the next 10 years. Table 3.5 summarizes the results for line current, node voltage and power loss for three cases: (a) when no plug-ins are integrated into the feeder, (b) when plug-in vehicles with uncoordinated charging are integrated into the feeder at 30% penetration level, and (c) when plug-in vehicles with optimally coordinated charging are integrated into the feeder at 30% penetration level. It can be clearly seen that with uncoordinated charging, the limits on the line current and transformer power rating have been exceeded, the node voltage has dropped by almost 3%, and power loss has increased by 1.3% compared to the case without plug-in integration. On the contrary, with optimally coordinated charging, the base-line conditions for line current, node voltage and load power have been resumed and power losses have been increased by only 0.7%. A higher penetration level can result in a larger voltage drop if uncoordinated charging is implemented. These results clearly demonstrate the significance of coordinated charging, that will be made possible by incorporation of smart metering, in securing a stable voltage profile, and avoiding exceeding of line current and power rating of the feeder. This directly translates into relieving the need for distribution grid expansion and reinforcement exclusively due to penetration of plug-ins.

Table 3.5
Power quality and losses for IEEE sample grid [54].

Parameters	Without PHEVs	Uncoordinated Charging	Coordinated Charging
Load [kVA]	120	168	120
Line Current [A]	182	266	183
Node Voltage [V]	213	207	213
Power Losses / Total Load [%]	3.1	4.4	3.8

The voltage support and regulation can be provided locally using switched capacitors combined with transformer tap changers or static reactive power compensators (SCR-based SVC and IGCT-based STATCOM). A thorough study on a per-case basis has to be performed to see which scheme is more flexible and economical: expanding and reinforcing the distribution system infrastructure to cope with the integration of plug-ins with uncoordinated charging, or incorporation of smart metering in the context of smart grid to enable coordinated charging. Since smart meters will be the future of consumed energy measurement in residential, commercial and industrial sites, the second option seems to be more viable and economical, and thus, advantageous. Furthermore, the inverter-based interface between the plug-in vehicles and grid provides the possibility of participation in the grid voltage control; to accommodate this, the inverter should be accurately sized and operated.

High penetration of PEVs with uncoordinated charging can disturb the balance of active power generation and consumption, and thus, result in deviations from the standard frequency. If the plug-in vehicles are plugged in whenever possible, the system operator can use the energy stored in the batteries of these vehicles to help regulate the frequency. Attempts to regulate frequency, even though local to the generation site, can affect the frequency of the whole system, as frequency is a global parameter, in contrast to the voltage that is a local parameter. According to [55], an average car in the US is driven only around 1 hour per day. The pattern of vehicle use should be very similar in Canada, including Ontario. If all or most of these cars have plug-in capability, a huge number of vehicles will be parked and ideally plugged in. This will provide a great opportunity for frequency regulation through coordinated bidirectional transactions between the grid and the grid-connected vehicles.

According to [56], plug-in vehicles can support a range of ancillary services including frequency regulation and spinning reserve. However, the revenue gained from providing regulation services is much higher due to more frequent occurrence of regulation than that of acting as a spinning reserve. Frequency regulation is responsible for maintaining the frequency of the grid at the standard value (60 Hz in North America). This is normally performed via real-time communication signal sent to the generators by the grid operator. The frequency regulation signal can call for either regulation up or regulation down, depending on whether the load exceeds the generation or vice versa. The timescale of the regulation signal is typically much smaller (minute-by-minute throughout the day) than those of the daily fluctuations in the load and economic dispatch (hour-by-hour). Regulation is contracted capacity on an hourly basis, and dispatched over intervals between four seconds and one minute, depending on jurisdiction. Typically, regulation is dispatched for a short duration (a few minutes at a time) and the dispatched amount is much smaller than the contracted amount. This implies a good application for a plug-in vehicle whose battery is connected to the grid via a high-power connection, since this allows for the battery to charge or discharge slightly, thus causing very little wear to the battery compared to what happens when going through deep cycles of charge and discharge. To take advantage of this opportunity and accommodate bidirectional transactions between the grid and plug-in vehicle for frequency regulation, the battery must be properly sized and an appropriate V2G contract has to be in place.

Since the PEV is connected to the grid most of the time, the power flow control and protection of the connection become very critical. The power and current have to be monitored so as not to exceed the safe limits. Battery SOC has to be monitored to make sure the desired SOC is available upon the net departure. The depth of discharge and the rates of charge and discharge have to be monitored, as they are directly related to the health of the battery, its life-time, and thus the cost of operation of the plug-in vehicle. From the protection point of view, besides regular protections such as over-current, anti-islanding protection (IEEE Standard 1547) has to be in place, as the plug-in vehicle has to be treated as any other grid-connected distributed generation unit which should disconnect from the point of common coupling when a breaker on the grid side is opened.

4.4 PEV Metering and Retail Pricing Issues

Formulating appropriate tariffs and connection charges for the PEVs is an important issue because that impacts the penetration level of PEVs, as well as the level of revenue earnings for the Load Serving Entity or LDC as the case maybe. It can be assumed that the PEVs will be connected to the LDCs distribution grid either as individual entities directly at the household level or through load aggregators. In case PEVs are connecting to the LDC for charging as individual entities at the household level, it is extremely difficult to segregate the household loads between PEV-load and non-PEV load. In such cases, the best tariff option would either be real-time pricing or time-of-use rates for the household. Through either of these pricing schemes, the individual household will seek to schedule its PEV charging load in such a way that its electricity payments are minimized. In this context, the smart charging systems discussed in Section 4.2 would make it possible to monitor real-time market prices and optimally schedule PEV charging operation directly at the household level. On the other hand, the tariff mechanisms for the load aggregators will have to be somewhat different from the household ones, due to the magnitude and nature of loads being added to the LDC by these aggregators.

In an ideal situation, the transactions between the grid and the PEV are bidirectional. The vehicle is charged from the grid to maintain an acceptable state-of-charge based on the driving range planned; it stores energy beyond the planned driving range if the installed storage capacity allows for this; and it discharges into the grid when it is asked to while maintaining higher than a specified state-of-charge to be able to drive afterwards. The bidirectional transactions between the vehicle and the grid through the charging station can serve the purpose of voltage/frequency control as well (V2G); these transactions have to be coordinated through communications. Depending on the protocol governing the vehicle-grid transactions, a metering system is required to measure the power exchanged and the costs based on the time of the transactions. The smart meters that utilities are installing with communication and potential net-metering capabilities are most appropriate. Installing these meters at homes facilitates integration of small DG units such as roof-top PV systems as well. For public charging stations, the metering has to be done through communication. The vehicle has to be identified by an IP and charged for the net energy consumed. Communications also facilitate guiding the car owners to the closest charging station when low in SOC and indicating which station has free spots to be used without waiting.

Net-metering is a simplified way of metering the energy consumed and produced at a home or business with its own renewable energy source (e.g., roof-top solar PV) [50]. The same concept may be extended to the V2G operational modes in PEVs and can be implemented at the aggregators' level or even at individual households. Typically, in net-metering, excess electricity produced by the source spins the electricity meter backwards, effectively banking the electricity until it is needed by the customer. This provides the customer with full retail value for all the electricity produced. Net-metering provides a variety of benefits for both utilities and consumers. Utilities benefit by avoiding the administrative and accounting costs of metering and purchasing the small amounts of excess electricity produced by small-scale facilities. Consumers benefit by getting greater value for some of the electricity they generate and by being able to interconnect with the utility using their existing meter. The bill savings for the customer (and corresponding revenue loss to the utility) will depend on a variety of factors, particularly the amount of excess electricity produced.

According to [57], in Ontario, the shift to smart meters for homes and small businesses is expected to be complete by the end of 2010. These meters track the electricity consumption stamped with the time of use to facilitate implementation of time-of-use pricing. This allows utilities to manage their resources more economically by rewarding the consumers who shift their heavy use of electricity to off-peak hours and penalizing those who are not smart and flexible enough to make any changes to their lifestyle and culture of energy use. Note that the cost of providing electricity changes in the course of a day: in off-peak hours, less expensive sources are used to produce electricity, whereas in high-demand hours, more expensive forms of generation are employed. The price of electricity can be different from one municipality to the other; however, the following current time-of-use prices set by the Ontario Energy Board (OEB) and reviewed on November 1st and May 1st for adjustment, gives an idea about the pattern of change and how the consumes can save money and help the utilities at the same time. In summer (May 1st to October 31st) and Winter (November 1st to April 30th), on weekdays, 7:00 am to 11:00 am and 5:00 pm to 9:00 pm are considered on-peak hours, 11:00 am to 5:00 pm mid-peak hours and 9:00 pm to 7:00 am off-peak hours. During weekends and holidays, all hours of the day are considered off-peak. The price of electricity is 9.3 cents/kWh, 8.0 cents cents/kWh and 4.4 cents/kWh for on-peak, mid-peak and off-peak hours, respectively. This demonstrates the high economical gain that can be achieved by taking advantage of time-of-use pricing.

Ontario's smart meter infrastructure connects electricity consumers to a wide computer network. The IESO will act as the interim smart metering entity responsible for the central data repository. The IESO will collect and manage smart meter consumption data and will use it to create time-of-use bills. New electricity bills will provide information about how much electricity has been used during the various peak periods. The plan is for LDCs to provide the previous day's electricity consumption information on a secure site on the web.

