Pacific Institute for Climate Solutions
Knowledge. Insight. Action.

Electrifying the BC Vehicle Fleet

Opportunities and Challenges for Plug-in Hybrid, Extended Range & Pure Electric Vehicles

Liam Kelly, Trevor Williams, Brett Kerrigan and Curran Crawford
Institute for Integrated Energy Systems, University of Victoria

November 2009

University of Victoria | SFU SIMON FRASER UNIVERSITY THINKING OF THE WORLD | UBC THE UNIVERSITY OF BRITISH COLUMBIA | UNBC UNIVERSITY OF NORTHERN BRITISH COLUMBIA

The Pacific Institute for Climate Solutions
gratefully acknowledges the financial support
of the Province of British Columbia through
the BC Ministry of Environment.

Pacific Institute for Climate Solutions

University of Victoria
PO Box 1700 STN CSC
Victoria, BC V8W 2Y2

Phone 250-853-3595
Fax 250-853-3597
E-mail pics@uvic.ca
www.pics.uvic.ca

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This white paper examines the possible benefits and obstacles related to the widespread adoption of plug-in hybrid electric vehicles (PHEVs), extended range electric vehicles (EREVs), and fully electric vehicles (EVs) in British Columbia (BC). These vehicles, collectively referred to as plug-in electrified vehicles (PEVs), have the potential to significantly impact both the electricity and transportation sectors; these considerations are outlined in this document.

The BC government has set tough greenhouse gas (GHG) emissions reduction goals for the near and long term. Electrified vehicles have the potential to significantly reduce the emissions intensity of the transportation sector by displacing petroleum from the transportation energy-supply chain with electricity from the grid. This connection would allow clean power derived from hydro plants or other renewables to be introduced into the transportation energy stream, reducing the sector's GHG impact and exposure to volatile fuel prices.

There are currently several different hybrid electric vehicle (HEV) architectures available, each ultimately deriving their energy from internal combustion engines, but using batteries and electric motors to electrify the drive train. This blending of power from engine and electric motors provides an opportunity to increase the efficiency of the engine and recover kinetic energy through regeneration during braking. PHEVs have a distinctly larger battery module compared to standard HEVs, and can thus provide drivers the opportunity to store energy onboard from electric sources external to the vehicle. EREVs completely decouple the engine from the wheels.

Recent transportation studies have shown that most BC commuters travel a median one-way trip length of 6.5 km by vehicle. Current PHEV and EREV technology would allow most BC commuters to travel to and from work on electric energy alone, thus providing significant reductions in petroleum use compared to even HEVs. EVs have no engine, and therefore derive all their energy from grid electricity, foregoing the range extending mode of PHEVs. This typically limits their range (which may still be palatable to some users) unless very fast chargers or battery swapping schemes are implemented.

A large number of PEVs connecting to the electrical grid in an uncontrolled fashion may present problems for BC Hydro. In large numbers, these vehicles would create a significant increase in aggregate demand. If the vehicles are plugged in during times of peak electricity demand, BC Hydro will be forced to increase its generation and transmission capacity, driving up electricity prices. This would also affect BC's ability to sell electricity to the Alberta and US markets during peak times, as is presently done. However, during non-peak times, the grid is underutilized and may accommodate a large number of PEVs. Several methods of controlling vehicle electrical load to match these non-peak times are under investigation. Time-of-day electricity pricing will provide users financial incentives to charge at off-peak times, and advanced grid control technology (known as SmartGrid) could give BC Hydro the ability to control the charging of vehicles remotely. The import/export of power across US and Alberta borders is complex and obscured by transaction accounting and is therefore beyond the scope of this report.

Large-scale PEV adoption may also have positive impacts on the electricity grid. Currently, intermittent and unpredictable renewable electricity resources, such as wind and solar, are often not available to supply electricity during periods of high demand. PEVs can potentially act as energy storage devices, accepting power from wind and solar plants whenever they are plugged in, making such energy sources more attractive to the utility. It has also been proposed that if vehicles have energy remaining in their batteries after driving, they might sell energy back to the grid during periods of high demand, increasing the grid's reliability; this concept is known as Vehicle-to-Grid (V2G) technology.

The diffusion of significant numbers of PEVs into the personal vehicle market will take many years, although conversion kits are being developed to electrify the existing fleet. Currently, consumers are reluctant to invest large amounts of capital into vehicles with a limited track record in real world conditions. However, uptake is encouraged by governmental up-front purchase incentives and tax rebates. Diffusion is also accelerated with rising gasoline prices, which have been directly correlated with the number of hybrid vehicle purchases. Finally, installation of a public charging infrastructure, allowing drivers to charge at work, grocery stores, shopping malls and other destinations, will maximize return on consumers' investment by avoiding more expensive fuel purchases, provided there is no gasoline tax-loss clawback in the form of additional taxation on electricity for PEV use.

PEVs may also be suitable as fleet vehicles. Since fleet operators, both government and private, typically perform more rigorous economic analyses than the average consumer, compelling business cases may be made for PEV investment based on significant savings from avoided fuel costs. In order to influence purchase decisions, the provincial Green Fleets BC program was established with the aim to help businesses reduce emissions in their fleet vehicles and improve fuel efficiency. It has also been suggested that fleet PEVs may be excellent candidates for use in V2G applications, which may provide additional income to businesses, depending on the price paid for V2G electricity, which at present is a large uncertainty. Moving forward, several areas of further study have been identified, including:

Technical	Socio-economic
• Detailed quantification of grid impacts and GHG emissions reductions under various adoption scenarios	• Incentive structures to stimulate the construction of public charging infrastructure
• SmartGrid technologies as a method of controlling PEV charging	• Creating effective purchase incentives, business grants and evaluating the influence on transportation, power production and GHG emissions
• Standards and procedures for the installation of public charging infrastructure	

In addition, there are safety issues to be evaluated that are related to a PEV based transportation fleet, not only with respect to electrical infrastructure provision, but also toward ensuring private individuals have the means to travel in the case of emergencies such as during extended winter power outages or severe natural disasters, when the electrical grid may be compromised. A PHEV or EREV may in fact be very beneficial in such circumstances, since it would still retain the ability to travel using its engine, while also providing an electrical stand-alone power source for emergency lighting or heating. Informed by these studies, incisive government policies can accelerate the adoption of PEVs, moving the province of BC closer towards achieving its energy and emissions goals.

1. OVERVIEW

This white paper examines the possible benefits and challenges associated with widespread adoption of plug-in hybrid electric vehicles (PHEVs), extended range electric vehicles (EREVs), and fully electric vehicles (EVs) in British Columbia. This class of vehicles are collectively referred to as plug-in electrified vehicles (PEVs). Impacts on the transportation and electricity sectors are investigated. Five key areas are explored in detail:

- Barriers and attractors in the transportation sector
- Near-term impacts for the electricity sector
- Possible greenhouse gas (GHG) emissions reductions and strategies to ensure maximum benefit from the vehicles
- Economic costs and benefits
- Evaluation of current policy in other jurisdictions and desirable policy directions for British Columbia

2. TECHNICAL BACKGROUND

2.1 Motivation for PEVs

The emissions inventory for British Columbia (BC) in 2007 estimated that the transportation sector contributed 37% of the total GHG emissions in the province. Passenger vehicles in BC contribute 14% of the total provincial emissions, while heavy duty vehicles add a further 9%, as shown in Figure 1. These GHG emissions result from the technologies used to deliver the transportation service and the growing demand for this service (Gouge et al., 2008). If British Columbia is to meet its 2020 GHG emission reduction targets, incentives and regulations will need to be put in place to address these realities. The incentives and regulations must deliver the most effective GHG reductions to BC as a whole, considering all sectors, while minimizing adverse socio-economic costs.

