

**STRATEGIC ANALYSIS FOR BC HYDRO IN RESPONSE  
TO PLUG-IN HYBRID ELECTRIC VEHICLES**

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**PROJECT SUBMITTED IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR THE DEGREE OF  
MASTER OF BUSINESS ADMINISTRATION**

**In the  
Faculty of Business Administration**

**Andrew Dennis Flostrand & Francis Martin Haran, 2008**

**SIMON FRASER UNIVERSITY**

**Summer 2008**

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## **ABSTRACT**

This project addresses the question of how the adoption of Plug-in Hybrid Electric Vehicles (PHEVs) in British Columbia will impact the demand for electricity from BC Hydro. We develop three adoption scenarios along with an analysis of how each of these scenarios will affect BC Hydro's key performance metrics. We utilize a balanced scorecard to look at the effect of four possible strategies on the impact of PHEVs on BC Hydro's metrics. We find that the best of the four strategies analyzed is one in which BC Hydro adopts a dynamic rates system, which allows their customers to set a buy and a sell price for the electricity used to charge their PHEV battery. As well as adopting a dynamic rates system, the optimum strategy also utilizes reverse metering where the vehicle owner can sell their battery-stored power back to the grid or alternatively uses it to power their home.

**Keywords:** Plug-in Hybrid Electric Vehicle; BC Hydro; Batteries; Reverse Metering; Electricity Rates; Dynamic Metering; Dynamic Rates

**Subject Terms:** B.C. Hydro; Electric Power – British Columbia

## **EXECUTIVE SUMMARY**

Fuel cost and environmental concerns are building a demand for plug-in hybrid electric vehicles (PHEVs), driving advances in battery technologies which have to date been the constricting factor. Despite the concerns over batteries, several major automakers have declared their intention to mass-produce PHEVs for market introduction in late 2010. We have utilized data from the academic literature to construct a model of how PHEVs will impact BC Hydro in the 2010 to 2030 time frame; three market penetration scenarios were developed.

The introduction of PHEV products to the market means that, beginning in 2010, BC Hydro will take on the role of supplying energy for this rapidly increasing segment of the vehicular transportation market. This will significantly impact the residential market in the two areas of total energy demand, and power capacity demand. BC Hydro must accommodate the total energy demand by planning energy supply strategies to meet it over the coming decades. The capacity demand however can be very effectively managed using features provided by the Smart Metering Infrastructure (SMI) planned for implementation in 2012. This would be done by changing the residential rates structure to one that incentivises customers to adjust the timing of their high power draw activities. If through these measures, the power draws for vehicular use can be shifted so that they do not coincide with the existing daily demand peaks, then the currently projected capacity demands will not be significantly affected.

Today's hybrid electric vehicles almost exclusively utilize Nickel Metal Hydride batteries, however the energy density capability of this technology is limited. It is therefore believed that Li-ion technology, with its great energy density potential, will dominate in the future and will most likely be the battery of choice for plug-in hybrid electric vehicles. The Li-ion batteries store electrical energy with very high efficiency, meaning that the energy they are charged with that has not been consumed through driving remains available as a resource which can be drawn back from the PHEV and used for other purposes.

Collectively, all of the PHEVs that hold a charge and are connected to chargers supporting bi-directional energy flow constitute a large virtual battery that is distributed throughout the province. BC Hydro can draw value from this virtual battery in two ways. The first way is as an emergency energy reserve during unexpected distribution interruptions. Our most probable 2020 projection indicates that a community could operate for approximately one hour on this resource while field crews work to restore primary power. The second form of value exists if customers draw energy into their batteries during the valleys of a daily demand cycle, then use the portion of this energy not consumed by driving to run other appliances during the peaks. In this case, the daily capacity demand would actually drop below forecasts that do not include PHEVs.

To avoid unnecessary detrimental impacts and achieve the potential benefits of supplying energy to the future PHEV fleet, BC Hydro must structure incentives for customers to align their charging patterns with the interests of the utility. The most direct method for this is to use the real time monitoring functionality already designed into the SMI in order to charge differential rates based on time of day. This is a policy already

used through much of Europe, where customers have accepted tiered rate structures because gains from efficiencies are shared with them through lower average energy costs. For BC Hydro to access the battery-stored energy as an additional resource, they need to develop a reverse rate policy that creates incentive for customers to; i.) Install grid tie chargers and ii.) Sell their energy when BC Hydro needs it. The optimally efficient form of such a rate structure is a continuous one where the price charged for energy consumed, and the price paid for energy provided, by the customer at any time is linked to the instantaneous marginal cost of supply to the utility. By this model, the customers would be empowered to shape their demand to minimize their costs and maximize the efficiency of the system, while guaranteeing the corporation a fixed margin at all times.

By constructing a balanced scorecard decision framework and calculating impact ranges for the priorities of Reliability, Sustainability, Financial Strength, and Customer Convenience, we have demonstrated that the argument for BC Hydro to seriously investigate development and implementation of the above floating rate structure is very strong. The first stage however would be to target the SMI implementation date of 2012 for the introduction of a two tier (peak and off-peak) tariff policy with the capability for reverse metering during emergency situations. The second stage of advancing to dynamic rates would involve a major change in the economics of electricity distribution and must be studied from the perspective of integrating with other business activities. We recommend beginning exploratory research in this area with an ultimate implementation envisioned for circa 2020.

## **DEDICATION**

### **Frank**

To Faith, Duncan and James, thanks you for your love, support and patience during my two-year absence.

### **Andrew**

To Holly for allowing me to regale her all summer with enthusiastic and incessant chatter about dams and carbon and battery powered cars of the future.

## **ACKNOWLEDGEMENTS**

The authors are grateful to Dr Elicia Maine and Dr Sudheer Gupta for reviewing this thesis. Their valuable input, academic direction and encouragement throughout the process of writing this thesis has made it an enjoyable learning experience. We would also like to extend our thanks to David Ince, Patrice Rother and Mark Dubios-Phillips of BC Hydro for finding time in their busy schedules to answer our questions and teach us about the needs of BC Hydro. It has been their invaluable input that has enabled us to produce a thesis that we hope will contribute to the planning of British Columbia's future energy needs.

## **DISCLAIMER**

This paper was prepared based on publicly available information for the purposes of completing the requirements of the SFU Management of Technology MBA program. The thoughts, analysis and conclusions drawn are those of the authors, and do not represent the opinion of BC Hydro.