In the case of PEVs, the installation of smart meters and implementation of time-of-use pricing translates into large differences in the cost of energy use over the lifetime of the vehicle. In the light of potential advantages of integration of electricity and transportation sectors via implementation of smart grid initiatives and PEV proliferation, it is most beneficial to take advantage of the fact that smart meters are being installed in the electricity distribution system of Ontario by making the metering systems for the home-based and public charging stations compatible with the smart meters. In fact, since PEV owners will eventually pay the utilities for their electricity consumption, it is wise for the local distribution companies to get involved in the business of charging stations and the metering systems that go with them. An alternative will be giving the right to the companies which make the charging stations to install smart meters for keeping the account of charging and other transactions between the plug-in vehicles and the grid in close collaboration with the LDCs. With the existing wide-band communication channels, it will be relatively easy and efficient to integrate a many useful features in the metering systems of the charging stations.

On a larger scale, one can think of a much more interesting scenario. Imagine a plugged-in vehicle registered for participating in bidirectional transactions with the grid as a unit of distributed, mobile generator/energy-storage/load fleet. At any charging station (home or public), the time-stamped consumed electricity is acquisitioned and communicated to a central entity responsible for keeping track and account of electricity consumed by the PEV. Any of the participating (registered) vehicles has an identifier code that allows it to be recognized by the charging station and receive the required service. This allows the account of all the transactions made by this vehicle to be kept separately from those of others. Then, the data collected and transmitted to the central entity will be used to calculate the net kWh exchanged between the vehicle and the grid, as well as the net cost of electricity consumed, and produce a real-time histogram of energy exchanged. This information will make the electricity bill for the vehicle that can be accessed and viewed by the car owner at any time on a secure website, and paid for. In this way, the metering system at the charging stations will be very simple. The power is measured at set time steps and stamped with time. There can be a small processor onboard the meter that calculates the energy in set intervals to reduce the load on the transmission channel and central entity responsible for accounting. With an internet connection, this data is delivered to the central entity, where everything else is taken care of. The payment for the services received does not have to be monthly; it can be done at the convenience of the car owner.

5. Electricity Market:

5.1 PEV Impact:

The battery storage of an individual PEV is too small to impact the grid in any meaningful manner – either as a load (G2V) or as a generation source (V2G/V2H). An effective approach to deal with the negligibly small impact of a single PEV is to group them together – from thousands to hundreds of thousands. The *aggregation*, then, can impact the grid both as a load (G2V) and a generation/storage (V2G) device. Such aggregation will help represent the PEVs as a load or a resource of a size appropriate to exploit economic efficiencies in electricity markets. It has been argued in [26] that the "Aggregator" would be a new player in the electricity market whose role would be to collect the PEVs by attracting and retaining them so as to result in a MW capacity that can impact positively the grid. The size of the aggregation is indeed the key to ensuring its effective role. The Aggregator would also provide interface with the ISO/RTO, whose responsibility is to operate and control the bulk power system, and with the energy service providers (ESPs) who provide the electricity supply to customers through the distribution grid.

In terms of load, an aggregation of PEVs represents the total capacity of the batteries, an amount in MWs that constitutes a significant size and allows each PEV to benefit from the buying power of a large industrial/commercial customer. There are additional economic benefits that accrue as a result of the economies of scale. The aggregated collection behaves as a single decision maker that can undertake transactions with considerably lower transaction costs than would be incurred by the individual PEV owners. So, the aggregated entity can make purchases – be it electricity, batteries or other services – more economically than the individual PEV owners can and can pass on the savings to each PEV owner.

5.1.1 Load profile and elasticity

The addition of the load of the aggregated PEVs for charging during the night not only helps in valley filling of the load curve, but also consequently, decreases the need for regulation services. As a result, the units in the resource mix need not be turned off during the night and would be ready for the morning load pick-up. This is expected to reduce the overall cost and increase the overall benefit. In addition to lowering off-peak regulation needs, the aggregated PEVs may also be deployed to provide day-time regulation service to the grid given the fast response capabilities of the batteries, in the order of milliseconds [26].

It is clear that in all cases, the night time charging "fills in the valley" and so provides a more level load profile than the evening charging. Since utilities would prefer the increased utilization of existing capacity rather than having to build additional capacity, they would be expected to prefer night time charging. In a study reported in [27], the impact of adding a 2 kW evening charging and night charging scenarios for the year 2030 is studied. It is seen that the annual peak load rises by 5.4% in the East Central Area Reliability Coordination Agreement (ECAR), but in regions with a higher percentage of vehicles, and for a 6 kW evening charging scenario the difference is more pronounced. California has a 9% rise in peak by 2020 and a 28% rise by 2030. However, the peak load is not affected if charging is done at night. With the larger number of vehicles in 2030, all regions see new peak loads if vehicles charge in the evening, regardless of the power level. So even though the total energy demand increase attributed to PEVs is in the range of 1 to 5%, the peak capacity demand increase has a much wider range from no change to 28%.

The batteries of the PEV aggregation can either absorb or discharge energy depending on the state of charge of each individual battery, but can do so with a much faster response time than conventional units. The deployment of aggregated PEVs for such regulation service may not necessarily involve the supply of energy but simply the use of the capacity they provide. The PEV aggregation can act as a very effective resource by helping the operator to supply both capacity and energy services to the grid. To allow the operator to ensure that the supply-demand equilibrium is maintained around the clock, the PEV aggregation may be used for frequency regulation to control frequency fluctuations caused by supply-demand imbalances. Regulation requirements vary significantly from on-peak to off-peak periods. A battery may provide up-regulation or down-regulation service as a function of its state of charge. Depending on its value for each PEV in the aggregation, the collection may be deployed for either regulation up or regulation down at a point in time. Resources that provide regulation services are paid for the capacity they offer.

Typically there is a need for down-regulation service during the night, while during the day both up- and down-regulation may be required. The high prices for night-time regulation are representative of the situation in other ISO/RTOs. For example, for the California ISO, the price of regulation at 3am was higher than 250 $/MW/h eleven times in April 2006, nearly one out of three nights [26]. Indeed, compliance with the unit commitment schedules becomes difficult in the low-load conditions during the off-peak periods. While the operator may not wish to turn units off, in some cases, there may be no choice. Therefore, these situations lead to the much higher prices for the regulation down service during the off-peak periods, particularly when compared to those for the regulation up and the regulation down services in the peak periods. The addition of the load of the aggregated PEVs for charging during the night not only increases the load but also, consequently, decreases the need for regulation services. As a result, the units in the resource mix will not need to be turned off during the night and will be ready for the load pick-up in the morning.

In the context of Ontario, the OPA has instituted DR programs in which participants can receive compensation for curtailing their electricity demand [52]. Among the possible options of reducing consumption, as recognized in these programs, are: load interruption, load shifting and behind the meter generation (excluding diesel, coal, bi-fuel, and bio-diesel). There is no maximum limit on the number of hours of operation and a minimum of 0.5 MW load reduction is required, for at least one hour. Participants are required to offer their own "strike price" on a monthly basis, at which they are willing to curtail load, which must be higher than the minimum defined Floor Strike Price for the month.

Inclusion of PEVs in DR programs can substantially help introduce load elasticity to the Ontario system. However, given that a minimum of 0.5 MW of load curtailment is required, individual PEVs would not be able to meet this requirement; the solution in this case would be to consider PEV aggregators, instead of individual PEVs, as participants in this program. These aggregators could provide the same demand relief to the system during times of system peak and other critical conditions, and would essentially be considered as "behind the meter generation." Suitable policies need to be implemented for inclusion of PEV aggregators in DR programs.

5.1.2 Generation dispatch

The PEVs can help to address the underutilization of generation and transmission capacity which is usually seen in power systems. Because of the differing characteristics of power generation and distribution, combined with extremely volatile demand patterns, the power system requires that capacity and infrastructure is available for unexpected events. Depending on climatic conditions, the peak demand occurs during certain seasons (winter/summer etc.) and certain time of day (afternoon/mornings etc.). The rest of the time the transmission grid and the generating capacity is not fully utilized. The PEVs could contribute to grid operations by reducing the number of times generation plants are shut down and restarted, which guarantees cost savings on dispatching power.

A key question in such operational impact of PEVs is when would consumers recharge their vehicles? The optimum time for ISOs would typically be at night when demand is low and low-cost plants are the marginal producers. Any additional generation would come from these low-cost plants and not strain the existing transmission and distribution system. However, for consumers the preferred time (in the absence of incentives) is likely to be as soon as they are within easy access to a plug. Charging at that time is most convenient because the driver is then at the vehicle already and will likely want to keep the battery as fully charged as possible in case the car is needed soon.

There are various ways for utilities to influence customer choices, including pricing schemes favoring night time charging or regulatory fiats on vehicle charging. Technically, it may be through smart chargers that know the price of power and/or driving habits of the owner. The intelligence could be in the charger or in the vehicle itself. Such questions are fertile areas for more extensive analysis. Consumers could also recharge at their places of work, giving them additional range. Employers could offer this option as a benefit to employees, or local governments could offer daytime recharging to reduce afternoon air pollution (since more battery power would then be used during the evening commute). Utilities and businesses could even install the infrastructure to allow consumers to plug in anywhere and have the cost of purchased power added to their bills.