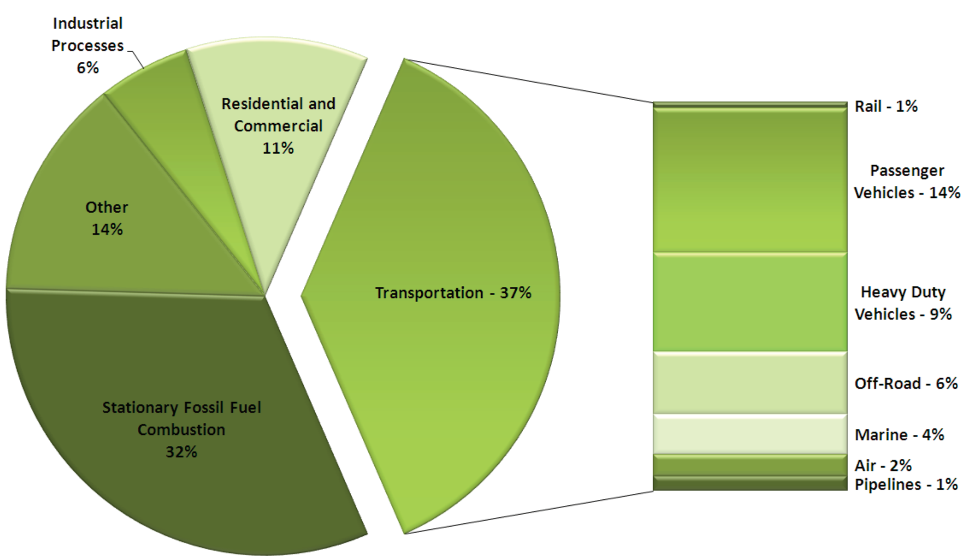


Figure 1: Provincial GHG emissions for 2007 (Ministry of Environment report, July 2009)

Over the last century, two entirely separate and distinct energy systems have arisen: the electrical utility grid network and the transportation sector. Both systems provide a *service* to the consumer, in one case lighting, running electrical appliances and computers, and the other moving people and goods around. The electrical grid has evolved to accommodate many *sources* of energy such as coal, natural gas, hydro, wind, and nuclear. The transportation sector meanwhile is nearly entirely dependent on *one source* of energy – fossil fuels. There is no existing technology to couple the *service* of transportation to the sources of energy supplying the electrical grid system.

Some researchers (Bradley and Frank, 2009) have pointed out that by using the *currency* of electricity to power transportation, there can be interaction between these two massive energy systems, thereby providing a myriad of benefits to both systems, while increasing the number of energy sources for use in the transportation sector. Figure 2 graphically depicts the different pathways from energy sources to services. By using electricity as a currency, transportation can be moved away from its dependence on fossil fuels towards an emphasis on green fuels, while continuing to provide the *service* of transportation. This coupling of energy systems will require strong policy and investigative research for it to be completely understood and its full potential realised.

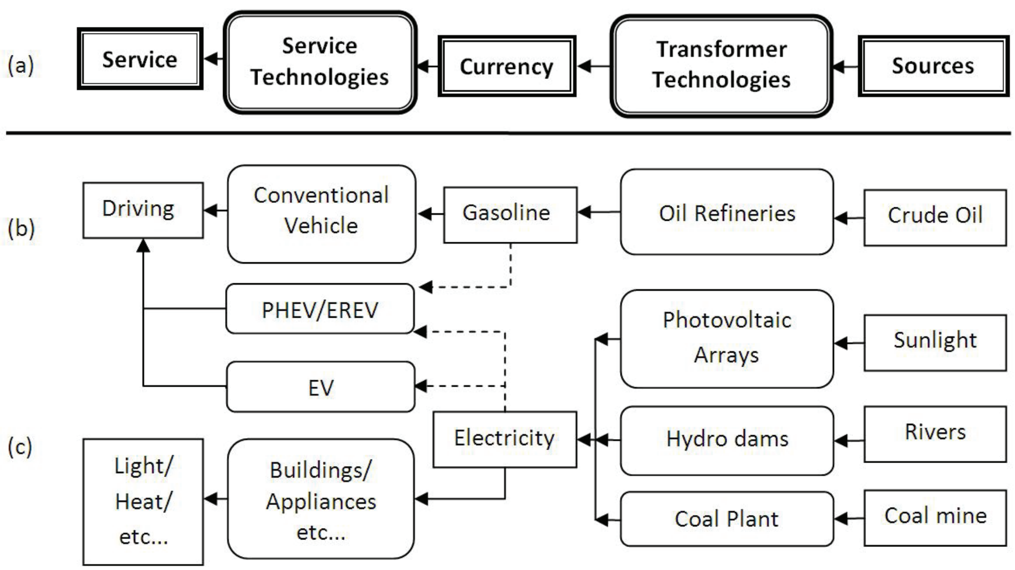


Figure 2: Energy system architecture. (a) General architecture, (b) example of transportation and (c) provision of electricity showing multiple sources

The demand for personal transportation, i.e. passenger vehicles, has been increasing steadily over the last two decades in BC. From 1990 to 2008, the number of registered vehicles under 4.5 tonnes increased from 2.21 million to 2.54 million, an increase of 0.83% per year (Statistics Canada, 2008). The increasing number of vehicles on the road, and the trend towards larger vehicles, has caused emissions of carbon dioxide from passenger vehicles to increase at a higher rate than the growth of new vehicle sales. From 1990 to 2006, total passenger vehicle emissions in BC climbed from

10.8 to 12.8 Mt of CO_2e, an increase of 1.15% per year. This undesired growth in emissions has been mitigated somewhat by an increase in fuel efficiency for the majority of new vehicles, thereby reducing emissions intensity.

For PEVs to be an effective mechanism for reducing road transportation emissions, it is necessary to understand not only the number and types of vehicles on the road, but also how these vehicles are used. In BC, as in the rest of the country, the personal vehicle is the most frequently used mode of transportation for commuting to and from work. In a recent report of BC driving statistics (Norton, 2008), 79% of commuters used a vehicle to get to work. The median one-way travel distance for all commuters in B.C in 2006 was only 6.5 km. This data also shows that a large portion of commuters (40.5%) travel less than 5 km to work, and that only 8% of commuters are travelling more than 30 km one way (Statistics Canada, 2006). One of the main markets proposed for PEVs is for use as commuter vehicles, as the technology is already capable of providing the required distance for a large portion of commuters. PEVs have been investigated as a means of reducing the use of petroleum for passenger vehicles, decreasing local transportation emissions and simultaneously providing a benefit to the electrical grid (Tomic and Kempton, 2007; Kempton and Tomic, 2005b). Of course, electrification of mass transit options such as the SkyTrain, busses and trolleys also offer the same benefits, in addition to reducing congestion for those commuters willing and able to access those options.

2.2 Regulatory Environment for PEVs

The recent BC Utilities Commission (BCUC) report on BC Hydro's Long Term Acquisition Plan, (BC Hydro: LTAP Decision, 2009), highlights an incomplete and contradictory approach to the regulation of energy in BC, in particular with respect to electrification of specific services (including transportation). For example, the report proposes the substitution of electric heaters with natural gas-fired heaters for domestic hot water and space heating applications, termed electric "load avoidance". This is justified in the report by pointing out that marginal demand for electricity – generated centrally with attendant efficiency losses – is likely to be met by relatively costly and dirty natural gas-or-coal-fired generation. The report's conclusions reflect Hydro's primary mandate to satisfy electrical demand at low cost, a requirement that "load avoidance" helps to meet. Thus, by focusing on cheap electricity, the existing regulatory framework inadvertently discriminates against widespread adoption of PEVs, which could theoretically increase demand. Moreover, any additional generation required for PEVs that is provided by coal or natural gas will enhance GHG emissions, a consequence that flies in the face of BC's Climate Action Plan.

It is therefore recommended that the BC Hydro and BCUC mandates, which presently focus solely on electricity costs, be realigned to recognize that there is value in establishing a diverse and flexible energy supply that is derived from a variety of sources. Their plans and regulatory frameworks should also explicitly include growth of an electrified transportation sector and include consideration of GHGs of the two coupled systems. This approach, when combined with the load-leveling and other services that a PEV fleet could provide, will offer the greatest long-term net benefit to the provincial energy system.