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## **GLOSSARY**

ABSU	Accucenture Business Services for Utilities
BC	British Columbia
BCTC	BC Transmission Corporation
BCUC	BC Utilities Commission
BEV	Battery Electric Vehicle
CAIDI	Customer Average Interruption Duration Index
CV	Conventional Vehicle
DSM	Demand Sided Management
EDV	Electric Drive Vehicle
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
IC	Internal Combustion
IPP	Independent Power Provider
LTAP	Long Term Acquisition Plan
NiMH	Nickel Metal Hydride
PHEV	Plug-In Hybrid Electric Vehicle
SMI	Smart Metering Infrastructure
SOC	State of Charge

# 1: INTRODUCTION

Through the period of 2012 to 2020, BC Hydro will face a convergence of three significant factors:

1. The Corporation's triple directive of exemplary performance in financial, environmental, and social impact dimensions.
2. The soon to be mass-marketed plug-in hybrid electric vehicles (PHEVs) and Electric Vehicles (EVs) which will increase grid demand.
3. The upgrade of their distribution and metering infrastructure to a model capable of supporting reverse energy flow and real time communication between the utility company and client end devices.

It is the purpose of this report to analyze the potential impact of PHEVs and the batteries they contain on the demand for electricity from BC Hydro. We develop low, medium and high adoption scenarios for PHEVs. We use a model to estimate what impact these PHEV adoption scenarios will have on the demand for electricity from BC Hydro. The particular timeframe that we concentrate on within this report is between 2012 and 2020. The PHEV impact is identified in the context of the underlying BC electrical power situations that may be present in 2020.

Once we have developed our PHEV scenarios we then present four generalized response strategies that are available to BC Hydro. These response options are:

1. No fundamental change in demand side policies.
2. Simple peak and off-peak rate structure.
3. Peak and off-peak with reverse metering.
4. Reverse metering with dynamic rates.

In the third and fourth strategies, the intrinsic portability of the vehicle's stored energy introduces issues related to the source of the energy they store. The report outlines how this may result in outcomes not aligned with the renewable energy goals of BC Hydro. For instance, such issues would arise if vehicles were charged out of the BC jurisdiction or from non-clean energy sources. This report discusses potential strategies to mitigate such issues.

## **1.1 Introduction to Plug-in Hybrid Electric Vehicles (PHEVs)**

For the past 100 years, the vast majority of vehicular transportation has been powered by petroleum based liquid fuels, i.e. gasoline and diesel. For many years, scientific and environmental groups have been issuing warnings over the concerns they have with the environmental impacts of carbon dioxide emissions from the burning of fossil fuels. However, it has not been until relatively recently that political forces have resulted in governments encouraging “greener” transportation. In parallel with this growing environmental concern, the price of crude oil has sharply increased to unprecedented levels with no foreseeable reasons for a reversal of this trend. Also a number of jurisdictions, including BC, have put into place Pigovian carbon taxes which have further increased the price paid at the pump. The escalating gas prices have created a strong economic incentive for higher fuel efficiency vehicles.



Although there has been a long history of research into fuel-efficient vehicles including pure electric vehicles, it was not until Toyota launched its Prius hybrid electric vehicle that battery-assisted technology made a sustained and successful appearance in the automotive market place. The Prius first made its appearance in North America in 2000 and its sales have risen year-over-year ever since. The batteries in the Prius charge by capturing power from the car during braking; these batteries cannot charge directly from a wall plug and store only enough energy to accelerate or to propel the car for short distances. The fundamental shortcoming of the current generation of hybrid vehicles is that the initial source of energy is entirely liquid fuel. Liquid fuels, on a per unit of usable energy basis, currently cost roughly three times the residential rate for electricity. In order to overcome the short limited range short coming of HEV vehicle and increase the fuel efficiency the electrical capacity of the batteries have to be increased. Therefore, the next logical step to the HEV is one where the larger, higher efficiency batteries can be used and re-charged from the electricity grid, hence making a plug-in hybrid electric vehicle (PHEV). PHEVs will have the ability to drive a certain range on electrical power alone with no tailpipe emissions during this time. PHEVs are classified by the maximum all electric range that can be achieved on one battery charge, for example a PHEV-20 has a 20 mile all electric range whereas a PHEV-60 has a 60 mile all electric range. With the adoption of these PHEV vehicles there will be an obvious extra demand for power from the grid to charge their batteries. The first adoption of these PHEV vehicles is likely to occur in 2010, with future adoption rates then being dependent upon the level of carbon tax, the environmental concerns of consumers and the price of gas. This report develops three scenarios for PHEV adoption within BC, and then presents four possible strategies

that BC Hydro could implement. We use a balanced scorecard analysis to recommend which of these responses BC Hydro should adopt in the case of each scenario.

## **1.2 Corporate Background**

BC Hydro is a provincial Crown corporation with the mandate to generate, purchase, distribute and sell electricity. BC Hydro is regulated by the British Columbia Utilities Commission (BCUC) under the Utilities Commission Act. The BCUC approves the rates charged by BC Hydro. BC Hydro's purpose is to provide low cost power for generations of BC residents. BC Hydro's financial mandate is to maintain a long term revenue-to-cost ratio of 1, meaning that net income after operating costs and capital asset depreciation is targeted to achieve fair returns on equity to the shareholder (Province of BC). Fair returns are defined in the 2007 Annual Report as "calculated to equal, on a pre-income tax basis, that of the most comparable investor-owned utility" which for fiscal 2007 was 13.10%.

## **1.3 Structure of the Report**

The design of this report applies the Framework for Comprehensive Strategy Analysis (Broadman & Vining, 2003). After providing a background to the electrical power industry in BC, we analyse how the demands on the industry are projected to evolve over the next two decades. Chapter 3 then provides an analysis of PHEV technology and its predicted progress in the near future. We then develop a model that predicts the effect of PHEV vehicles on the energy and capacity demands for electricity in BC in the 2020 timeframe through inputs of PHEV market penetration predictions in combination with predicted battery advancements and BC population demographics.

Chapter 4 discusses the electrical distribution models used today and planned for as part of a major smart metering infrastructure (SMI) upgrade scheduled to complete in 2012. This SMI will be a key component in developing a strategy to manage PHEVs that will draw their energy from the BC electrical grid. Chapter 5 provides an internal analysis of BC Hydro and will discuss its power generation and distribution, how it utilizes independent power providers, organizational structure, and short term priorities.

In Chapter 6, we discuss the corporate performance of BC Hydro from the context of its triple-bottom-line. The later half of the report (chapters 7, 8, and 9) provides the report's fulcrum and solutions analysis that outlines four possible strategies that BC Hydro can implement to address the impact of PHEVs on the demand for power from BC Hydro. We then go on to use a balanced scorecard (Kaplan & Norton, 1992) to develop strategic recommendations.