The G2V option can also be compared – in concept, in some of the technology, in marketing, and in administration – to the existing residential Direct Load Control (DLC) programs implemented in various utilities. The utility DLC programs recruit residential customers to participate voluntarily. The utility installs radio-controlled switches in the customer's house. During times of peak demand, the utility can remotely cycle off ("dispatch") some of the customer's heavy appliances, such as water heater and air conditioner. The customer receives a small yearly payment and is contractually guaranteed limits on use (e.g. the utility not exceeding a maximum number of DLC actions and a maximum time per dispatch and, for air conditioning, a maximum off-cycle such as 1.5 min per half-hour). In utility planning and management, large DLC programs are similar to peak power plants; DLC is even dispatched in the same way – a central control station has controls to turn off large blocks of customer equipment, like the switches used to turn on power plants. In a comparative study of DLC options and PEV operating in G2V mode discussed in [28], it was found that the PEV offers the same equipment cost to utility, yet five or more times the peak support capacity.

The PEV penetration impact on IESO's day-ahead dispatch will be minimal because the PEVs will not be bidding into the market in the day-ahead stage. The Day-Ahead Commitment Process (DACP) of the IESO will therefore not be able to consider the PEV demand directly. However, if the PEVs are connected to the grid through load aggregators, it eventually may be possible for the IESO to enter into contractual mechanisms with the aggregators and in such a case the DACP could incorporate the PEV penetration.

In the Ontario power system, the base load is typically met by large nuclear generators which usually have a "must-run" status over a period of several days. With large-scale penetration of PEVs, the unit commitment (DACP) decisions would likely be changed and other generators- such as coal/hydro or even gas-fired generators may need to be committed at these hours. This will also impact the Pre-Dispatch Prices (PDPs), i.e., the day-ahead forecast of the system marginal prices and consequently also increase the HOEP, as discussed in more detail below. On the other hand, because of the changed unit commitment decisions, more generators will be on-line at off-peak hours, and the IESO can benefit by increasing exports to neighboring system at these hours. This will increase capacity utilization as well as revenue earnings for the IESO.

The actual PEV demand will appear in the real-time dispatch stage in the IESO system, making significant load contributions. Such a situation can be viewed as demand spikes in real-time, for which the IESO has to be prepared to provide adequate generation support and regulation services. This will certainly impact the HOEP.

5.2 Electricity Prices Vis-à-vis PEV Penetration:

In [27], electricity prices are shown to be the most sensitive indicators of PHEV penetration; thus, for the various scenarios considered in several US regions, prices may increase by as little as 1.2% and as much as 297%. It is argued that as demand increases, if the effects of PHEVs on capacity planning are not considered, prices are forced up in competitive markets. It is demonstrated that these prices are very much contingent on time of recharging.

The Ontario's marginal cost of generation and consequently the HOEP is significantly low during night-time hours and even negative sometimes as previously discussed. In this context and as discussed in Section 3.2, the penetration of PEVs will benefit the customers because of the low (even negative) HOEP, while the Ontario power system will benefit from increased capacity utilization and increased revenue during night-time operation. However, there can be an adverse effect of large-scale PEV penetration on the generation dispatch in the Ontario system, especially if the PEV charging period is concentrated during a certain period of the day. This adverse effect would arise when the PEV penetration level, denoted here by the change in overall system demand at an hour k, ΔPD_k, is large enough, i.e., larger than a threshold value x_o ($\Delta PD_k > x_o$), so as to modify the unit commitment (DACP) decisions of the IESO and thereby impact the selection of the marginal generator for that hour; this thereby will impact the HOEP and result in increased electricity prices at certain hours. Thus, the impact of PEV penetration on HOEP can be mathematically expressed as follows:

$$HOEP_k = \begin{cases} HOEP_k & \Delta PD_k^{PEV} \le x_o \\ HOEP_k + \Delta\rho_k^{PEV} & \Delta PD_k^{PEV} > x_o \end{cases}$$

In the above, if the PEV penetration level ΔPD_k is below x_o, there is no impact on the HOEP, while when it exceeds x_o, the HOEP would increase by $\Delta\rho_k$. It should be noted that the above model assumes that the PEV operates only in the G2V mode; for V2G operation, this model can be readily modified accordingly.

The electricity market may also see a reduction of PEV connectivity to the grid at the hours of increased prices for G2V operation, *if* these prices are properly conveyed to the PEV user. In this case, an overall equilibrium condition of PEV connectivity and prices would be reached, allowing the Ontario system and market to achieve an "optimal" PEV penetration level from the electricity market perspective.

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CHAPTER 4 – POLICY ISSUES AND ACTIONS

1. Purpose

Here we identify the barriers, policy and regulatory issues related to consumer adoption of plug-in electric vehicles (PEVs) in Ontario, from the consumer, manufacturer and markets points of view, since the main technical issues are addressed in the detail in the previous two chapters. There are several important, but interrelated, questions that need to be addressed such as:

- Who will pay for the infrastructure (e.g., the charging stations)?
- What communication infrastructure should we use – the existing one or a new one?
- How will vehicles communicate with the grid – through wires or wirelessly?
- If smart charging becomes a requirement, who will control charging – the utilities or the customers?
- Where will the intelligence be located – in the car, the grid or the building owner?
- What is the appropriate role for government and regulators in enabling a smooth transition to a PEV world?

Specifically, we describe the key barriers under each of the following categories and propose possible solutions:

a) Infrastructure Issues: first mover conundrum, costs and requirements
b) Consumer Issues: consumer acceptance, growth of demand and consumer control
c) Utility Issues: interconnectivity, regulations, standards
d) Battery Issues: costs, uncertainties, replacement and life cycle management
e) Markets and Business Models: communications, billing and settlements

For each of the above, we describe the context, identify the "cutting-edge" work being undertaken in other jurisdictions, and highlight possible solutions and summarize by providing specific actions or recommendations relevant for the Ontario context.

Figure 1.1 (Chapter 1) shows how the key stakeholders are linked and specific groups who will play a role in the Ontario market place. The interactions amongst these stakeholders will ultimately determine the outcomes and whether wider adoption of PEVs will take hold in Ontario. A convergence of the needs of consumers and ability of the grid to deliver will be necessary for success. Different stakeholders possess different information and their goals vary; for example, consumers (low cost, reliable performance), connectors (business growth and opportunity), grid operators (stable, uncongested system), financial community (new business opportunities) and government agencies (environmental performance, economic development).

2. Infrastructure Issues

A transportation system that includes at least a modest number of PEVs will require not only new products to be purchased by consumers – i.e., the vehicles themselves – but also an associated infrastructure that would be "new" – i.e., a network of charging stations, both at the "home" location of the vehicle, as well as "on the road." In addition, there will also be the need for a broader infrastructure (including mechanics trained in the maintenance and repair of such vehicles and inspectors for safety validation of charging stations) to be in place for successful deployment. If this infrastructure proves to be inadequate in the early stages, even for the early adopters, it will create a negative environment and dampen the prospects for future success.

While this broader infrastructure needs to be in place to support even the "first" batch of PEVs on the road, the early high cost and uncertainty about future outcomes is a barrier that must be recognized. Indeed, the conundrum is that even though the subsequent presence of a large number of PEVs would justify the investment in infrastructure, there is no guarantee that, to quote a phrase, "if you build it, they will come." In more formal terms, it is the challenge of providing "public goods," or the means whereby the "dilemma of collective action" can be successfully navigated [1]. Important to recognize is the fact that there is significant risk associated with this initial investment in PEV infrastructure. This is a risk that the private sector entities may not be willing to underwrite and hence – because development cannot simply be on the back of (or through the wallet of) the first purchasers or early adopters – there is the need for specific policy actions to attempt to overcome this barrier.

One of the findings of the Mckinsey study [2] for NYC indicates that the projected level of adoption of PEVs should not threaten the stability of the electric grid as long as most chargers are "smart," allowing charging to take place during off-peak hours. The study indicates ongoing coordination will be necessary to support infrastructure planning that takes into account electric vehicles and continue to adjust planning as the growth of electric vehicles is better understood.

Smart charging mechanisms, however, are a key requirement that will help utilities manage demand. Thus, the time during which a vehicle is being charged will play a significant role in alleviating the need for additional infrastructure. This view is consistent with the Ontario analysis described in Chapter 3.

We describe below some key barriers and possible solutions to mitigate the problems:

2.1.1 Who pays for the charging infrastructure?

This is a barrier that needs to be addressed. The large-scale roll out of plug-in electric vehicles across Ontario will not happen overnight. It will take anywhere from three to five years for a significant share of the early adopters to hit the road, and longer for a critical mass to emerge. This is mainly because the vehicles are not presently available and because their early adoption rates will vary from one region to another (e.g., urban and suburban south-western Ontario might expect relatively heavy levels of activity, while the rural eastern part of the province, or north-western Ontario might be expected to be somewhat slower in uptake).