2.3 PEV Technology

Hybrid electric vehicles (HEVs), such as the popular Toyota Prius, are common in the vehicle market today. They use conventional internal combustion (IC) engine technology, albeit with smaller and sometimes modified combustion cycles (e.g. Atkinson), optimized to complement the capabilities of the electric motor/generators in the transmission system. These engines are used in combination with a small battery and sophisticated power electronics to increase the fuel efficiency of the vehicle, augmented by regenerative braking. A plug-in hybrid electric vehicle (PHEV) takes the hybrid technology one step further with the addition of a larger on-board battery that can be recharged from the grid. Extended range electric vehicles (EREVs) are able to power the vehicle in all power demand situations solely through the electric motor(s), by completely decoupling the engine from the wheels through mechanical or electrical means. This enables EREVs to operate in either all-electric (i.e. purely battery powered) or charge-sustaining (i.e. the IC engine is the ultimate energy source) modes. Full electric vehicles (EVs) dispense with the IC engine, and use an onboard battery as the only energy source, typically resulting in decreased range and lower top speeds. The EV category includes electric scooters, motorcycles and neighbourhood electric vehicles, as well as high powered sports cars. For all categories of PEVs, the battery can be recharged from any standard household outlet, providing a benefit to PEV owners in the form of reduced fuel costs and emissions.

There are multiple options for PEV drive train configurations, a fact attested to by the diverse set of configurations being considered by auto manufacturers. For example, Chevrolet will be manufacturing the Volt starting in 2010 (GM, 2009). The Volt is considered an EREV because an electric motor will supply all of the propulsion power for the vehicle. When the battery runs low, an IC engine will turn on to power an electric generator and recharge the battery, thus increasing the range of the vehicle. PHEVs typically adopt a parallel drive train architecture, similar to today's hybrid vehicles, that attempts to optimize energy management to maximise fuel efficiency through use of both the battery and a small IC engine. Although the PHEV uses energy stored in the battery and will operate in low power demand situations in electric-only mode, in comparison to the EREV, it will require some petroleum in standard driving conditions regardless of trip length. Therefore, in contrast to PHEVs, EREVs have more powerful electric motors and a smaller IC engine optimised for operation at a set engine speed.

Regardless of the type of PEV or the architecture used for the vehicle's drive train, all contain a battery energy storage system. The current state-of-the-art in battery technology is the lithium ion (Li-ion) battery. These batteries will likely be used in near term PEVs because of their longer lifetime, higher charge-discharge efficiencies and specific power advantages relative to other battery chemistries (Bradley and Frank, 2008). The size of the battery used will depend on the type of vehicle and the desired all-electric range (AER). The Chevrolet Volt, discussed earlier, will have a 64 km AER that is claimed to provide 75% of American commuters with enough battery energy for a return trip to work. This battery will be rated at 16 kWh of stored energy, with discharge cycles limited to ~8 kWh to maintain longevity, and will take 6-7 hours to recharge on a standard household outlet (110V). Many other near-term PHEVs will have smaller batteries in the 5-12 kWh range.

Some researchers have pointed out that PHEVs and EREVs can help to transition the transportation sector towards hydrogen (H_2) fuel cell vehicles (Suppes, 2005), by eventually replacing the IC engine with a fuel cell powered by hydrogen. PEVs have a near term advantage over pure H_2 vehicles because of the relative availability of infrastructure (wall outlets and gas stations), compared to the production and distribution requirements of hydrogen. For this reason, fuel cell research and pilot projects should continue to be developed, but near term emphasis should be directed toward PEVs. It remains to be seen whether PEVs or pure H_2 vehicles will eventually win out, given the ongoing development in battery, biofuel, fuel cell and drive train technologies.

2.4 PEVs and the Grid

Before discussing the impacts that PEVs may have on the electrical grid in BC, it is important to examine briefly how electricity is generated and delivered to customers. Generation of electricity in BC is done by BC Hydro, primarily through hydro-electric dams located far away from the load centers (areas of high electricity demand, such as the Lower Mainland). This power flows in bulk through the transmission system, managed by the BC Transmission Corporation (BCTC), at high voltages to reach distribution centers. The power then flows through local distribution networks where the voltage is adjusted to meet the requirements of a household (110/220 V). The system operator at BC Hydro changes the level of generation from the facilities to meet the ever changing demand, and also to maintain reliability and ensure enough transmission capacity at all times. A constant adjustment of generation is necessary to ensure that these conditions are met at all times.

Demand for electricity, while highly variable, follows predictable day-to-day and seasonal patterns allowing for day-ahead and hour-ahead scheduling to take place. In some instances, electricity is also imported and exported to markets in the US and Alberta, sometimes to meet demand, but more often for economic reasons. For example, low cost electricity, derived from coal plants in Alberta, is imported into BC in periods of low demand at night, and high-value electricity from BC Hydro is sold back to Alberta during peak periods during the day.

The impact that PEVs will have on the electricity grid is largely dependent on the market penetration of these vehicles. With large numbers of PEVs connected to the grid, the effects may be significant and must be understood and managed. To estimate the capacity of the provincial grid for charging PEVs, it is necessary to examine typical hourly electricity demand profiles, as shown in Figure 3. Predictably, the load increases throughout the day and peaks around 6 PM in the evening, when the majority of commuters arrive home after work. This time during the evening hours corresponds to the time when PEV owners would be plugging their vehicles into the grid for charging. This presents a problem to the grid: at peak demand times, the marginal cost of electricity is the highest and generation levels are at their maximum. The additional demand on the grid from PEV charging during these peak hours is undesirable from the grid operator perspective and could be severely detrimental to the grid. Thus, it is beneficial to have the vehicles charge during the off-peak hours, requiring some form of external control over the vehicles, or consumer incentives to self-regulate.

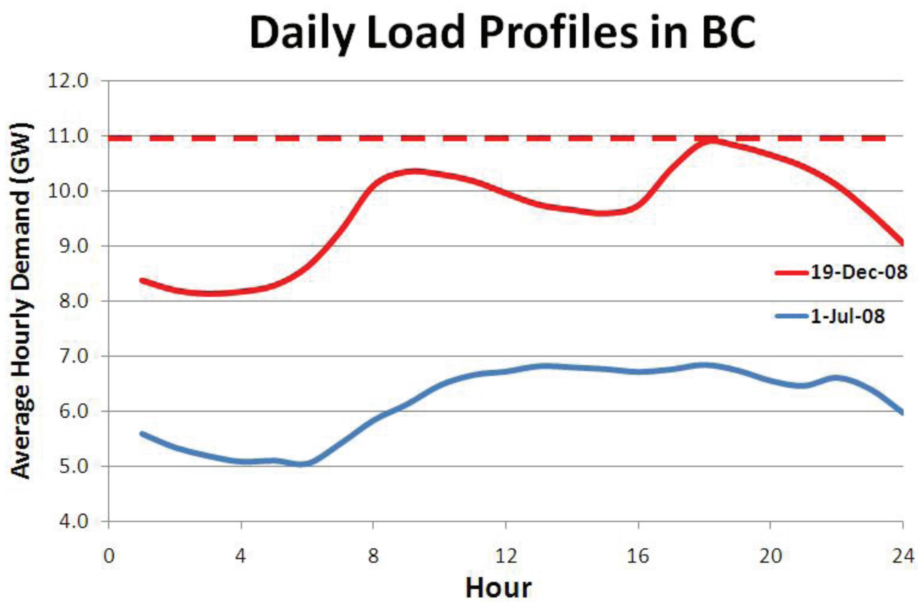


Figure 3. The highest and lowest electricity demand days for 2008

If PEVs were charged strictly during these off-peak times, known as "valley-filling", there is a significant amount of underutilized generation capacity that could be harnessed for vehicle charging, if all the technically available generation capacity was utilized. Using the Chevrolet Volt's claim that a 16 kWh battery will provide 64 km of electric-only range, and given that the average commuting distance in BC is much less and a maximum of about 80% of the entire battery capacity is allowed to be used during operation, a conservative recharge estimate of 13 kWh per day is assumed. Provided these vehicles are not charged during on-peak times, an estimate can be made for the number of vehicles that could be charged without the need to add costly generation capacity. The worst case scenario occurs during the winter, yet the unused capacity during this time could still charge nearly 2.4 M light duty vehicles. Since there are around 2.54 M registered vehicles in BC, this represents market penetration of almost 100%, which obviously will not be seen for many years. In the summer, when there is much more spare capacity, the grid could theoretically support over 8.8 M vehicles.