## **2: INDUSTRY ANALYSIS – BC HYDRO AS A PUBLIC UTILITY**

### **2.1 Mandate**

BC Hydro presents their formal mandate on the first page of their 2007 Annual Report (BC Hydro, 2007). It reads as follows:

“BC Hydro’s mandate is to generate, manufacture, distribute and sell power, upgrade its power sites, and to purchase power from, or sell to, a firm or person under the terms of the Hydro and Power Authority Act.

Our company owns the majority of the transmission and distribution systems that deliver electricity in the province. BC Hydro is regulated by the British Columbia Utilities Commission (BCUC), which is responsible for ensuring that BC Hydro operates in the best interests of our customers while providing a fair return to the shareholder, the Province of British Columbia.

BC Hydro’s purpose is: Reliable Power, at Low Cost, for Generations.”

This mandate identifies BC Hydro as being responsible for all stages in the electrical power supply chain, whether directly providing the services or contracting their supply with providers outside of the corporation. This amounts to between 43,000 GWh/year and 54,000 GWh/year of electrical energy with a capacity (maximum power available at any one time) of 11,300 MW. This energy is transported from generation stations by approximately 18,280 km of transmission lines and connected to the customer sites by a further 56,000 km of distribution lines. To supplement their core operations, BC Hydro has developed formal agreements with a range of key business

partners. These partners include Accucenture Business Services for Utilities (ABSU), British Columbia Transmission Corporation (BCTC) and approximately 91 electricity purchase agreements with various Independent Power Producers (IPPs). The 44 purchase agreements which were operational in 2007 provided 1,500 MW of capacity and over 6,041 GWh of energy. The 2007 Long Term Acquisition Plan (LTAP) identified a 2007 Call to Power to acquire 5,000 GWh/year of clean (renewable, non greenhouse gas producing) energy for delivery by 2015 (BC Hydro, 2007).

BC Hydro operates as a functional monopoly in its role as electric power utility to 1.7 million customers throughout the province. The BCUC which regulates BC Hydro's policies is described in the 2007 Annual Report as:

“The BCUC is an independent regulatory agency of the provincial government, operating under and administering the Utilities Commission Act. The BCUC's primary responsibility relative to our industry is the regulation of the energy utilities under its jurisdiction to ensure that the rates charged for energy are fair, just and reasonable, the the shareholders of utilities have a reasonable opportunity to earn a return on their invested capital, and that utility operations provide safe, adequate and secure service to customers.”

The regulatory authority of the BCUC over the rate and tariff policies used by BC Hydro limits their autonomy. Any initiative to modify these policies involves an application for changes being made to the BCUC which then will weigh their merit in light of the priorities and values of the stakeholders before approving or denying the application.

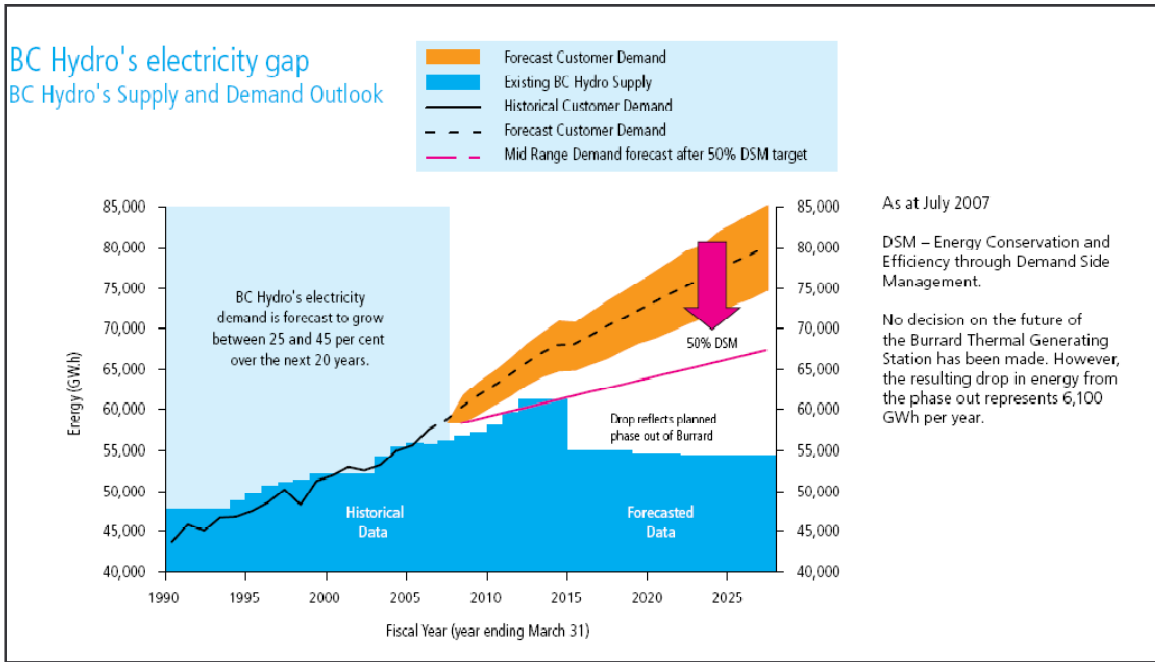
## **2.2 Current and future supply and demand**

BC Hydro is a net importer of electricity with 10 to 15% of demand being met by imports. It has been mandated by the BC government that BC Hydro should become a

net exporter of electricity by 2016. Figure 2-1 shows the historical and forecasted energy supply and demand for BC. It can be seen from examination of Figure 2-1 that historically the BC energy supply has matched demand reasonably well up until the past several years. However, when we examine the forecasted demand it can be seen that, if it continues to grow at its historic rate, then demand will be far in excess of that that can be provided by the current supply infrastructure; this supply and demand gap becomes even more severe in 2015 if the Burrard thermal generating plant closes as planned. In order to close this future energy gap, BC Hydro will have to address the issue from both the demand and supply sides.

On the demand side, BC Hydro is taking a demand sided management (DSM) approach which will principally be managed by Power Smart. On the supply side, BC Hydro will have to increase its power generation infrastructure via possible projects such as developing site C on the Peace River, purchasing power from independent power providers (IPPs) or possible implementation of net metering strategies.

**Figure 2-1: BC's yearly energy requirements to 2030 (BC Hydro, Feb 19 2008).**



### 2.2.1 Demand Side Management (DSM)

Power Smart has the goal of incentivizing BC Hydro's customers (both residential and commercial) to implement efficiencies that otherwise would not be implemented.