Solutions and Actions: The problem can be addressed and targeted at specific stakeholders, in different communities and regions, as follows:

1. Homes: Early adopters have two choices that come at a low cost. A third option is somewhat more expensive, but it may prove attractive to a small cohort of early adopters.
   a. The Level 1 charger (120 V) circuit in existing homes requires no additional installation cost. Early adopters with access to a garage or a driveway circuit may simply wish to charge at night (six to seven hours for a full charge) and thus benefit from the low cost of off-peak electricity. In this way, the costs and operational challenges are minimal.
   b. Regarding the installation of a Level 2 home garage charger (see below) or driveway circuit, this could be provided either free or at a small cost to the first adopters. The cost of the equipment and the installation could be shared between the utility and the customer; the utility portion of the cost could then be recovered over a two to three year time period. The utility should lead this program because it has the relationship with the customer, it can install any override controls and it gives them the capacity to encourage customer charging at times when it is best from a utility operation perspective.
   c. Level 3 charging is the preferable option for those consumers requiring a fast-charging capability at home. These customers should primarily bear the cost, although the car

manufacturers may provide incentives as part of their sales and marketing initiatives. Alternatively, the utilities may provide incentives to allow the installation of charging time override features in order to optimize utility operations.

2. Workplace/Businesses: Charge stations would need to be provided at parking locations. The cost of installation and electricity use would be recovered by including it as part of the monthly parking charges paid by individual users; this could be payroll deductions or included as part of the employee's benefits package (similar to encouraging employees to use gym facilities).
3. Public: Public charge stations would be installed in high traffic zones and all three options for charging (that is, Level 1, slower charging; Level 2, charging in three to four hours; and Level 3, fast charging) would be made available over time; each option would be priced accordingly. The public installations could be built either by means of a utility-municipality partnership or by means of private sector investment.

2.1.2 What if the plug-in electric vehicles cause peak demand to increase?

In the absence of appropriate planning, it may be that the increased presence of plug-in electric vehicles causes grid-wide demand to increase during peak periods, i.e., afternoons during the summer, and mornings and evenings during the winter. One of the findings from a recent McKinsey study [2] on the prospects of next-generation vehicles in New York City was that the projected level of adoption of PEVs should not threaten the stability of the electric grid as long as most chargers are "smart" – i.e., that they would allow charging to take place during off-peak hours. The study further found that ongoing coordination would be necessary in order to support infrastructure planning that takes into account electric vehicles; moreover, such planning would need to be "adaptive" in nature, as the impact of a growing fleet of electric vehicles increasingly became better understood. In any case, smart charging mechanisms that will help utilities accommodate when a vehicle is being charged may play a significant role in alleviating the need for additional infrastructure.

Solutions and Actions: Solutions to this potential problem include smart chargers that allow the utility to control or to override power flows at these peak periods (e.g., similar to the "Peaksaver" program that is currently available to building operators in Ontario). Additional incentives may include the provision of free home and public charge spots, as well as free or cheaper electricity at off peak times.

2.1.3 What if the process of regulatory approvals proves to be too cumbersome and unwieldy?

With any new initiative, there is the likelihood that procedures to approve innovative technologies will become "bogged down" in bureaucratic red-tape – administrative organizations with oversight responsibilities may not have "standard operating procedures" upon which they can draw, so may prove excessively conservative when fashioning a response. While close oversight is, of course, desirable, a strong monitoring role by stakeholders (public interest groups and affected parties) can play a key role in ensuring processes do not delay the initiative unnecessarily.

Solutions and Actions: In response, two actions can be taken to help to reduce this anticipated barrier. First, leadership can be shown by Government. A policy directive is an effective mechanism and can be issued to the lead agencies responsible (most likely the Ontario Power Authority, the Ontario Energy Board or TSSA or others to allow for fast-track permitting of charging stations). Second, attention can be paid to the relevant building codes and standards. More specifically, Government can ensure that new building construction and that buildings under renovation are in compliance with codes that support the requirements of plug-in electric vehicles at an appropriate level of charging requirement for the number of approved parking spots in the facility.

2.1.4 How can the issue of providing an adequate infrastructure be managed with multiple stakeholders across different sectors, municipalities, utilities and regions?

We have already referred to the challenge of "collective action" above. Ensuring that the preferences of multiple participants converge around a single goal is not a small feat.

Solutions and Actions: To improve the prospects of securing a positive outcome, two strategies should be adopted. First, a "champion" agency should be identified and empowered. More specifically, a key planning agency in the Government – likely the Ontario Power Authority – should be charged with the mandate to deliver on the Ontario vision. This is the same agency that has the responsibility for planning the provincial electricity supply. Thus, primary mandated role of the agency would be to deliver on the Ontario vision of an enabling infrastructure from a planning perspective and to promote concept of electric vehicle mobility.

And second, a comprehensive stakeholder process should be established. As the lead agency, the Ontario Power Authority (or an alternative) would work with the utilities, municipalities, car manufacturers, community groups, academic institutions and non-governmental organizations to develop a clear set of regional plans for implementing the electric mobility initiatives. This would include the purchase and/or lease of vehicles, the early enablement of construction of charging stations and the creation of incentive packages in preparation for large scale roll-out.

3. Consumer Issues: Costs, Control and Acceptance

A number of issues related to the role of consumers in the development of a PEV-system require attention. For one, cost will be important, and it will be important to consumers. PHEVs will have higher upfront costs, and that will inevitably be a deterrent to purchases. Operating costs will be lower, which will mean that the higher initial costs can eventually be recouped. Several studies have confirmed that, to drive the same distance, a conventional gasoline vehicle could cost more than four times as much as the electricity to move a PHEV [3]; another study puts the difference at five times [4]. The Electric Vehicle Technology Roadmap for Canada [5] provides an estimate of consumer costs of an ICE-based vehicle and an EV. Although it is argued that the annual cost of energy is about 8-10 times lower for the electric vehicle, its initial cost is currently high because of high battery costs. However, the life-cycle costs of batteries plus electricity are expected to decline in the future; several breakeven scenarios are presented. Analyses by RMI also show that PEVs can save money for consumers at current gasoline prices (see Figure 4.1).

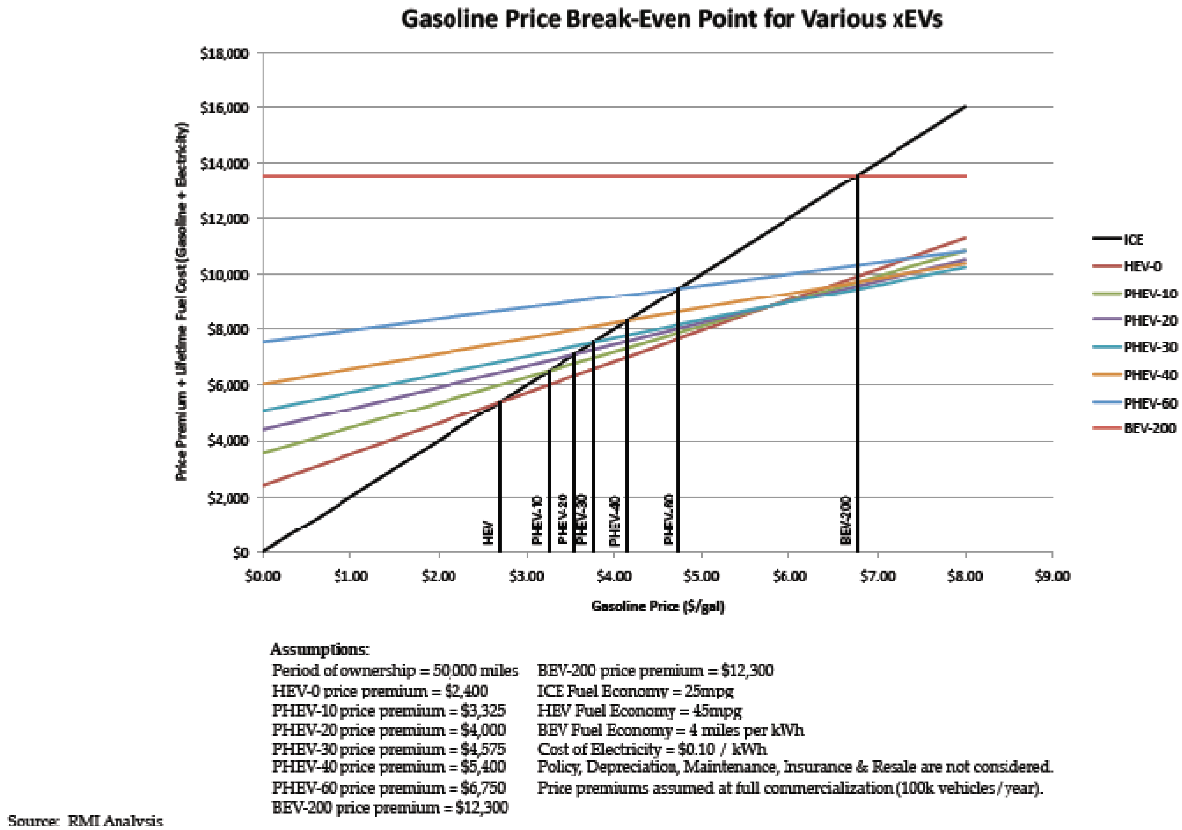

Figure 4.1. Breakeven analysis for PEVs [15].