This simple aggregate analysis serves to illustrate that from an overall perspective, there are no immediate threats to the grid from PEVs which will take time to penetrate the market, provided the charging of vehicles is controlled in a manner that avoids the peak demand hours. A number of options under investigation to encourage vehicle owners to charge their vehicles during the low demand periods of the day are discussed in the next section. It should be noted that although the aggregate analysis show no immediate threats, some local circuits may require upgrading to handle additional loads from PEVs. Also, load profiles may vary from the typical profile shown above, depending on the customer's location and typical electrical loads in the area. Any future analysis of grid capacity for PEVs should be done on regional or local scales to account for both of these factors.

It is important to note that the discussion in this section focuses on the technical power constraints on the BC grid system. Generation capacity refers to the ability to provide sufficient power to the vehicles, while grid capacity refers to the ability of the grid to transmit that power from generator to vehicle. Section 3.4.2 discusses the related energy and economic constraints that will further bound the possibilities for PEV integration in BC.

2.4.1 At the Plug

No standard currently exists for a universal plug to interface with the vehicle. Although a standard 3-prong plug connected to a usual socket could work initially, a more advanced connection is desirable, but only if universally adopted. This standard would allow the vehicle to charge at two voltages, 110 and 220 V, and also contain components necessary to allow for vehicle communication with a grid operator or other 3rd party, possibly via wireless connection. These more advanced features will remain a minor issue, until such time as methods or incentives are in place to reduce PEVs charging during peak demand.

The charge rate that will eventually become standard with mainstream PEV adoption will likely not be provided through the standard home wall socket. The wall socket that is found in a typical house is rated at 110V AC, with amperage rating of 15 or 20 A, giving a power rating of 1.4 kW and 2.0 kW respectively. Using the figure of 8 kWh discussed earlier for the GM Volt, this would entail a charge time of about 7 hrs. This is referred to as a Level 1 charging station, as defined by the National Electric Code. This will likely be used for PEVs entering the market in the short term, however, Level 1 charging was intended as an entry level standard, and for emergency situations in the future. Level 2 chargers will likely be widely used in the future, and are rated at 220 VAC at up to 40 A, giving power ratings of 9.6 kW and a charge time of 1.3 hrs for 8 kWh of useable charge dependent upon battery module current and thermal limits. Level 2 circuits are similar to those used for household dryers and stoves. Finally, some level 3 chargers have been created, running from 60-150 kW. However, this level of charging is impractical in residential applications and will likely only see use in commercial or fleet applications (Morrow, 2008). It should also be noted that from a power generation perspective (i.e. BC Hydro), higher charging rates may be preferred due to their higher charge efficiency relative to the lower levels, meaning less energy is lost during delivery of useable power to these vehicles (BC Hydro, 2009). Conversely, higher charge rates may create problems from a grid perspective (i.e. BCTC) since vehicles will be placing higher power demands on the grid when they are plugged in, relative to vehicles plugged in at lower charge rates.

In a previous survey of PHEV users (Kurani et al., 2007), it was shown that the behaviour of consumers is not necessarily in line with what is best for the utility grid. The surveyed users were not encouraged to charge at certain times during the day, and were not subject to changing electricity prices. Consequently, users frequently plugged their cars in during the day, and very few considered the effects of their charging on the electricity grid. There are several methods that could influence the consumer to plug in their PEVs to ease the burden on the grid. The utility could introduce time-of-day pricing to allow consumers to choose their charging time to minimize cost by taking advantage of lower rates during off-peak hours. In turn, charging during peak demand times (high price) would be discouraged. Another method may be to offer customers a preferred rate for PEV electricity, discounted particularly in the evening. The survey showed that very few users actually calculated their fuel cost savings, indicating that this method may not be enough to encourage desired charging behaviour.

Under a smart meter system, power consumption and cost of use information is provided to the customer in real time. Advanced smart meter designs could enable PEV charging to be remotely controlled by BC Hydro. This would allow BC Hydro to actively control when the bulk of the PEV load comes online, and allow them to plan generation and pricing accordingly (U.S. Department of Energy, 2006). This may require the installation of a separate meter dedicated to PEV charging, unless the meters will be able to distinguish between vehicle charging and other loads. These meters and the system controlling it would be the first stage in establishing a vehicle-to-grid (V2G) power system.

An alternate configuration could be a mix of consumer and utility control. Consumers may program their vehicles to respond to pricing signals, with the schedule communicated to the grid operator for generation planning purposes. Also, during periods of excess generation or high renewable energy output, the grid could dispatch vehicle load to take advantage of intermittent renewable energy sources.

On the vehicle itself, the battery may be owned by the consumer, the car maker, or possibly by the utility. Since the utility may want to control charging of the batteries and use the vehicles as dispatchable loads, it may be favourable for them to have full control of the charging (and discharging, as in the case of V2G). The car maker might instead own the battery, and lease the usage rights to the utility and/or consumer. Although these arrangements do not allow the owner to manage their entire vehicle, it may provide significant capital cost savings to the consumer, making PEVs a more palatable financial decision.

Opportunity charging refers to the consumers' desire to plug in their vehicles whenever they are parked, maximizing electricity consumed instead of gasoline. Consumers have shown a desire for opportunity charging (Kurani et al., 2007) at home, work, the shopping mall and other destinations. This will require the installation of charging station infrastructure on the street and in parking lots. Opportunity charging may be detrimental to the grid depending on the local behaviour of consumers, but it effectively extends the all electric range of PEVs, and could potentially accelerate their success in the marketplace. It has been shown that the cost of adding additional charging infrastructure in commercial facilities is much less than the cost of a larger battery for emergency backup power (Morrow, 2008).

The installation of new charging infrastructure would help PEV drivers recoup the large capital cost of the vehicle faster, by ensuring electric power is available as frequently as possible. However, the best locations for installation of new charging infrastructure are determined by several factors. First, vehicle usage and ownership patterns vary widely between urban, suburban and rural users. Second, it is likely that more affluent neighbourhoods will be the first to adopt these vehicles, causing a "clustering" of PEVs in certain areas. Finally, single family homes are more likely to have access to electrical plugs than those who live in apartments and park on the street or underground. These factors must all be considered when deciding where demonstrators and useable public infrastructure should first be installed.

2.4.2 PEV and Renewable Energy Integration into the Grid

Two important sections of the recent BC Energy Plan call for new power projects to achieve net zero emissions and also for the province to derive 90% of total electricity generation from renewable sources (hydro, wind, biomass, tidal, geothermal, etc.). These constraints will ensure that BC becomes a leader in renewable energy while decreasing the environmental impact from the electricity sector. Of course, there are issues associated with renewable energy technologies, intermittency being a key concern. The unpredictability of natural phenomena such as wind speed and direction, rainfall and solar radiation cause most renewable energy projects to have low capacity factors.[1]

Intermittency and unpredictability cause a host of problems when considering large scale integration of renewable generation. Conventional generation is able to produce and curtail power on demand (subject to fuel availability, ramp rate limits, maintenance, etc.), a quality referred to as "dispatchable". The dispatchability issues associated with renewables can be mitigated with the use of large-scale energy storage technology, i.e. the energy can be used when it is needed and stored when it is not. Storage systems can effectively boost renewable generators' capacity factors, making them more useful and easier to integrate into the larger system. Industrial scale storage systems, however, are currently cost prohibitive and there is little international experience with them apart from pumped hydro, where excess electricity is used to pump water back up into reservoirs, to be used later.

PEVs have been proposed as a means of large scale, distributed storage for intermittent renewable generation (Kempton and Tomic, 2005b; Bradley and Frank, 2008). The concept is made possible by the fact that a majority of vehicles are parked at any given time, and could therefore be used as "mobile energy sources", supplying V2G energy (see section 3.1) during periods of high demand and storing it during periods of high renewable output or low demand.

With the recent wind integration projects on the horizon for BC Hydro (BC Hydro, 2008) , approximately 3% of future system capacity will be from wind power, with the possibility of increases if more wind projects are awarded in upcoming calls for clean power. At present, wind power projects representing an additional 17% of provincial capacity are in the feasibility study stage. The timing of the availability of the wind resource is very important for planning and grid operation. The introduction of large amounts of wind increases the possibility of new transmission bottlenecks, especially if the wind power is located far away from major load centres, like the proposed wind farm in the Peace region of northern BC. Often the wind is strongest during the early morning hours when electricity demand is at its lowest, requiring the curtailment of hydro or a decrease in low cost imports. Charging PEVs that are in communication with the grid through a smart device may allow the wind energy to be utilized to its full potential during the low demand hours. This synergy of PEVs and intermittent renewable energy may not be fully realizable until the penetration of PEVs is significant and able to store enough energy to support the renewable infrastructure.