Some examples of the Power Smart incentive schemes include:

#### Residential Incentives:

- Fridge buy back. A scheme to encourage home owners to give up their spare fridge/s.
- Compact fluorescent light program. Information and advice promoting the adoption of compact fluorescent bulbs over incandescent bulbs.
- Coupons and rebates for such energy saving devices as wall mounted clothes dryers and energy efficient thermostats.

#### Commercial Incentives:

- Energy saving studies on schools, universities, colleges, etc.
- High performance building program. Works with commercial building owners and developers to implement and incentivize the best energy saving practices.

There are three additional DSM strategies. First, BC Hydro plans to deploy a smart metering infrastructure in over 1.7 million residential and commercial facilities by 2012. The SMI will transmit energy usage data to both BC Hydro and the user. The user will have a display that will show their energy usage data in a form that can be easily interpreted. This increased visibility will educate power consumers on how the energy they purchase is used with the hope that this will result in them reducing their energy usage. This smart metering can also be part of the strategy used to manage PHEVs and will be discussed in section 4.2. Second, rate structures can be used to displace load demand from peak times to off-peak times: this has the benefit of flattening the demand curve throughout the day. Again, some sort of variable rate structure can be used to manage PHEV usage and this will be discussed in Section 8.2. Currently BC has a flat rate structure. Lastly, BC Hydro plans to increase the portfolio of Power Smart programs.

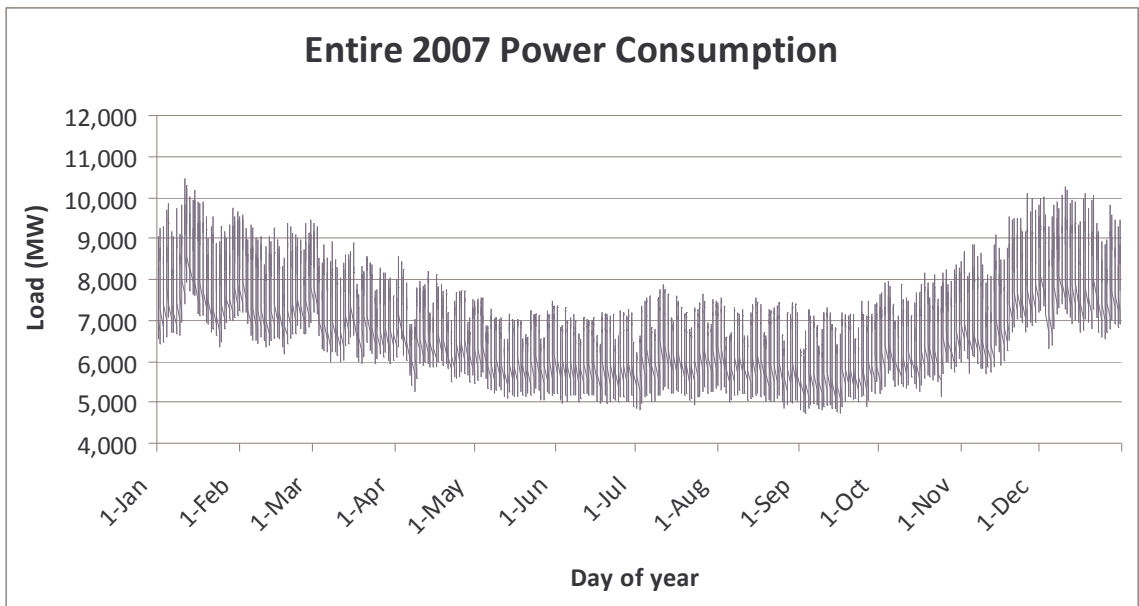
Figure 2-1 shows the reduction in energy demand that BC Hydro expects to obtain from all of its DSM strategies. For example it can be seen from Figure 2-1 that, in 2020, the mid-range customer demand forecast is 74,000 GWh. With DSM, the energy requirement in 2020 will be reduced by 10,000 GWh or 13.5% to 64,000 GWh.

Probably of more importance from the perspective of PHEVs is the peak capacity demand on power from BC Hydro. Capacity demand is at its highest in BC during the



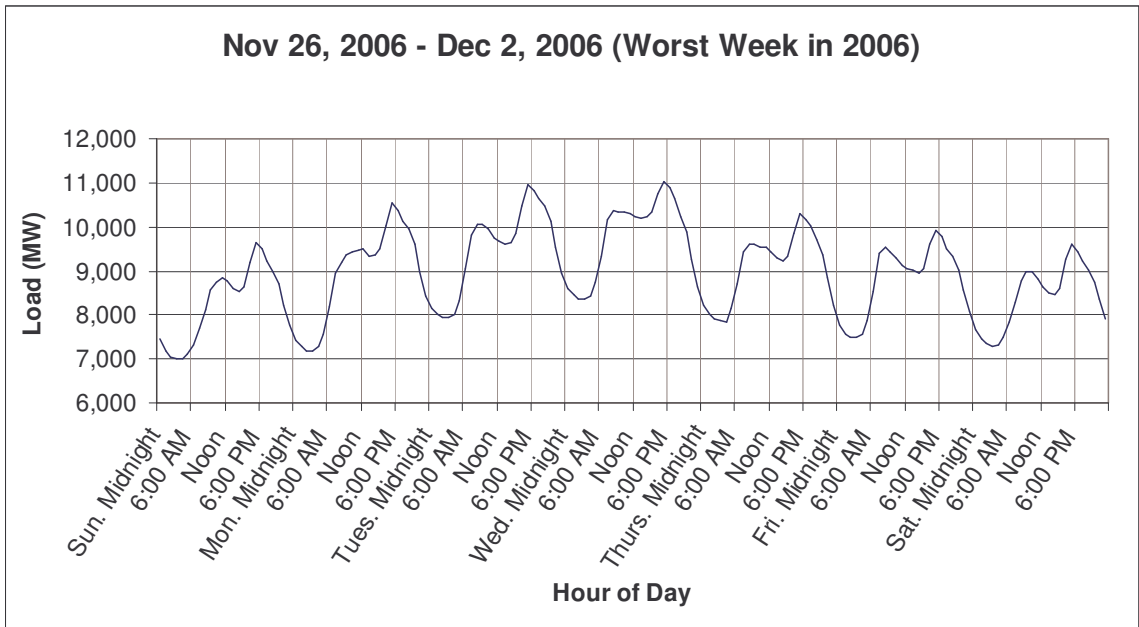
cold winter months. We have graphed the capacity data that is tracked and readily available from the BC Transmission Corporation (BCTC) web site (BC Transmission Corporation, 2008). By examination of Figure 2-2, it can be seen that the maximum power demand in BC occurs during the cold winter months from mid-November to mid-February.