Purchasers often do not always make such calculations. The literature on the purchase of energy efficiency devices shows significant reluctance on the part of consumers to incur high early costs. It has often been observed that even when incremental capital costs can be recouped quite quickly – through operational savings – purchases are still not made. “Many efficiency investments that are attractive at social rates of return of 2 to 5 percent are unattractive at credit card interest rates of 18 percent or more” [6]. Similarly, one worldwide survey asked people what payback time they would find acceptable before investing money to save energy: “One fourth of them said they would never spend any money to improve energy efficiency; 50 percent said they wanted to earn back the investment in two years or less.” This led the researcher to conclude: “This means that about 75 percent of the public will require economics that are just not there” [7, 8]. Turning more specifically to vehicles, research suggests that vehicle purchasers do not generally calculate the value of the savings from improved fuel efficiency [9]. A survey in the United States found that more than half of those who had an answer said that they would need to recoup the higher initial costs of a fuel-efficient vehicle, through lower operating costs, within either one or two years [10]. Moreover, not only do purchasers not quantify the quantifiable, but they also appear to quantify the non-quantifiable: more specifically, earlier studies of electric vehicles reported that "consumers felt they would need compensation exceeding $10,000 to deal with the inconvenience of owning an EV compared to a conventional vehicle," in terms of perceived sacrifices with respect to "comfort, freedom, flexibility, and mobility" [11]. Thus, notwithstanding the fact that many "willingness-to-pay" studies suggest that people will be willing to pay an initial premium in order to achieve environmental and long-term financial goals (see [3] and [10] and others), research on what people actually do – when given the opportunity to act on their intentions – nevertheless point to this being a barrier.

A second issue worthy of note involves consumer acceptance more broadly. It is important to recognize that consumers are not simply looking for the service of "mobility" when deciding upon which vehicle to purchase; a number of intangibles, factors that cannot be deemed to be purely "rational," come into play. Of course, early adopters of new, sustainability-advancing technologies may feel that they are "doing their part" in moving society through a necessary energy transition, but this may be the minority. The majority of others, however, may "remain impatient and close-minded about new energy technologies" [12]. "Instead of embracing new energy technologies, some rely on notions of tradition and familiarity when they make consumer choices, especially when dealing with hardware that requires huge capital costs (and often the acquisition of sizeable debt)" [11]. They are often conservative, tending to "resist technologies they perceive as untested, radical, or different" [11].

There may be pumped-up expectations about the performance of PEVs – performance levels that are reached under "ideal" conditions. These conditions may not only be climate-dependent, but also conditional upon specific kinds of driver behaviour. To operate a PEV most effectively, many argue, a new style of driving must be adopted in order to take advantage of the particular characteristics of the vehicle – in particular, the regenerative braking systems. The truth, however, is that most drivers "prefer higher top speeds, more aggressive acceleration, and less coasting – actions that reduce fuel economy" [11]. In short, word could get out that vehicles are not performing as well as anticipated (advertised) – already performance is falling a bit short of expectations [13].

Finally, customers, generally, may not know about PEVs, or they may have misperceptions about them. "Canadians generally have very little knowledge or understanding of electric vehicle technology (EVT), both in terms of how it works and what types of EVT vehicles are currently available" [14]. They have concerns, and have shown resistance. Table 4.1, for instance, reports upon the results of a survey of more than 1,700 Canadians who have reported at least some interest in purchasing or leasing a hybrid vehicle. With all seven barriers having been show to be at least "somewhat important" to at least half the respondents, issues clearly remain.

Table 4.1
Barriers to purchasing a PHEV [14]

Barrier	%age of respondents saying "very important'	%age of respondents saying "somewhat important'
Reliability	64	31
Maintenance / operation costs	62	32
Higher purchase price	49	42
Limited access to plug-in locations	48	37
Ability to carry heavy loads	30	37
Availability of sizes / styles	27	46
Need to plug in to recharge battery	25	36

Other investigations, however, send more encouraging messages, as the case of the EV Technology Roadmap for Canada [5], which summarizes some of the recent survey data conducted by Electric Mobility Canada, Pollution Probe and Environics of Canadian perceptions of electric vehicles. Study [2] exploring the adoption of electric vehicles in New York City by Mckinsey & Company, identifies key factors that would drive consumers to purchase electric vehicles, and what the city and other stakeholders could do to facilitate early adoption of this technology in the short term. This study has found that:

- There is a potentially large group of early adopters willing to change behavior to accommodate electric vehicles. A distinct population of "early adopters" is very positive about electric vehicles and willing to change habits to adapt to the requirements of electric vehicles. This may include, for example, switching from an on-street parking space to one in a local parking garage to access necessary charging infrastructure. The research also has found that their attitudes, rather than their driving or parking behaviours, are strong indications of their willingness to adopt electric vehicles. Specifically, early adopters have expressed a desire to espouse an environmentally-friendly lifestyle, possess vehicles with the latest technology, and/or to challenge themselves to reduce their fuel usage.

- These early adopters will likely outstrip the available supply of EVs to the New York market for at least the next five years. The research projects that, by 2015, up to 14-16% of all new vehicles purchased by New Yorkers could be electric vehicles.
- Thus, the study suggests targeting early policy actions to those issues that early adopters find most important. Efforts focused on other consumer segments should wait for several years. Given the likely strong demand among early adopters and the limited short-term supply of vehicles, initial actions would be most effective if they focused on helping early adopters enter the EV market.

Early planning for the Ontario context benefits from these insights; however, studies for the Ontario market need to be conducted to determine which of these kinds of insights are most relevant for the Ontario urban and suburban situations.

3.1 How can consumer demand be catalyzed?

To understand better the way to stimulate interest among potential early adopters in Ontario, specific market studies and assessments should be conducted. Moreover, demand can be potentially created through the development of education programs, demonstration projects and fleet car strategies. These activities should involve the automakers in order to assist them in focusing on delivering a product that consumers value. The assessment should also clearly delineate segment usage scenarios and differentiate consumers by vehicle or services.

Financial incentives to consumers often play an important role as well. Free electricity could be provided at charge points during "off-peak" or even "mid-peak" times; this may help to influence consumers' decision-making calculations and, at the same time, it may not have a significant impact on the utilities' revenue streams during the early stages of planning and production.

Finally, linkages with peoples' present technology choices (e.g., personal mobility devices, smart phones and son) are critical. Applications should be developed that allow consumers to integrate this mobility choice seamlessly into their broader lives – the use of such technology for vehicle charge point billing is one such example. Not only would this make it easier to use, but it would also serve to enhance the overall consumer experience.

3.2 How can demand and supply be matched – in other words, how do you overcome the "chicken and egg situation'?

The availability of automobiles and the commitment by manufacturers to requisite production levels remains unclear, partly because these same automobile manufacturers need confidence that future consumer demand will emerge. In other words, as already alluded to above, how does one accommodate the modest level of "early adopters" while needed a larger future market to secure the business decision?

To begin to overcome this barrier, the corporate fleets, city and regional transit authorities, provincial government fleets could commit to buy a certain number of plug-ins through RFPs for major purchases or leasing arrangements. Additionally, stakeholder groups could establish a system whereby interested consumers signal their interest in such purchases early – and they communicate this in terms of an "early deposit" to reserve a plug-in hybrid vehicle. Such a system could generate an additional 5,000 commitments during the first two years. Collectively, this could provide the motivation for the automobile manufacturers to focus on the product.

3.3 How can upfront costs for consumers be reduced to increase acceptance?

To overcome customers' reluctance to the higher initial capital costs for the vehicles, partnership with financial institutions and automobile dealers could be developed so that low-interest loans for plug-ins, based on projected lower operating costs from gas savings, are offered. Indeed, all key incentives, i.e., vouchers for home chargers, coupons for free off-peak electricity, other rebates, etc., could be bundled at the time of purchase, so that capital cost barrier was lowered to the greatest extent possible.

3.4 How can consumer hesitation – because electric vehicles represent a new paradigm in mobility – be overcome?

In [22], the "Lessons Learned from Alternative Transportation Fuels" are that:

- Highly nonlinear "tipping points" have important implications for the magnitude of government investment. "Tipping points" are critical thresholds that, if exceeded, would permit self-sustained growth (e.g. of demand or charging stations)
- Understanding of "clustering" (locating charging points in high demand areas) should be a priority for new infrastructure development

- There is a need to balance between “consumer” and “fleet” approach for early investment in new vehicles. The effectiveness of strategies should be judged on the basis of whether they provide seeds for positive feedback loops. A fleet-driven approach must consider what mechanisms would contribute to eventual “spillover” into a mass market. A consumer approach may wish to target high fuel consumption users to improve charging point profitability

Some important conclusions emerging from an MIT study that evaluates potential for PHEV penetration in the consumer market using economic models are [23]:

- Lower vehicle cost mark-ups may hasten PHEV market entry, especially in the absence of a climate policy.
- In the short term, the lower cost of electricity compared with refined fuels on a per mile basis will favour adoption of vehicles with longer all-electric ranges.
- Optimization of battery size will depend on current battery cost and performance limitations.
- Large-scale adoption of the PHEV could offset the economic welfare cost of pursuing a climate policy by increasing electricity demand and reducing refined oil consumption.
- Optimal emissions minimization requires concurrent reduction in power sector emissions

3.5 Solutions and Actions

To help consumers “take the plunge,” specific actions can be taken so that these same consumers can effectively envision themselves as part of the PHEV-transition. For example, the concepts of sustainability and environmental stewardship can be made more tangible by providing visible benefits, including, for instance, preferential parking locations (similar to disabled access) or free downtown parking, access to HOV lanes and reserved airport parking. Additionally, consumers, municipal governments, local business and utility education plans could be created. These would including test drives and develop “quick lease” options for individuals and fleet consumers through effective partnership with financial institutions.