[1]The capacity factor is the amount of energy produced by a generator divided by the amount of energy it would have produced if running at full power for the same time period.

It should be appreciated that BC is a unique jurisdiction, given hydro's dominance in the BC generation mix with an extensive existing transmission network to bring the power to load centres, and the arbitrage power exchanges with fossil-fuelled neighbours. Integration strategies for PEVs in BC will therefore be unique and require careful study of challenges, such as avoiding increased imports of coal-derived electricity at night, *and* opportunities, such as better utilizing the transmission grid by exploiting the localized storage opportunity of PEVs. Of course, other jurisdictions can provide useful comparisons and inspiration, depending on their generation mix and experiences with embedded features such as distributed cogeneration technologies (e.g. combined heat and power (CHP)).

3. OPPORTUNITIES AND CHALLENGES

3.1 BC Hydro and Vehicle-to-Grid

Researchers working on PEVs and V2G technology have investigated the potential for using V2G-capable fleets for use in power markets (Kempton and Tomic, 2005a). To maintain a high level of reliability in any electricity system, multiple power markets are required. These are generally broken down into four main categories, listed in order of increasing monetary value: baseload, peak power, spinning reserve and regulation. Each market differs in response time, duration of power dispatch, cost and contract terms (Kempton and Tomic, 2005b). Baseload is the bulk power that is used during all periods of the day; it has the longest duration and highest power requirement. Electric vehicles are not well suited to sell power into this market. Peak power is used for periods of predictably high demand. Spinning reserve is provided by fast-response generators, which are not generating power but kept "spinning" in order to be brought on-line quickly in case of a contingency. Finally, regulation is a power market that responds on very short time scales – seconds to minutes - and is used to keep the frequency and voltage steady on the grid.

The most lucrative power markets for PEVs are the spinning reserve and regulation markets. Spinning reserve charges are paid simply for having reserve capacity available and for being able to respond quickly, but are infrequently called on to provide that capacity. If vehicles are connected to the network and communicate through an intelligent device, then the amount of power that is available from the vehicles is easily determined. Coupled with the fast response capability of the vehicles' electrical systems, this power market is well suited to PEVs. Of course, the certainty of vehicles being connected for the duration of the time necessary to provide spinning reserve contracts is one of the major obstacles for this type of V2G.

Regulation is the very short timescale power balancing that is required by the system to maintain proper frequency and voltages. This type of power market matches well to the capabilities of distributed electric vehicles. Regulation requires not only power to flow into the grid but also at times when generation slightly exceeds demand power must flow into the batteries. PEVs could potentially provide these small timescale fluctuations with little change in the battery states of charge due to the up/down characteristic of this power market. This has been proposed as the most competitive market into which vehicle operators could sell power (Kempton and Tomic, 2005b), and takes advantage of the distributed resource offered by PEVs without adversely impacting their primary functionality as transportation vehicles.

The V2G concept is gaining some momentum but it will be some time before it is realized on a large scale. BC Hydro currently uses its hydro resources to meet the spinning reserve and regulation requirements at very low cost: thus V2G may not be as beneficial in the BC context, compared to V2G scenarios in power markets dominated by thermal sources (e.g. coal, natural gas) where the price of ancillary services is high. However, changing the operating strategy of the hydro resource by utilizing PEVs in a V2G strategy could provide extra revenue or increase the reliability and stability of the grid, particularly with moves towards "smart" micro-grids. Clearly, there is more research needed specific to regions of BC, as certain areas may be more likely to adopt V2G than others. For example, transmission constraints on Vancouver Island and other areas distant from load centres, may benefit more from V2G, as it may provide increased reliability and also allow for the deferral of capital investment in transmission and generation projects.

Battery durability is also an area requiring further research, as the battery lifetime may be negatively affected by frequent deep charging/discharging cycles. Given that hydro bills are a relatively low percentage of most users' household bills, in order to attract attention and warrant interactive involvement by the PEV user to engage in active use of V2G, there needs to be a pricing incentive over the flat rate. Otherwise, the user does not benefit from BC Hydro's potential use of the PEV battery as a storage medium. Whilst speculative, leverage factors of four or more are thought to be required to encourage the implementation and use of V2G.

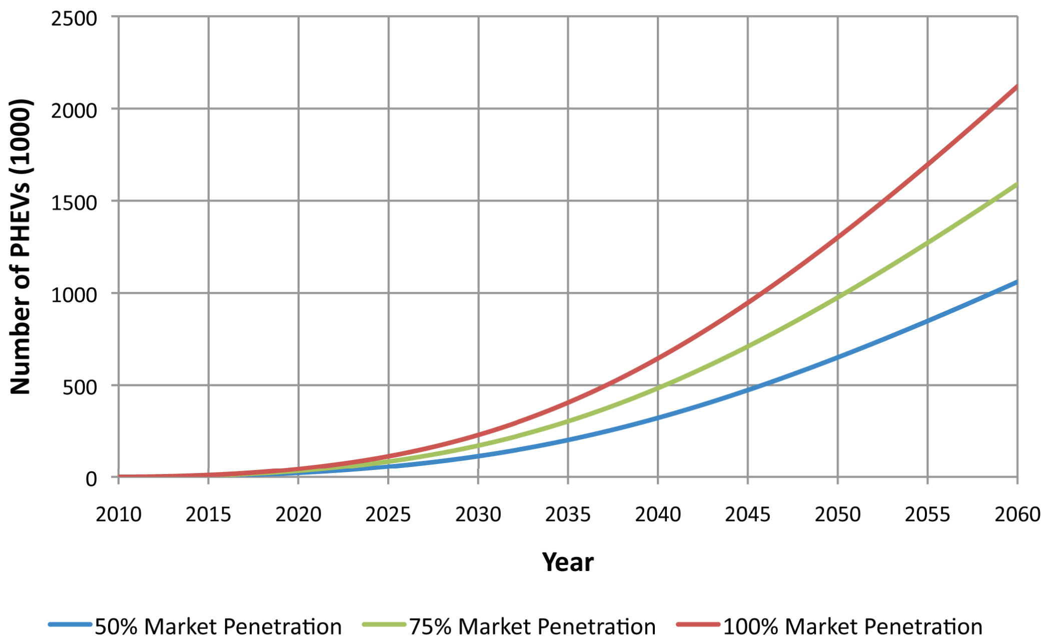
An important near-term alternative to the use of PEV batteries for V2G on to the larger grid is in vehicle to home (V2H) applications. Unlike V2G, which requires much great utility control and use of the batteries, V2H directly benefits a home owner in a number of ways. During power outages, the batteries may power critical home functions. Alternatively, micro generation, such as solar, may be used to recharge an owner's vehicle.

3.2 Personal Vehicles

To estimate the number of PEVs on the road in the future, a brief market penetration study was performed based on the analysis by Short and Denholm using a simple Bass market diffusion "S-curve" model (Short and Denholm, 2006). The analysis assumes three cases of PEV penetration as shown in Fig. 4. Of course, the actual penetration depends on vehicle economics, technology advancement and the availability of other vehicle alternatives. In the near term, PEVs will be attractive to the "early adopter", while the risk averse consumer may wait to see if the technology is all that it promises to be.

As PEVs penetrate the vehicle market, there will be a certain threshold number of vehicles at which the first large-scale impacts to the grid may be seen. When near this threshold, proper vehicle control or time-of-use charging rates should be in place to minimize the impacts. Another threshold number of vehicles may exist that makes V2G an economical prospect. The timeframe and magnitude of these thresholds should be determined well before PEVs become widespread.