**Figure 2-2: The 2007 annual cycle power demand in BC (created by authors).**



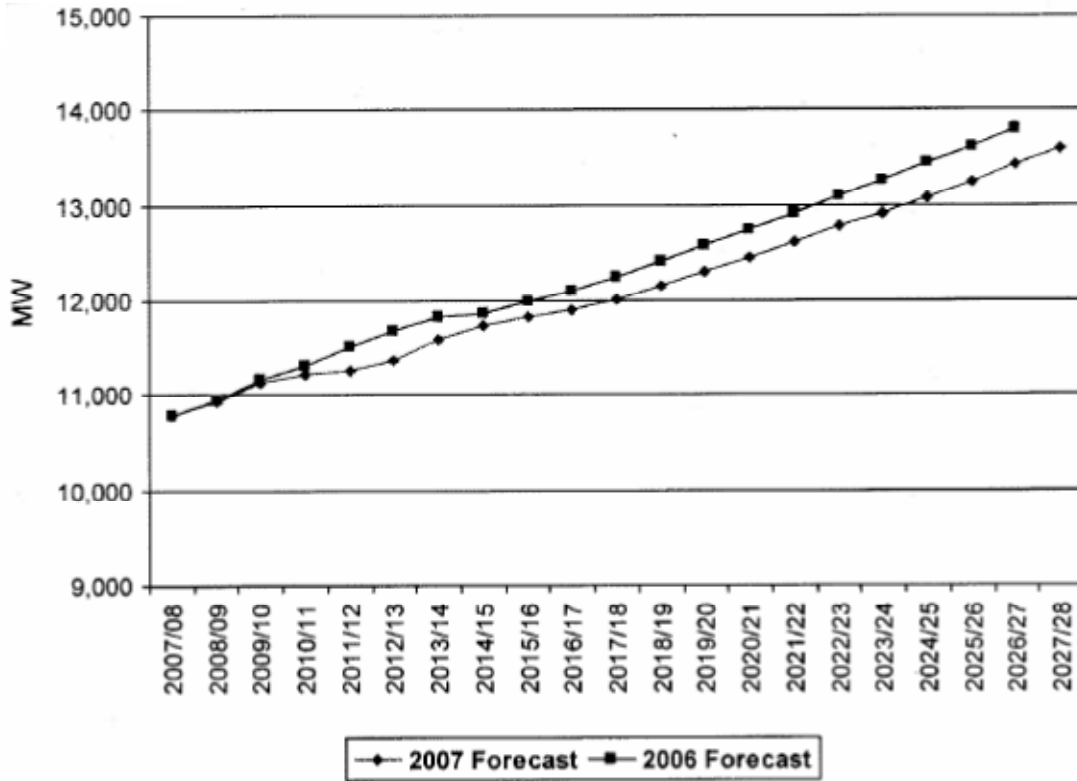
The BCTC web site contains historical power demand data from April 2001 to the present. We analyzed all historical power demand data on the BCTC web site and discovered that the highest demand occurred in 2006 in the week beginning Monday the 26<sup>th</sup> of November, the load demand for this week is shown in Figure 2-3. The peak load during this week was 11,039 MW which is only 261 MW or 2.3% short of BC Hydro's maximum capacity of 11,300 MW.

**Figure 2-3: Daily load demand for the week containing the highest load between the period of April 2001 to present (created by authors).**



Since we are interested in the effect of PHEVs on future peak demand, it is interesting to present the data in Figure 2-4 (Ince, 2008). It can be seen from Figure 2-4 that the forecasted peak demand before DSM in 2020 will be approximately 12,300 GW which is 1,000 GW greater than the current peak capacity available from BC Hydro. The forecast shown in Figure 2-4 is based on the projected growth of BC's population without implementation of demand sided management and without PHEV adoption.

Figure 2-4: Total integrated peak demand requirements before DSM (Ince, 2008).



### 2.3 The Dynamics of the Power Industry in BC

The power industry in BC and the world is currently very dynamic. There are a number of reasons for this including: 1. concerns over global warming, 2. environmental sustainability concerns, and 3. escalating oil prices. The British Columbia provincial government has clearly stated (BC Ministry of Energy, Mines and Petroleum Resources, 2008) that they are mandating the province to be entirely energy self sufficient by the year 2016. All new energy generation plants constructed to meet this target must be carbon neutral.

The BC government’s bill 44, which passed into law on November 29, 2007, requires that all Crown corporations (including BC Hydro) have to be carbon neutral by

2010. Since BC hydro obtains over 90% for its power from hydroelectricity then this may not be a difficult target to meet. However, a further requirement of the same act is that BC as a whole reduces its GHG emissions by 33% of 2007 levels by 2020 and by 80% of 2007 levels by 2050. In order to accomplish this, the province may want to rely more on the GHG free emission of Hydro electricity. For example, heating in BC is mainly natural gas based and a switch to electrical baseboard heating would therefore reduce the GHG emissions but increase the energy demand on BC Hydro.

### **3: EXTERNAL ANALYSIS OF PHEVS**

#### **3.1 What is a PHEV?**

**3.2 HEV's are regular gasoline vehicles that have battery packs installed to enhance gas mileage. They achieve enhanced gas mileage by using the batteries to capture energy that would otherwise be wasted to heat energy during the braking of the car. The batteries also charge directly from the internal combustion engine. A HEV vehicle can also have its gasoline engine switched off while stopped or while going down hill: this can be done without detriment to the gasoline engine's lifetime or efficiency because of the electric engine that is powered by the batteries.**

A plug-in hybrid electric vehicle (PHEV) is a type of hybrid electric vehicle (HEV). Both of them contain components of an electric vehicle (EV). In order to define PHEVs and to put them in context, it is worthwhile to first define and provide an overview of HEVs.

HEV's began to obtain a foothold in the North American automotive market with Toyota's introduction of the Prius. The Prius was first introduced to the US in August 2000. In Toyota's first full year of sales (2001) in the US, Toyota sold 15,556 vehicles (Dawson, 2004). The cumulative sales of the Toyota Prius vehicles in the US were approximately 540,000 by the end of 2007, and approximately 900,000 worldwide (Schreffler, 2008). We believe that there are two main reasons for this explosive growth: 1. increasing gas prices, and 2. more environmentally aware consumers.

As of January 2007, fifteen hybrid models were available across North America, Europe and Asia. In 2006, 0.7% of world car sales were HEV's (350,000) – 60% of

these sales were in the US, accounting for 1.3% of US new car sales (Anderman, 2007). One of the main reasons for the acceptance of HEV's is that even if the batteries run out the car is not stranded because of the presence of the gasoline engine.