4. Utility Issues: Interconnectivity, Regulation, Standards

When envisioning a future with PEVs in it, critical interconnectivity issues inevitably arise. On the one hand, PEVs have very much a “local feel”: the technology, at least at these early stages, is being deployed within restricted geographical areas (e.g., densely-populated urban centres) largely because the range of these vehicles is modest, i.e., they do not stray too far from home! Another reason for a restricted focus is that the regulation of electricity and transportation in North America has traditionally fallen to sub-national jurisdictions – namely, parts and/or collections of individual U.S. states and Canadian provinces.

But there are nevertheless reasons to reflect upon these issues at a "higher level." It is fully anticipated that, over time, vehicles will be able to travel further and further from home. This will be by virtue not only of technological developments serving to improve, for instance, battery performance, but also because of the broader (and denser) expansion of the supporting infrastructure. Additionally, there are economic motivations for individual businesses to expand their horizons: the development of PEVs is happening across the continent (let alone around the world), so entrepreneurs in this new space should be aware of developments in other jurisdictions, should they have hopes of eventually selling their goods and/or services in those same locations.

This challenge, i.e., of coordinating various local initiatives, has been widely recognized, and debate has ensued. Responding to the question: "Do we need a standardized, national recharging system?," two alternative answers have been offered [15]:

1. "Yes. Consumers need to be able to drive [an] electrified vehicle anywhere with minimal hassles. OEMs and battery makers need universal platforms to produce at scale. … [Alternatively,] a collage of solutions could hamper long-term, large scale implementation."
2. "No. Each region will have different electrified vehicle adoption rates, and has a different grid network. Plus, most EVs will be used regionally. A standard system is unrealistic. … A universal system might be much harder to implement quickly …"

It, of course, may not be the case that these two pressures are necessarily mutually exclusive. A key conclusion from a study on the business prospects in this space is that standardization is critical, but that an "open architecture," to accommodate diversity, is also necessary. Consider these headings, representing each of these perspectives: "Standardize and integrate" and "Modularize to modernize" [16]. In any case, the attention being accorded the internationalization of the smart grid (e.g., the work of the International Electrotechnical Commission, the Canada-US Clean Energy Dialogue) represents clear evidence that spatial connectivity remains an issue. The integration of electricity and vehicles in this space further means that integration across sectors is also critical [16].

Solutions and Actions: Harmonization of codes, standards and regulatory requirements is a key requirement. Regulatory consistency between utilities and across regions is another key risk factor for producing compatible vehicles. A lack of uniform regulation also presents a large risk to connector business models.

As noted above, not only are new components to our transportation system being envisioned (individual PEVs), but a new infrastructure to support the same is also part of the future landscape. Accordingly, a number of new codes and/or standards – to deal with these new elements – will inevitably be required. These will focus upon the safety and quality of the PEVs themselves, as well as the safety and quality of the different facets of the supporting infrastructure – chargers in buildings (and other static locations), for example. This is a significant challenge. Indeed, when 125 executives from automobile OEMs, suppliers and influential third parties were interviewed, the top barrier affecting the future utilization and effectiveness of a new generation of vehicles was the "creation of global standards." "Companies throughout the value net, including external players such as government and telecommunications companies, will need to work together to establish a common platform that enables vehicles and components from different manufacturers and geographic locations to communicate seamlessly." [16]

The EV Technology Roadmap for Canada Report [5] has identified the need for codes, standards and testing (see section 5.3.5) that needs to put in place in order to manage, effectively, the new system that emerges. Harmonization of North American standards and practices concerning the integration of PEV components including charger interfaces is another important element required for effective implementation. Thus, ANSI, the IEEE, SAE, UL, ISO and, in Canada, the Canadian Standards Association and Transport Canada's Road Safety Directorate are all key players. Internationally, there are developments in terms of standard setting as well. What remains clear, however, is that a new regulatory framework will need to be developed.

It is incumbent upon the Ontario Government to continue its twin-track strategy of provincial initiative coupled with multilateral dialogue. Already, this has been the track record in the "smart grid" domain, with its province-wide initiative to support universal deployment of "smart meters," coupled with the thought-leadership demonstrated by the formation of the Smart Grid Working Group, activity at the provincial-level, which has attracted attention from around the continent. Additionally, through multilateral institutions (like the Northeast Power Coordinating Council), provincial institutions continue to advance a dialogue with their regional neighbours. This provides a good model for the way in which strategies should unfold in the PHEV issue.

5. Battery Issues: Costs, Uncertainties, Replacement and Life Cycle Management

High battery costs and uncertainty in key parameters (durability, disposal, life-time, second-use) render consumers, automakers, and utilities unwilling to assume the risk of ownership. Thus, issues related to batteries have implications for all aspects of the chain.

EPRI study [24] is the first to present comprehensive life cycle cost analysis for HEVs and battery electric vehicles – NiMH, lithium ion and other advanced batteries are discussed. The report presents methods and quantifies costs for many agents in the PHEV system: (i) methods for calculating life-cycle costs of PHEV; (ii) quantification costs to OEM and consumers; and (iii) quantification of the battery pack cost($ / kWh) required to make PHEV at cost parity with conventional vehicles. Some of the important conclusions of this report are that consumers' willingness to pay for PEVs range from about $2,250 more for a midsizecar (HEV) to $3,600-$4,000 more for a mid-size (PHEV20). Some of the major non-technical factors influencing battery costs are a stable market situation, a predictable regulatory environment and consistent production volumes. These factors will help encourage capital investment and automation. The study's cost calculations lend support to lease agreements for battery packs as the most effective for adoption. In such a scenario, consumers will see small operating cost over time rather than a large upfront cost.

The UC Berkeley report [17] focuses on several key parameters that include: (i) battery economics and utility integration; (ii) innovative business models, ownership, and value streams for electric-fuel technologies, (iii) alternative battery cost reducers; (iv) up-front cost versus life-cycle cost dilemma; and (v) valuable electric services from plug-in vehicles.

5.1 Solutions and Actions

1. Promote early battery replacement: Change battery design requirement from 10yr to 3yr warranty. Current battery designs and regulations result in over-design relative to an optimal case that would promote fast adoption (e.g., California Air Resources Board requires a 10 yr battery with a 150 000 mile warranty). This is a significant drawback, because this trades-off first costs for higher lifecycle costs.
2. Robust secondary usage of battery: A strong secondary use market with applications in the utility T&D sectors may include: (i) transmission support, (ii) light commercial load following, (iii) residential load following, and (iv) distributed node telecommunications backup. The quantification of additional value for secondary use of batteries is an important benefit that must be considered as part of future plans that include re-cycling and full life-cycle management of the battery impacts to the environment.
3. Battery uncertainty and cost: Develop technical and economic research to quantify key life-cycle parameters, and in particular the value of used batteries and the best strategy for deployment.
4. Develop light-weight vehicles rather than increase battery capacity.
5. Allow utility rate-basing of battery purchases, including used and new EV batteries, for key utility grid applications.
6. Promote second use "bundling" utility placement of EV batteries with household solar PV installations to help smooth the solar contribution or peak smoothing.
7. Facilitate recycling operations that have volume thresholds to be practical.

5.2 Markets and Business Models

A PEV is a transformative technology, i.e., it aims to deliver a key consumer service (namely, "mobility') in a fundamentally-different manner. It is still envisioned that a vehicle would move individuals and goods from place to place, but the means by which that vehicle would be energized – namely, gradually moving from reliance upon an internal combustion engine fuelled by an infrastructure delivering petroleum products to an electric one powered by a distributed system of electricity generators – are so different, that the changes cannot simply be considered incremental. As such, it is not surprising that it could well prove difficult to catalyze change – inertia is a powerful force, and substantial effort will be required if the proverbial "tipping point" is to be passed.

The California Public Utilities Commission report [18] provides a comprehensive analysis and a discussion of policy options that include for example:

- Rate design options, including the potential for a state-wide electricity rate for PEVs.
- Vehicle incentives to encourage Californians to buy and operate PEVs, including ratepayer funded incentive programs.
- Options for development of metering and charging infrastructure for PEVs.
- Options to streamline permitting requirements and contractor installation of residential PEV charging equipment.
- Development of policies that encourage partnerships between regulated and unregulated companies that are beneficial to ratepayers.
- Consideration of options to incorporate PEV charging with renewable energy supply, including, but not limited to, PV arrays over charging.