Figure 4: Forecasted market penetration of PEVs in BC



The first and most obvious motivation for PEVs in the personal vehicle market is fuel savings. Simply put, the cost of driving with gasoline is far more expensive than the equivalent amount of driving with electricity. The estimates for savings of gasoline depend on the amount of driving, how much driving is done in "all-electric" mode and the type of vehicle. The Electric Power Research Institute (EPRI) in the US has estimated the fuel cost savings at US $600/year at a gasoline price of US $3/gallon (US $0.80/L) and electricity at US 7.6¢/kWh (Sanna, 2005). Conducting a similar analysis for BC, based on an average of 13,454 km/year (Stats Can, 2007), 80% all-electric driving, gasoline at $1/L, and 7¢/kWh electricity, the driver would save $740/year in fuel costs compared to a conventional vehicle. Interestingly, it has also been pointed out that most people who purchase a vehicle do not properly assess the fuel cost or efficiency of their vehicle (Sovacool and Hirsh, 2008). Apart from gasoline savings, maintenance costs are likely to be lower than fossil fuel vehicles, due to expected decreased maintenance requirement for low duty internal combustion engines and relatively high reliability electrical machines. Based on estimates such as these, the payback period to recoup the initial higher purchase price of a PEV will be less than the lifetime of the vehicle.

Another market for PEVs is likely to come from early adopters who purchase the vehicle for its environmental benefits, regardless of increased cost or actual performance. The social benefits of owning a "green" vehicle may stimulate the market for PEVs, especially from more affluent consumers who wish to appear environmentally friendly. Conversely, the high initial capital cost of the battery and its associated power electronics may dissuade some people from buying the vehicle in the early stages, even if incentives and proper warranties are in place. If the cost of retrofitting existing vehicles with batteries is lowered, this could also help to stimulate the market.

There is currently no active Canadian federal government policy in place to offer incentives or rebates for PEVs. The recent EcoAuto rebate program offered through Transport Canada was closed as of December 31, 2008. BC does offer the Scrap-it Program, which offers up to $1250 for vehicle owners who trade in an older low efficiency vehicle for a less GHG intensive one. Another provincial program, the Social Services tax benefit, provides up to $2000 of the tax payable on hybrid vehicles; this program has been extended to 2011. Other similar policy action in this area could help to encourage purchases of PEVs to ensure the maximum benefit to the province. A recent paper from the US examined the impact these types of programs had on the adoption of hybrid vehicles. The report concluded that high gas prices were much more important to the consumer than tax rebates, but that an upfront incentive payment seemed to be the most effective rebate (Diamond, 2008). Bill H.R. 1331 introduced in the U.S. House of Representatives would give up to US $6000 in rebate for the purchase of PHEVs with batteries in excess of 4 kWh capacity (U.S. Congress, 2007).

Other jurisdictions in Canada and abroad have been implementing policy to ensure that PEVs become widespread. For example, Ontario recently announced a partnership with Project Better Place, a company devoted to increasing electric vehicle infrastructure (Project Better Place, 2009). The company builds electric-vehicle networks powered by renewable energy to give consumers an affordable, sustainable alternative for personal mobility. Similar projects through Better Place are underway in Denmark, Israel, Australia, Hawaii and California. The plan is to build a network of battery swapping stations that can replace vehicle batteries with fully charged ones in less time than it takes to fill a tank of gasoline. This model tackles the challenge of providing unlimited range to EVs by battery swapping, whereas PHEVs and EREVs rely on an internal combustion engine to ensure that trips of unlimited length are possible. Ontario is also introducing rebates of $4000 to $10000 for PHEVs and EREVs based on their battery capacity.

The Rocky Mountain Institute, a non-profit, independent think tank created Project Get Ready, a collaborative effort to share knowledge of PEV introduction and program development between cities and communities. They aim to foster PEV growth by helping cities become leaders of PEV technology and adoption (Rocky Mountain Institute, 2009). They have created a menu of the most important actions that cities should take to be ready for PEVs, including some financial analyses.

Public charging stations will provide user benefit but user pay-per-use is unlikely to provide sufficient return on capital investment, at least for the initial installations. Publicly funded charging networks, similar to charging stations in London and other major cities, appear to be the most expedient process to bring about initial charging station deployment. Private investment in a public access, pay-per-use, charging infrastructure would likely require tax incentives and government financial support. Public access street level, parkade and provincial buildings such as hospitals, libraries and others, will likely require some level of government funded, public access charging to facilitate PEV market penetration.

Private, in-home charging stations are likely to be self-financed by the home owner, who will perceive either a financial, self interest, or social benefit, advantage to investing in this technology. Other private individuals, living in multi-dwelling buildings, will have to rely on owner/builder interest in providing a user-pay or free-use charging station. Vancouver recently enacted multi-dwelling bylaws, requiring 10% availability of plug-in stations as a first step in preparing for PEVs.

3.3 Fleet Vehicles

Fleets of vehicles, whether government or corporate, are another potential avenue for the adoption of PEVs. Unlike most consumers, fleet managers typically make detailed economic and market analyses before purchasing or retiring bulk numbers of vehicles. This careful consideration for fuel economy and vehicle price may make PEVs attractive in certain fleets, similar to the high adoption rate of hybrid vehicles in taxi fleets seen in BC. Fleet vehicles have unique driving patterns, as they are used mainly during the day and not usually during the evening. They may be parked for long periods of time and may have high city driving cycles. These characteristics offer some interesting and unique economic opportunities for managers to transition their fleets to PEVs.

It has been suggested that corporate or government fleets of vehicles could become early adopters of V2G technology. Fleets of vehicles are often all parked in one area for long periods of time allowing them to provide some ancillary grid services while plugged in. This power could then be sold into the grid to help recover the cost of the vehicles or even generate profit. The parking garage or lot could be upgraded to allow for fast charging of vehicles; this would increase the benefit to the grid and also benefit the vehicles as they could be charged quickly.

An investigation of revenue from the sale of power for grid regulation in four US power markets was undertaken by Tomic and Kempton (Tomic and Kempton, 2007). They estimated that a fleet of 100 Think City vehicles (www.think.no) could generate a net profit of US $7,000–$70,000 and remain profitable in all power jurisdictions studied while increasing the stability of the grid. There are numerous types of vehicle fleets that could benefit from this type of technology and also save costs in fuel and maintenance, while decreasing their operating emissions and improving grid reliability and stability. Delivery trucks, government vehicles, forklifts, transit vehicles and perhaps taxi fleets all present opportunities for PEV implementation.

The government of BC has already mandated a few key policy actions to enable government and private fleets to reduce GHG emissions and enable green vehicle technologies. Briefly, support to reduce emissions and improve fuel efficiency is being offered through the Green Fleets BC program. The government has further plans to use its purchasing power in the marketplace to influence development of more environmentally friendly choices. This will be accomplished by implementing an environmentally responsible procurement strategy; switching government fleets to PEVs would be an excellent area to apply this strategy. Already the province of BC operates the largest hybrid vehicle fleet in the country. This type of environmental leadership should continue with additional programs like the Ministry of Energy, Mines and Petroleum Resources (MEMPR)'s plug-in hybrid program, which put 15 PHEVs into operation during the summer of 2009.

3.4 Province of BC

BC is differentiated from other jurisdictions in Canada in two important ways relevant to PEVs. First, BC's hydro resource with large reservoirs can provide relatively clean electricity, as highlighted in the following sections. Secondly, BC's main population centres in the Lower Mainland and Vancouver Island are relatively warm and temperate compared to the rest of Canada. This will avoid the challenges associated with extreme hot and cold ambient temperatures and the resulting demands placed on the batteries in particular for operating in these conditions, including the provision of heating or air conditioning to the vehicle's interior cabin.

3.4.1 Emissions Reductions

Perhaps the most important opportunity for BC when considering PEVs is the potential for large scale province-wide reductions in GHG emissions. Unfortunately, accurately quantifying the future reductions in emissions that are possible with PEVs is difficult for a number of reasons. First, there is uncertainty in the rate at which PEVs will penetrate the new vehicle and retrofit markets, an aspect that is dependent on many factors such as the readiness of the battery technology and the willingness of consumers to adopt a new kind of vehicle. Secondly, information is needed on the amount of driving that will be done by the vehicle operators and the proportion that is done in an "all-electric" mode, another technological and operator dependant factor. Third, and perhaps most important, is how the vehicles will be charged. For example, the emissions intensity (tCO_2e/GWh) produced in generating electricity is a time-dependant factor that changes with the amount of electricity imported, exported and generated domestically. Changing the operation of the electrical grid and how PEVs are controlled/charged will change the impact that PEVs can have on the transportation system.