A PHEV is the next logical evolutionary step for the HEVs. A PHEV will have larger batteries, which will be charged by plugging them into the electricity grid. Therefore, unlike a HEV, this means that the batteries can now be charged with electricity that has been derived from an energy source other than gasoline. Thus, if the grid's electricity is generated from a clean source of energy such as hydro (as is the case in BC), then the power in these batteries could potentially be emissions free. If the grid obtains its power from "dirty" sources such as coal without carbon sequestration or smoke stack filters, then the environmental impact could be higher than gasoline charging. PHEVs with 20 and 40 mile battery ranges have been reported to have the potential to reduce a HEV's gasoline consumption by one-third and two-thirds respectively (Kliesch, 2006).

Currently, there are no PHEVs commercially available, but a number of automotive manufacturers have announced their intention to release a PHEV in the near future. Maybe the most well known concept PHEV at the current time is GM's Chevy Volt. Although no official launch date has been given for this vehicle, Chevrolet's web site (Chevrolet, 2008) states that the company has a large development team working towards a date at the end of 2010. The current major concerns regarding the release of these vehicles are the cost, lifetime and safety of the batteries to be used.

A measure of consumer demand for PHEVs is the fact that a number of companies are offering plug-in conversion kits for the Toyota Prius (Wikipedia, 2008).

These companies are most certainly filling a niche consumer market. Toyota is currently working on PHEV research but, as of yet they have still to announce when and if they will offer a PHEV vehicle in the future.

### **3.3 Battery technology**

Currently, the vast majority of HEV batteries are based on nickel metal hydride (NiMH) technology. Although NiMH is currently the most prevalent battery technology on the market, it is widely believed that the higher energy density and lower potential cost of Li-Ion batteries will displace NiMH in the time frame in which PHEV will gain significant market penetration (Anderman, 2007). The worldwide market for NiMH HEV batteries is currently \$600M per annum. In order to obtain the required lifetime (minimum of ten years), these batteries only use 10% of their rated capacity on a regular basis – an additional 30% can be used in extreme operating conditions. In other words, the HEV battery typically holds a mean charge of  $50\pm 5\%$  in normal operating conditions. On the other hand, EV batteries have a requirement to be fully re-charged when the vehicle is not in use (typically at night) and then be fully discharged during operation (typically during the day).

The requirements on PHEV batteries are different from either that of HEV or EV batteries in that they have to operate from a fully charged state and operate in a charge depletion mode (just like a EV) until they reach some threshold low state of charge at which time they are then switched over to a “charge-sustaining” mode where they operate like a HEV battery. This mode of battery operation optimizes the lifetime of the battery while still providing a significant electric only range. The main technological hurdle facing the mass production of PHEV vehicles is the very demanding requirements on the

vehicle's batteries. The specific battery technology attributes explored in the following sections are: 1. cost, 2. lifetime or durability, and 3. safety.

### 3.3.1 Cost

Table 3-1 is taken from Kliesch, 2006 and summarizes the energy storage requirements and costs for HEV and PHEV in the near and long-term. The definition of long-term used in Table 3-1 is the period in which the volumes reach the hundreds of thousands per year. These long-term costs also assume that production is in low cost centres such as China. The numbers given in Table 3-1 are in approximate agreement with those given by Dr Menachem Anderman before the US Senate Energy committee on January 30, 2007 (Anderman, 2007). It is also worth noting that some experts argue that, in order to obtain the battery lifetime of 10 years, energy storage has to be increased by a factor of 1.5 to 2, increasing the storage capacity of the 20 mi PHEV to 9 to 16 kWh and also increasing the costs respectively.

**Table 3-1: Battery energy storage requirements and cost for hybrid and plug-ins using NiMH batteries (Kliesch, 2006).**

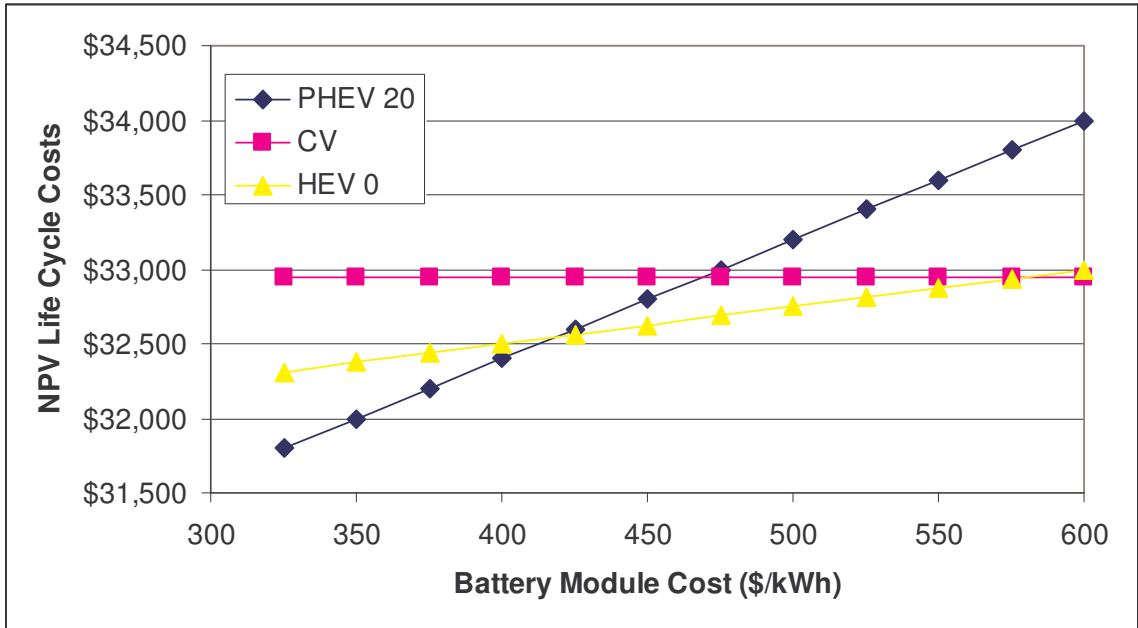
Type of Vehicle	Energy Storage (kWh)	Current Cost (\$/kWh)	Long-Term Cost (\$/kWh)	Current Cost per Vehicle (\$)	Long-Term Cost per Vehicle (\$)
Hybrid	1-2	2,000	400 <sup>#</sup>	2,000-4,000	400-800
20-mi range PHEV	6-8	1,600	320 <sup>#</sup>	9,600-12,800	1,920-2,560
60-mi range PHEV	18-21	1,400	270	25,200-29,400	4,860-5,670