We have already described a number of barriers are in place – indeed, many different players face different challenges; in order to effect change, or a broader transformation, these various barriers will have to be surmounted concurrently.[4] As such, the thinking that has occurred with respect to the development of effective "business plans" is important to review. In the development of such plans, a variety of obstacles that need to be overcome have been identified. A "Technology Roadmap" prepared by the International Energy Agency focuses on four areas: (i) battery cost; (ii) vehicle range; (iii) driver information (drivers" ability to easily locate recharging stations); and (iv) critical mass and economies of scale [19]. Many of these have been examined, individually, in various sections of this chapter. The value of reviewing alternative business plans is to see how, collectively, they might be addressed.

Some of the most sophisticated work in the development of business models to encourage the update of electric vehicles and PHEVs has been carried out by the AEA Group, reporting to the United Kingdom's Committee on Climate Change. They considered four main business models:

[4] In their "construction of macro business models," Sentech identified six "primary components": consumer financial costs and benefits; consumer preference data; societal benefits; utility benefits; commercial building owner benefits; and battery alternative design and ownership options. This represents an alternative way of thinking about a coordinated response [20].

a) “Battery leasing. By retaining liability for the battery the manufacturer is committed to replacing it if its performance is sub-optimal. This removes a significant element of the financial risk for consumers. It also solves the problem of how to value the residual life of the battery at resale given that most battery technologies’ performance deteriorates with use. The monthly fee for leasing the batteries could simply switch from the original owner to the new owner. A further benefit to the consumer is that it allows the manufacturer to take advantage of any improvements in battery technology when the batteries are eventually replaced.
b) Mobile phone-style transportation contracts. To cater for different customer segments, Better Place plans to offer a range of EV models via a series of subscription pricing packages that will provide access to the network of charging points and battery swap stations. The company plans to own the charging points and battery swap stations as well as the car batteries, which will be considered part of the Better Place Network. Both the mobile phone style contract and battery swap station elements of the business model introduce a great deal of flexibility for consumers, which is a weakness of many of the other business models.
c) Vehicle leasing. The natural extension to battery leasing is to use a vehicle leasing business model to further reduce risk and minimise upfront costs. Vehicle leasing is currently being pursued by Mitsubishi as the initial business model for the i-MiEV electric small car, which is due to become available in the UK by the end of 2009.
d) Car-clubs. In the short term the “car club” business model could be a viable means of introducing the public to electric vehicle technology. In addition, it could provide added value in terms of promoting EVs and PHEVs. Indeed, it could be a means of allowing consumers to test EVs and PHEVs in real world conditions for a few weeks without the need to make a major financial commitment. Furthermore, the sight of EVs and PHEVs being driven around would raise their profile, especially given that car club cars are utilised far more heavily on average than conventionally owned vehicles. That said, that apart from Th!nk, there does not seem to be an appetite amongst manufacturers to use the car club model as a way of encouraging the uptake of EVs or PHEVs” [21].

They conclude that it is most likely that both the vehicle leasing (c) and the battery leasing (a) models will play significant roles in increasing the deployment of electric vehicles and PHEVs. In any case, and similar to other studies, they also highlight the particular challenge posed by the presence of (and centrality of) the battery in the overall system technology. Any business model will have to address the risks associated with its deployment.

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CHAPTER 5 – CONCLUSIONS AND RECOMMENDATIONS

1. Infrastructure Issues

Who pays, who benefits and what happens with the electrical system infrastructure with PEV charging, especially if "peak demand" increases significantly, are questions of concern. As shown here, these issues have a multi-layered time specific set of solutions that can be implemented to address the aforementioned concerns.

We observe that a large-scale adoption of PEVs across Ontario will certainly not happen overnight. Even with the existing incentives and continued support by key stakeholders, it will take anywhere from 3 to 5 years for PEVs to begin to assume any noteworthy share of the market and longer for a critical mass to emerge. This is mainly because the vehicles are not presently available, manufacturers are in the early stages of announcing roll-outs and consumer acceptance of these new technologies is not clear.

Development of the necessary infrastructure needs to be targeted at specific segments in different communities and regions and over different time frames, since adoption rates will vary from one region and municipality to another. Detailed assessments of market potential will be required and coordination of activities amongst planning agencies, utilities and auto manufacturers based on sharing of results will be necessary to ensure the requisite infrastructure is in place when needed.

1.1 Charging Plugs and Stations

For the 2010-2015 timeframe, charging needs can be managed with existing options without significant disruption. Beyond 2015, the planning process, further informed by emerging data on consumer acceptance, would be expected to address future needs.

- A prudent approach for early adopters would come at a low costs, since a 120V/15A circuit in existing homes presents no significant installation and operation challenges and costs for Level 1 overnight charging.
- An upgrade to the Level 2 home garage charger (240V for 3 to 4 hours charging time) could be provided either at a small cost (or as an incentive) to the first adopters. The cost of the equipment and the installation could be shared between the utility and the customer or the auto maker. The utility portion of the cost could then be recovered over a two to three year

time period. There is also an advantage to the utility to establish a positive relationship with the customer, install override controls (with customer agreement) and encourage the customer to charge at times when it is best from a utility operations perspective, based on established programs such as the Peak Saver program for demand response.

- Level 3 fast charging (less than 2 hours) capability will be necessary for those customers who opt for it. The technology is under development, but this premium service option, when available, can be targeted at those willing to pay for it. The auto manufacturers may provide it as an option in their sales and marketing initiatives. Alternatively, the utilities may provide an incentive to the customer to sign up and allow the installation of a "time of charging override feature" to help optimize utility operations.
- Workplace charge stations will be necessary to develop consumer acceptance of PEVs. The cost of installation and electricity use can be recovered in a number of ways. Options such as including it as part of the monthly parking fees paid by individual users; payroll deductions or within the employee's benefits package (e.g., similar to encouraging employees to use gym facilities).
- Public charge stations installed in high traffic zones can provide all three options for charging but at different prices: Level 1, slower charging as cheapest option; Level 2, for a three to four hour at mid price; and Level 3, fast charging at the highest price. As markets and business opportunities become clearer, the public installations could be led by either a utility-municipality partnership or private sector entity investment.
- To get to self-sustained growth, region-specific or neighborhood specific "maps" of vehicle purchases and demand for charging stations need to be developed. Such "maps" will be a powerful aid to understanding where clusters are emerging, to minimize problems for utilities and to pin-point location of charging points.

1.2 The Grid

Even though the grid and electricity market are currently able of supporting some level of PEV charging, significant PEV penetration levels will definitely impact the grid and its associated electricity market. Thus, careful planning will be required for a successful transition to PEVs.

1.2.1 Planning

- Our analysis shows 10-15% penetration of PHEVs in the light-vehicle transportation sector – PHEV30km-PHEV60km or PHEV20 PHEV40 such as the plug-in Toyota Prius and the Chevy Volt – will have a minimal effect on the grid and electricity prices, as long are charging takes place at night (off-peak hours). This will likely be the case for some time after the introduction of PEVs in the market in the next 3-5 years.
- Vehicles should be preferably charged at night; this will even have a positive effect on grid operation by reducing the growing generation dispatch problems in Ontario at base-load conditions. Until public charging stations are made available, this should not be an issue, as PEVs will most likely be charged at home – although a delay will have to be implemented in the charging systems so that by default charging takes place after the evening peak, i.e., after 10-11pm. Charging of PEVs during on-peak hours will have a significant effect on the grid that will have to be planned for, especially in highly populated areas such as the GTA where PEV concentration and early adoption may be significant.
- With wider adoption of PEVs, grid planners will not only have to consider the additional PEV-charging load for system planning but also be aware of formation of geographic "clusters" with the potential for negative impacts on the system. The problem of load forecasting is further exacerbated by unknown adoption rates of PEVs at the present time. A renewed emphasis on planning, with a special focus on understanding growth of clusters, will be necessary to ensure requisite infrastructure is developed to meet the needs in the 5 to 20 year timeframe. These time lags means a renewed emphasis on the planning and coordination function (see recommendation below for a "champion agency")

1.2.2 Technical Challenges

- A very large presence of PEVs in clusters, and, in particular, if it is the "fast charging mode," has the potential to stress the system and can cause the grid-wide demand to increase during peak periods. A key conclusion we draw is that the projected levels of PEV adoption would not threaten the stability of the electric grid as long as a good proportion of the chargers are "smart" and the utility has some override capability over PEV charging. Whether this becomes an impediment to consumer acceptance needs to be established through additional studies.