British Columbia enjoys one of the lowest-cost and lowest-emissions intensive generation mixtures in North America, due mainly to heavy reliance on hydroelectric dams. Reports from BC Hydro indicate that the emissions released from provincial operations, excluding electricity imports, was 291 $ktCO_2e$ in 2007, having an average emissions intensity of 22 tCO_2e/GWh (BC Hydro, 2008). The emissions intensity changes depending on the water conditions for that year and can be as high as 70 tCO_2e/GWh. In comparison, the Canadian average emissions intensity from all jurisdictions is more than 200 tCO_2e/GWh, while the US average is near 600 tCO_2e/GWh. The emissions values in BC are dependent on the quantity of water in BC's large reservoirs, with low water years relying more on fossil- fuel intensive generation to meet the shortfall from the hydro facilities.

One simple method of comparing the emissions from regular internal combustion (IC) engine vehicles to that of PEVs is to compare the emissions generated by driving one kilometre. The Electric Power Research Institute (EPRI, 2007) has found that a PHEV in "charge depleting mode"[2] would consume approximately 0.198 kWh/km of electrical power to match the performance of a vehicle with an average of 9.76 L/100km efficiency. Using a gasoline emissions value of 2445 gCO_2e/L (Environment Canada, 2006), an average internal combustion engine vehicle emits 239 gCO_2e/km, while a PHEV *driving only on* electricity would produce 4.35 gCO_2e/km using electricity stored from BC's grid at 22 tCO_2e/GWh, a very significant improvement.

[2] In charge depleting mode, stored electricity in the PHEV's battery is used for propulsion, rather than gasoline in the engine which is switched off in this mode.

Similarly, for a regular hybrid vehicle consuming a blend of gasoline and electrical power, such as the Toyota Prius, the emissions would be 155 gCO_2e/km. The emissions value for the regular hybrid represents the maximum emissions that would occur from a PHEV or EREV with a depleted battery. In this mode, the gasoline engine ultimately provides all the energy, operating in "charge-sustaining" mode with regenerative braking to increase efficiency, just as a normal hybrid vehicle does. If a worst case scenario for emissions intensity in BC is considered, using 70 tCO_2e/GWh and assuming a 10% import of coal derived electricity at 1000 tCO_2e/GWh, driving on electricity only would still produce only 32.23 gCO_2e/km.[3] The preceding is of course a simple analysis, heavily dependent on the electricity source used to charge the PHEV and on how the vehicle is driven. However, it does illustrate the massive potential improvement in emission reductions from driving on electricity. Thus, PEVs are clearly an excellent opportunity for BC to reduce GHG emissions.

A PEV life cycle analysis (LCA) considering the manufacture, operation and disposal of all components, would quantify the costs, (financial and environmental), attributable to owning, operating and disposing of a PEV for an individual, fleet and the province. In particular, the petroleum and GHG savings may be diminished by the cost of the battery module recycling or disposal. A provincial environmental use and disposal policy would likely be required, specifically related to PEV batteries, to ensure their recycling and avoiding or facilitating large-scale disposal. Repurposing the PEV batteries may mitigate the recycling cost to the original purchaser or disposer, and provide benefit for other end users. For example, BC Hydro could re-purpose the PEV batteries, even with reduced performance, for distributed energy storage, load balancing and voltage quality control at sub-station level, or as a backup for critical services. This would supplement a large PEV fleet providing ready access to large scale battery storage and support increased renewable energy penetration of the power mix, as well as provide improvements to qualitative and emergency power supply.

3.42 Economic Opportunities and Challenges

A number of fiscal challenges and opportunities arise for the provincial government when considering PEVs. The most obvious is a loss of tax revenue from the sale of gasoline because of the decrease in aggregate fuel consumption. This loss of revenue will be partially offset due to an increase in electricity sales accruing to BC Hydro, a crown corporation. Offsetting losses of gasoline tax by increasing electric rates for PEV drivers would require a separate metering system and a proprietary method to prevent plug-in to a regular power outlet. This seems a counter-productive measure, since one incentive for increased PEV ownership is lower travel costs. The recovery of lost gasoline revenue requires further study. Most gasoline tax revenue is used for road and highway construction and maintenance purposes.

An alternative means of tax collection could come in the form of an odometer tax, where a tax is paid on the annual (or monthly) number of kilometres driven by each vehicle. For example, this tax could be collected by ICBC at the time of insurance renewal. Such a system would tax all vehicles equally for the amount of road and highway use. Also, it doesn't require BC Hydro to become a tax collector and eliminates the need for a separate metering system for PEV charging.

[3] The 10% "worst case" is assumed from the Alberta-to-BC tie line limitation of 500MW and a lowest power demand calculated to be 5GW, as seen in Figure 3.

Earlier in section 2.4, initial calculations indicated that PEVs do not pose a technical problem to the BC system in terms of generation power constraints. With PEVs entering the system, the power demand profile for BC could be different from the current profile, particularly in terms of shifting loads to the overnight period, but could theoretically be supplied entirely by currently available domestic generators. However, the BC system, which is operated by Powerex, buys coal-based electricity from Alberta overnight when prices are low. Energy is then sold back to Alberta during the day, when prices are higher. This arbitrage makes use of the large energy storage possible in BC's hydro dams, and results in significant revenue for the province.

With PEVs introduced into the system on a large-scale, either additional purchase of fossil-fuel power from Alberta would be required, or additional hydro energy would be used to meet this new load. If the latter were the case, Powerex would have less hydro energy available to sell to the Alberta and US markets during peak time, which could constitute a significant loss of revenue. It is therefore important to differentiate between the technically available *power* from the generators in the BC system, which do not pose a barrier to PEV introduction, and the economic and energy considerations of the system's operation which do pose a potential barrier to PEV use.

Whilst early adopters are likely to be willing to invest in both PEVs and infrastructure, others in society are unlikely to be in a financial or social position to access the potential financial savings from owning and operating a PEV, with or without V2H or V2G. To ensure a level of social equity, some form of government investment in charging infrastructure is an absolute requirement, and further incentives for PEV purchase or lease may also be necessary, even if such an incentive program would also benefit users who would likely purchase PEVs in any event.

Offsetting losses of gasoline tax by increasing electric rates for PEV drivers would require a separate metering system and a proprietary method to prevent plug-in to a regular power outlet. This seems a counter-productive measure, since one incentive for increased PEV ownership is lower travel costs. The recovery of lost gasoline revenue requires further study. Since most gasoline tax revenue is used for road and highway construction and maintenance purposes, an alternative means of tax collection could come in the form of an odometer tax, where a tax is paid on the annual (or monthly) number of kilometres driven by each vehicle. For example, this tax could be collected by ICBC at the time of insurance renewal. Such a system would tax all vehicles equally for the amount of road and highway use. Also, it doesn't require BC Hydro to become a tax collector and eliminates the need for a separate metering system for PEV charging.

The cost of PEV ownership for the consumer is largely unknown at this point. Mainstream vehicle manufacturers are planning to bring PEVs to the market, but the cost/benefit to the consumer is dependent on various factors. Initial vehicle prices are largely speculative at this point, as are the depreciation rates of these vehicles. Major economic factors include the cost of gasoline, electricity, maintenance, taxes and incentives. Consumer preference towards these vehicles will also affect the uptake of PEVs.

There are some unique business opportunities for British Columbia to be a world leader with the introduction of PEVs. Local businesses stand to increase profits or expand because of the adoption of PEVs. For example, Azure Dynamics and Advanced Lithium Power are both creating the core technology for electric drive vehicles. As PEV technology becomes mainstream, it is likely that the number of electric vehicle retrofit programs of existing fossil-fuelled vehicles will increase, advancing the percentage of PEVs in the transportation fleet. REV Technologies Inc. designs and manufactures electric vehicle technologies and retrofits existing light-duty Ford fleet vehicles (REV Technologies, 2009), and stands to benefit from this emerging market.

There are other more indirect avenues for business development and employment that come with PEV adoption, such as the ability to communicate and synchronize the charging of vehicles through a vehicle aggregator, the creation of infrastructure for vehicle charging, and perhaps the increased capacity for renewable energy. For example, wind energy Independent Power Producers (IPPs) may have a business case to sell electrical energy to PEV users who provide a storage mechanism to buffer intermittent wind power generation. This could be extended to selling power through public chargers placed in parking lots at the workplace and shopping destinations. Experience in all these areas will then be a valuable asset for exporting both technology and implementation services to outside jurisdictions implementing their own PEV vehicle fleets.