<sup>#</sup> These prices should be achievable with volumes of 100,000/year (EPRI, 2004)

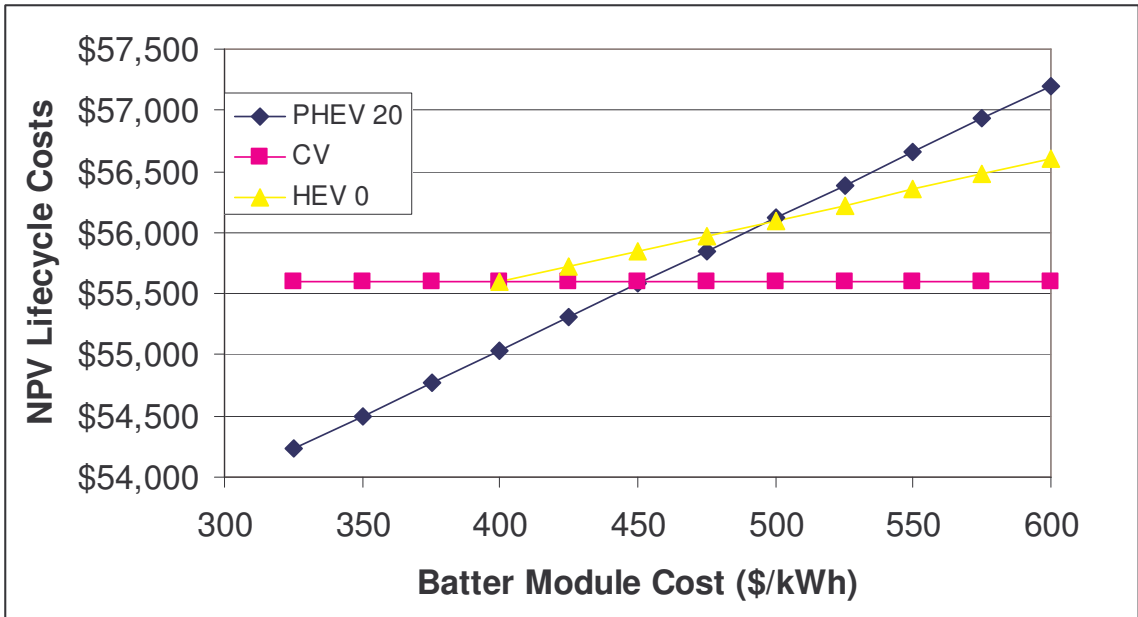


There is much disagreement in the literature on the precise battery cost requirements for PHEV's to become economically viable. The reasons for these disagreements include uncertainty on the future gas price, component costs of electric drive train parts such as electric motor and controller, reduced maintenance costs of PHEV, etc. For example, an early report by Anderman in 2000 (Anderman, 2000) concluded that a battery cost of \$235/kWh would need to be achieved to make PHEVs commercially viable. As time progressed, HEV vehicles achieved greater market penetration than expected and gas prices increased more than expected, so the breakeven battery costs for PHEV's increased. Figure 3-1 and Figure 3-2 shows results from a later report (EPRI, 2004) that gives the breakeven life cycle costs for batteries in HEVs and PHEV-20 vehicles. From Figure 3-1 it can be seen that life cycle cost parity with the conventional vehicle equivalent is achieved at \$471/kWh for a PHEV-20 mid-size vehicle and at \$455/kWh for a PHEV-20 full-size SUV. These numbers were achieved at relatively modest annual production volumes of 50,000 vehicles and a lifecycle time of 10 years. The report used a gas price of \$1.75/US gallon in their calculations, but today we are at a gas price close to \$4/US gallon. Although we do not have access to the model used by the authors, it is very likely that the recent unprecedented rise in gas price will have a significant impact on the breakeven calculation. It is also important to note that none of the cost models took into account the cost recovery that will be made possible with the contract that may be set-up with the power providers to enable demand flattening. In addition, government subsidies for reduced emission via a lump sum at purchase or via reduced carbon taxes were not taken into account.

**Figure 3-1:** Life cycle cost versus battery module cost for mid-size car (10-year, 150 mile case) (EPRI, 2004).



**Figure 3-2:** Life cycle cost versus battery module cost for SUV (10-year, 150 mile case) (EPRI, 2004).



Although NiMH batteries are the dominate technology utilized within current HEV vehicles, it is widely believed that the battery technology of the future will be Lithium-ion (Li-ion). This is because the energy per unit volume (and mass) of these batteries is predicted to be greater than those of NiMH; this is born out by the approximate worldwide R&D on Li-ion battery technology approaching \$1Billion. However Li-ion technology is still more expensive than NiMH. Li-ion batteries for vehicular transportation are currently more expensive than the NiMH equivalents. However the broad adoption of these batteries in consumer electronics as well as the increased volumes expected from PHEVs are expected to bring their cost to parity or better than the current NiMH batteries (Anderman, 2007).

### **3.3.2 Lifetime**

For the purposes of this report, the lifetime of a vehicle is defined as 100,000 miles or 10 years. As was the case with battery cost (discussed section 3.3.1), the early estimates turned out with hindsight to be pessimistic - as time progressed the real lifetime data started to show better than expected results. For example, a working group in 2000 (Anderman, 2000) estimated that NiMH battery packs could achieve 75,000 miles or six years of life, and that this would result in the EDV (electric drive vehicles) requiring two battery packs for the life of the vehicle. However, 4 years later, a report by EPRI showed that battery life was significantly better than expected. It can be seen from Table 3-2 that these new results show that NiMH battery packs had sufficient longevity to last for the entire life of an average vehicle.

Currently there is little information available on the achieved lifetime from Li-ion batteries because of the inherent time it take to build up statistically significant lifetime

data. However it is widely believed that Li-ion technology will eventually supplant NiMH batteries once issues such as heat management in the batteries is addressed (Anderman, 2007).