- To mitigate and manage the impact that high penetration and concentration of PEVs, “smart charging” strategies and technologies will have to be developed and deployed. This will facilitate the charging of vehicles at certain desired hours such as off-peak hours and/or during high wind or solar generation outputs. This will require the availability of smart grid infrastructure that permits two-way communication among the IESO, LDCs and PEVs. Thus, smart grids need to be planned and developed considering PEV charging as an integral part of the load and the associated energy management systems in households and buildings.
- In the short term, incentives to shape the load curve could include the provision of free home and public charge spots, as well as free or cheaper electricity at off peak times to allow for a capital deferral strategy for investment in the grid.
- With high penetration of PEVs, even if all charging takes place at night, there will be upward pressure on electricity prices. If these prices are conveyed in a timely manner to the PEV owner and/or smart charger, then optimal charging decisions can be made, thus “discouraging” charging at high-price hours while “encouraging” charging at low-price hours.
- Vehicle-to-Grid (V2G) as well as Vehicle-to-House (V2H) technologies present many potential advantages to the grid such as voltage and frequency regulation in the context of DG and smart grids, as well as providing energy storage for wind and solar power generation. However, these technologies will not be economically feasible until several of the issues with batteries discussed in some detail in Chapter 2 are resolved. Nevertheless, since battery and smart charging and grid technologies will likely improve in the long-term, V2G and V2H technologies need to be researched and developed now to be ready for deployment. Therefore, R&D investments in these technologies are recommended.

1.2.3 Standards

- Standards for PEV charging devices, installations and communications are currently under development by a variety of institutions such as SAE, ISO, UL and CSA. However, communication standards will be very much dependent on the standards finally adopted for smart grid applications, which are still very much under debate. Nevertheless, it appears that the majority of Smart Grid device developers and manufactures are leaning towards the adoption of ZigBee communication profiles and WiFi technologies for home area networks.

Therefore, it would be safe to assume that these protocols and technologies will likely become the standard for PEV changing applications; in fact, SAE is already developing standards for communications between vehicles and charging stations based on this assumption.

2. Institutional Aspects

We recommend a "champion" agency should be identified and empowered to ensure the policy goals can be attained. To promote sustainable mobility, the planning efforts must also address social science issues such as urban land use, transportation infrastructure investment, parking and charge stations and strategies for reducing congestion such as promoting public transportation and bike lanes.

The lead agency would work with the utilities, municipalities, car manufacturers, community groups, academic institutions and non-governmental organizations to develop a clear set of regional plans for implementing the electric mobility initiatives. This would include the purchase and/or lease of vehicles, the early enablement of construction of charging stations and the creation of incentive packages in preparation for large-scale roll-out.

3. Consumer Issues

A number of issues related to the role of consumers in the development of a PEV-system require attention:

- Fuel costs strongly favor PEVs with a per kilometer cost estimated to be 3 to 5 times lower than for a gasoline ICE vehicle. The capital costs, however, are higher and require significant further development for full commercial feasibility. The up-front higher cost issue will require a policy response and a detailed consideration of the credits that may accrue through reduction of the externalities imposed by GHG emission and air pollution. A vehicle with a 100 km all-electrical range incurs a manageable weight and cost penalty with an additional cost that will probably decline with greater uptake.
- To overcome customers' reluctance to the higher initial capital costs for the vehicles, partnerships with financial institutions and automobile dealers need to be developed so that

low-interest loans for plug-ins, based on projected lower operating costs from gas savings, are offered. A business strategy is needed to capture all key incentives such as vouchers for home chargers, coupons for free off-peak electricity, and other rebates, which could be bundled at the time of purchase so that the capital cost barrier is lowered to the greatest extent possible.

- There is a need to balance "consumer" and "fleet" approaches for early investment in new vehicles. The effectiveness of strategies should be judged on the basis of whether they provide seeds for positive feedback loops. A fleet-driven approach must consider what mechanisms would contribute to eventual "spillover" into a mass market. A consumer approach may wish to target high fuel consumption users to improve charging point profitability.
- To help consumers "take the plunge," specific actions can be taken so that these same consumers can effectively envision themselves as part of the PEV-transition. For example, the concepts of sustainability and environmental stewardship can be made more tangible by providing visible benefits, including, for instance, preferential parking locations (similar to disabled access) or free downtown parking, access to HOV lanes and reserved airport parking. Additionally, consumers, municipal governments, local business and utility education plans could be created. These would including test drives and develop "quick lease" options for individuals and fleet consumers through effective partnership with financial institutions.

4. Auto Sector Challenges and Battery Issues

High battery costs and uncertainty in key parameters (e.g., durability, disposal, life-time, second-use) render consumers, automakers, and utilities unwilling to assume the risk of ownership. Thus, issues related to batteries have implications for all aspects of the chain.

- There is a strong need to improve battery durability with thermal issues becoming much more critical as energy and power densities are increased. The most important component of the PEV is the battery pack that influences the primary cost, range (energy capacity), and weight. This cost/range trade-off drives the many challenges of developing an electric vehicle for a mass market.

- One promising feature of a limited range PEV (< 100 km in an all-electric mode) is the fact that it meets the needs of most urban and sub-urban families for most of the time. For an extended trip, the range anxiety is diminished by the fact that the vehicle can be operated by in a hybrid mode supported by a "conventional" gasoline ICE. The size of the battery back and its cost can thus be optimized to cater to the needs of most of the consumers whose most daily trips are measured only in the tens of kilometers. For this consumer segment, charging at home during off-peak hours with low cost electricity and without any requirements for major electrical upgrades to the home is a positive feature that would enhance acceptance.
- The low-daily-mileage characteristic of current drivers is why PEVs have potential to displace a large fraction of per-vehicle petroleum consumption. Studies are needed to provide Ontario relevant estimates of the magnitude of this petroleum displacement benefit.
- Customers with higher expectations for a vehicle to be used to drive longer distances and desire to charge as a faster rate will require batteries capable of a high recharge rate, upgrades to the home outlets (e.g., 120 V to 240 V if not available) at additional cost and expectation that there will be an appropriate refueling infrastructure – with high current and voltage port and thermal management – available away from home. This is a challenge that needs to be addressed through technology developments to ensure that rapid recharge does not have an unacceptable impact on battery durability and performance.
- In the present market context, the economic competitiveness of long all-electrical range vehicles (> 200 km) appears questionable and they will also require wide deployment of a rapid-recharge infrastructure. A high-end vehicle with a very large range (up to 600 km in the all-electric mode and costing $100k+), although available today, is very much a niche market commodity. The battery cost of the 200 km vehicle is expensive, and without significant incentives or additional benefits may not have great appeal to the consumer. Greater in-vehicle range capability makes the vehicle too heavy to be efficient and this would require significant technology development of the battery pack to address the energy density/weight trade-off.
- More accurate life-cycle analyses are needed to better guide decision makers considering PEVs in transportation strategies. The potential of post-PEV battery repurposing for grid applications such as ancillary services and backup power require more detailed life-cycle

analysis as well as demonstration projects in order to better assess the viability of these applications.

- Better, higher fidelity, modeling and in-field data for PEVs is needed. Of particular importance to fill a notable void in understanding is the need to acquire in-field trip behavior data for Ontario and various markets within Ontario, i.e., determine the actual drive cycles of drivers in Ontario. This also included assessment of the interaction of driver habits (e.g. acceleration and braking rates) with various PEV components.
- The challenge of the battery – its performance, cost, reliability and environmental attributes – will continue to be the dominant considerations in realizing the vision of sustainable mobility through electrification. Besides the technical barriers that need to be overcome, especially if V2G/V2H applications are to be considered, there is a role for business models to help reduce some of the adoption barriers over time. Some of the main business models identified include: battery leasing; mobile phone-style transportation contracts; vehicle leasing; and car-clubs.
- Current battery designs and regulations result in over-design relative to an optimal case that would promote a faster adoption of PEVs. The current battery design requirement introduces a significant technological challenge and it trades off first cost for higher lifecycle cost. Possible solutions to address this issue include: promote early battery replacement by changing the battery design requirement; promote a strong secondary use market with applications in the utility T&D sectors; develop technical and economic research to quantify key life-cycle parameters, including the value of used batteries; and allow utility rate-basing of battery purchases, including used and new EV batteries, for key grid applications.

5. Closure

In conclusion, we note that that gasoline and diesel engines will still likely have a major role in the near term as a vehicle's power train because the existing stock of vehicle turnover is slow. However, in the medium to long term future (beyond 3- 5 years and longer to 2050), there is excellent potential to exploit the strength of the electricity sector to transform the auto sector one step at a time as we move from ICE powered vehicles, to HEVs, to PHEVs, to E-REVs, and finally to all-electrical BEVs. In this context, we pose one critical question: Is Ontario competitively positioned at the moment relative to other jurisdictions? As the Province reflects upon its economic future (and, intimately connected to this, its social future as well), it is appropriate not only to examine the situation within Ontario's boundaries, but also to consider the extent to which this could be part of an effective development strategy for the future.

Our short answer is: At the provincial level, "yes;" however, at the municipality level, "no." In the US, it appears that the most creative and potentially-"game changing" policy efforts are occurring at the municipal level. This is because the actual first mover infrastructure is being installed and purchased by municipalities in that country. Thus, it would be prudent for an Ontario wide plan to consider the benefits of coordinating its provincial and municipal efforts. Since the objective is to have a competitive provincial economy, Ontario could gain an advantage by a well-thought out coordination strategy, something that other jurisdictions within North America have – it appears – yet to realize. Therefore, the time is ripe to seize this opportunity.

In this report, we have aimed to identify issues that need to be addressed and have proposed some solutions. While further attention is certainly needed so that the detailed plan for implementation is broadly informed and widely agreed, we feel that we have begun to structure the agenda. The onus is now on the stakeholders and Government to demonstrate leadership in this space by taking it further forward.