MOVING FORWARD

To take advantage of PEV technology, a combination of technical, social and economic issues have to be addressed in a focused approach, facilitated by BC government, industry, commerce and researchers. The following areas merit further in-depth study:

- Strategies for BC Hydro to define and implement a SmartGrid PEV metering, pricing and future control architecture that helps avoid peak-time charging, minimises GHG emissions and facilitates PEV adoption.
- Definition of public PEV infrastructure requirements and guidelines, for street-level, parking garage, shopping mall and work-place charging stations.
- Incentive strategies for public charging infrastructure deployment at minimum cost, perhaps by allowing private companies to sell electrical power at shopping malls, parking garages and other sites, to facilitate and accelerate charging infrastructure and PEV usage. This would require modification of existing BC Hydro restrictions governing the resale of electrical energy in BC.
- The BC Hydro mandate for carbon neutral power generation by 2020 can be either facilitated or aggravated by the growth of PEVs, dependent upon BC Hydro and BC government guidelines and policies, particularly with regard to implementing policies that recognize the interconnectedness of transport and electricity generation. A key consideration will involve reconciling the provincial earnings that accrue from sales of power through Powerex to neighbouring markets with the domestic requirements and timing of PEV loads which will tend to reduce the opportunities for those sales.

- Accelerating PEV introduction by purchaser incentives, business grants and public/private investment can help to achieve BC government transportation GHG emissions targets.
- Further market study is required into market adoption rates, including detailed analysis of the geographic distribution, demographics and preferences of users of the vehicles for future planning scenarios.

Given current political objectives and the foreseeable future trend in environmental concern amongst the general population, there would seem to be ample political mandate to pursue public investment in fast-tracking PEVs to market. Private investment, given the current financial climate, is unlikely to be forthcoming unless public seed monies and programs are in place and a clear government policy objective set forth. Fostering BC government, academic, commercial and industrial partnerships should fast-track large scale PEV introduction into the transport sector, with a commensurate investment and deployment of a SmartGrid/V2G infrastructure. In any case, strong international efforts to market and deploy PEVs will ensure they come to BC. Provincial planning should accommodate this eventuality to ensure that BC is well placed to maximize future domestic benefits and mitigate challenges.

GLOSSARY

kW, MW	kilo-watts, mega-watts: Units of power i.e. energy used per unit time
kWh, MWh	kilo-watt-hours, mega-watt-hours: Units of energy
PEV	Plug-in electric vehicle
PHEV	Plug-in hybrid electric vehicle
EV	Electric vehicle
EREV	Extended-range electric vehicle
GHG	Greenhouse gas
CO2e	Carbon dioxide equivalent metric for GHG emissions, in grams (gCO^2e) or metric tonnes (tCO^2e)
AC	Alternating current
V2G	Vehicle-to-grid
V2H	Vehicle-to-home
BC Hydro	Crown corporation responsible for generation and distribution networks
BCTC	BC Transmission Corporation, the Crown Corporation responsible for transmission networks
Powerex	Subsidiary of BC Hydro Corporation, responsible for power trading to other jurisdictions outside BC
BCUC	BC Utilities Commission, responsible for regulation and oversight of utilities

REFERENCES

BC Greenhouse Gas Inventory Report 2007 – Ministry of Environment Victoria BC, July 2009 http://www.env.gov.bc.ca/epd/climate/ghg-inventory/index.htm

BC Energy Plan, 2007. Government of British Columbia. http://energyplan.gov.bc.ca/

BC Hydro, 2008 Annual Report. http://www.bchydro.com/about/company_information/reports/annual_report.html

BC Hydro, 2008, Long-term Acquisition Plan, Appendix F3 Wind Integration Cost Assessment. http://www.bchydro.com/planning_regulatory/integrated_electricity_planning/2008_ltap/2008_LTAP_regulatory_documents.html

BC Hydro 2008 Long Term Acquisition Plan: Decision". July 27, 2009 http://www.bcenergyblog.com/uploads/file/BCUC%202008%20LTAP_Decision(2).pdf

BC Hydro, 2009. Private Communication.

Bradley T.H. and Frank, A.A., 2009. Design, demonstrations and sustainability impact assessments for plug-in hybrid electric vehicles, Renewable and Sustainable Energy Reviews, 13(1), pp 115-128.

"Canada Vehicle Survey: Annual", Stats Can, 2007. Cat.no 53-223-X)

Diamond, D., The impact of government incentives for hybrid-electric vehicles: Evidence from US states. Energy Policy (2008), doi:10.1016/j.enpol.2008.09.094

Electric Power Research Institute (EPRI), 2007. Environmental Assessment of Plug-in Hybrid Electric Vehicles, Vol 1: Nationwide Greenhouse Gas Emissions.

Environment Canada, (2006). National Inventory Report: Greenhouse Gas Sources and Sinks in Canada, 1990-2006. http://www.ec.gc.ca/pdb/ghg/inventory_report/2004_report/ann13_e.cfm

GM Website, 2009. http://www.chevrolet.com/electriccar/

Gouge B., Ries, F., Dowlatabadi H., Reynolds, C., Mazzi, E. and Lim C., 2008. An integrated Approach to Transportation Policy in BC - Pacific Institute for Climate Solutions. http://www.pics.uvic.ca/assets/pdf/Transportation.pdf

GridPoint, Inc., 2008. http://www.gridpoint.com

Kempton, W. and Tomic, J., 2005a. Vehicle-to-grid power fundamentals: calculating capacity and net revenue. Journal of Power Sources 144, 268–279

Kempton, W., Tomic, J., 2005b. Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy. Journal of Power Sources 144, 280–294.

Kurani, K., Heffner, R., Turrentine, T., 2007. Driving Plug-in Hybrid Electric Vehicles: Reports from U.S. Drivers of HEVs converted to PHEVs, circa 2006-07. Institute of Transportation Studies, University of California, Davis

Morrow, K., Karner, D. and Francfort, J. , November 2008. U.S. Department of Energy Vehicle Technologies Program – Advanced Vehicle Testing Activity. Plug-in Hybrid Electric Vehicle Charging Infrastructure Review.

Norton, J., BC Stats, Environmental Statistics, "Going the Distance: Commuting Patterns in BC", June 2008, Issue 2008-2. http://www.bcstats.gov.bc.ca/pubs/es/ES2008-2.pdf.

Project Better Place, January 15, 2009. Press Release: Better Place Partners with Ontario to Bring 'Car 2.0' Electric Car Infrastructure to Canada. http://www. betterplace.com.

REV Technologies Inc., 2009. http://www.rapidelectricvehicles.com/index.html

Rocky Mountain Insitute: Project Get Ready, 2009. http://projectgetready.com/

Sanna, Lucy, 2005. Driving the solution: the plug-in hybrid vehicle. EPRI Journal, 8–17 (Fall)

Sovacool, B. and Hirsh, R., 2008. Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. Energy Policy (article in Press).

Statistics Canada, Canadian Vehicle Survey, number of vehicles on the registration lists, by type of vehicle, British Columbia, in CANSIM Table 405-0005. 2008, Statistics Canada.

Statistics Canada, 2006 Census of Population, Statistics Canada catalogue no. 97-561-XCB2006010

Suppes, G., 2005. Roles of plug-in hybrid electric vehicles in the transition to the hydrogen economy. International Journal of Hydrogen Energy 31 (2006) 353-360.

Tomic J., and Kempton, W., 2007. Using fleets of electric drive vehicles for grid support. Journal of Power Sources 168 (2007) 459–468.

U.S. Department of Energy, Office of FreedomCAR and Vehicle Technologies. Energy Efficiency and Renewable Energy. May 4-5, 2006. Summary Report: Discussion Meeting on Plug-In Hybrid Electric Vehicles.

U.S. Library of Congress, 2007. H.R. 1331, http://thomas.loc.gov/cgi-bin/query/z?c110:H.R.1331:.

Pacific Institute
for Climate Solutions
Knowledge. Insight. Action.

University of Victoria
PO Box 1700 STN CSC
Victoria, BC V8W 2Y2

Phone 250-853-3595
Fax 250-853-3597
E-mail pics@uvic.ca
www.pics.uvic.ca

Printed on 100% post-consumer recycled paper.