**Table 3-2: Estimated miles on NiMH batteries for various EDVs (EPRI, 2004).**

<b>Vehicle</b>	<b>BEV miles<sup>a</sup> from off-board electricity on original pack</b>	<b>Additional engine miles<sup>a</sup> on original pack</b>	<b>Total miles<sup>a</sup> on original pack</b>	<b>Battery size (kWh)</b>
Mid-size PHEV 20	33,000 (with 80% cycles) – 66,000 (with 60% cycles)	About 100,000	130,000 – 150,000	5.9 – 8.0
Mid-size PHEV 60	100,000 (with 80% cycles) – 130,000 (with 70% cycles)	About 100,000	200,000 – 230,000	17.9 – 20.5
BEV 40 city car	75,000 (with 80% cycles) – 100,000 <sup>b</sup> (with 70% cycles)	None	88,000 – 110,000	9.1
Mid-size BEV <sup>c</sup>	130,000 – 150,000 <sup>d</sup>	None	About 150,000	27.0
Mid-size HEV 0	None	130,000 – 150,000 <sup>e</sup>	130,000 – 150,000	2.9

<sup>a</sup> Real world miles using a discount factor of 0.85

<sup>b</sup> 70% deep cycles (e.g. from 90% to 20% state of charge)

<sup>c</sup> For example Toyota RAV4 EV with 80-95 mile range per charge using 80% cycles

<sup>d</sup> ARB staff estimated only 74,300 miles on the first NiMH pack for a near-term BEV in their August 2000 report (California Environmental Protection Agency, 2000) Vehicle 3 ARB life-cycle cost model

<sup>e</sup> Compared to (EPRI, 2002) where Vehicle 22's first battery lasted 117,000 miles

### **3.4 Market penetration of PHEVs and EVs**

Predicting the market penetration for PHEV and EV vehicles in 10 or 20 years with any accuracy is very difficult. Many of the technological barriers are being overcome, driven by factors including rising oil prices, the need for the US to reduce

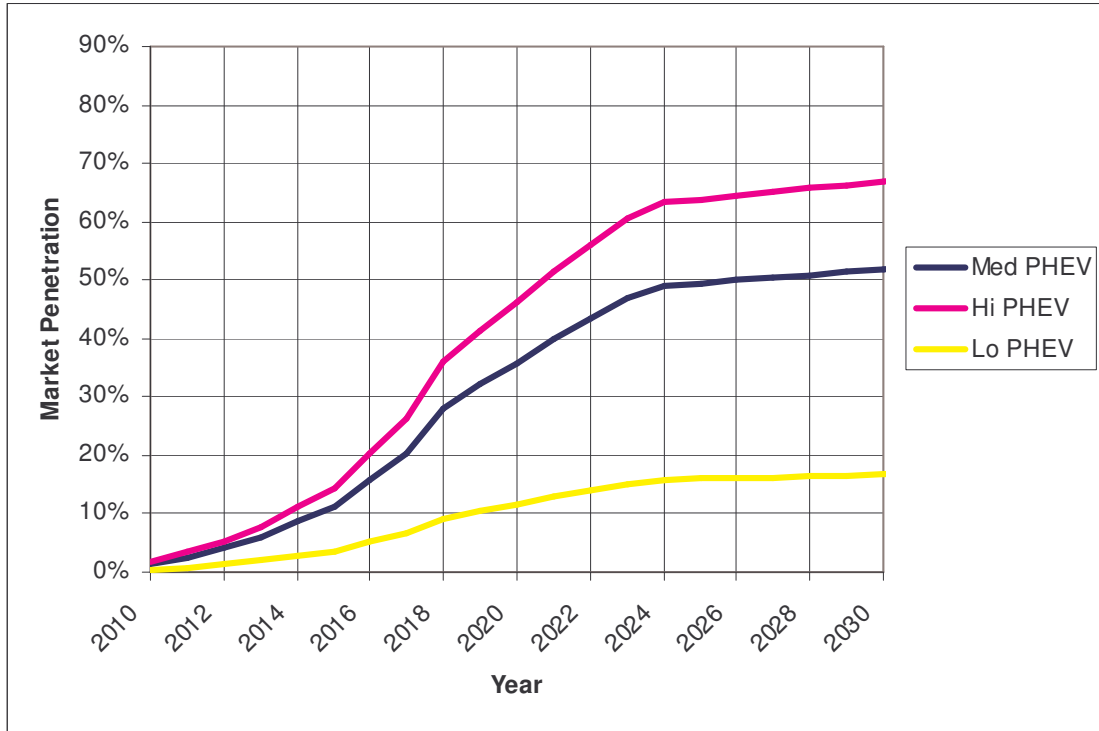
reliance on foreign oil, and the growing concern in developed nations over the effects of tailpipe emissions on global warming and air quality. To address the uncertainty in predicting future market penetration of electric drive vehicles (EDVs), we develop low, medium and high market penetration scenarios of PHEV adoption in BC. We use the same low, medium and high market penetrations as were used in EPRI, 2007. Table 3-3 and Figure 3-3 summarize the predicted market penetrations corresponding to the low, medium and high scenarios presented in EPRI, 2007. Table 3-3 presents the scenarios in 2030, while Figure 3-3 depicts the predicted PHEV fleet penetration from 2010 to 2030.

**Table 3-3: Market penetration scenarios from EPRI, 2007.**

**Peak new vehicle market share in 2050 for the three PHEV adoption scenarios**

2050 New Vehicle Market Share by Scenario		Vehicle Type		
		Conventional	Hybrid	Plug-In Hybrid
<b>PHEV Fleet Penetration Scenario</b>	Low PHEV Fleet Penetration	56%	24%	20%
	Medium PHEV Fleet Penetration	14%	24%	62%
	High PHEV Fleet Penetration	5%	15%	80%

**Figure 3-3: Low, medium and high PHEV market penetration in the 2010-2030 timeframe (adapted from EPRI, 2007).**



These market penetration scenarios were used in conjunction with the demographic of BC to predict the energy storage/need of the batteries in EDV over time. Table 3-4 summarizes the input parameters to our model to predict the size of the virtual battery available to the BC Hydro grid. The average PHEV battery storage in a car (in 2020) was obtained by assuming that, because of current size and cost restrictions, the first PHEVs to come to market in 2010 will be PHEV-20's with a battery size of 8 kWh (see Table 3-1 and Table 3-2). However with advances in R&D, larger capacity and more cost effective batteries will become available making PHEV-40 vehicles the average vehicle on the road in 2020. The battery size of the PHEV-40 will be around 13 kWh. We have therefore chosen the PHEV-40 vehicle with a battery size of 13 kWh for our analysis. A plugged-in to grid fraction of 90% was assumed, since we believe that by 2020 a smart metering structure with roaming capabilities will be in place

throughout BC. Also, Tomic states that – “The average personal vehicle in the US is on the road 4-5% of the day. Prior analysis estimates that at least 90% of vehicles are parked even during peak hours” (Tomic, 2007). Finally, the percentage of battery storage available to the grid of 80% was assumed because batteries have a reduced lifetime if they are run down to zero energy and therefore it was assumed that a lower limit would be set to conserve battery life.

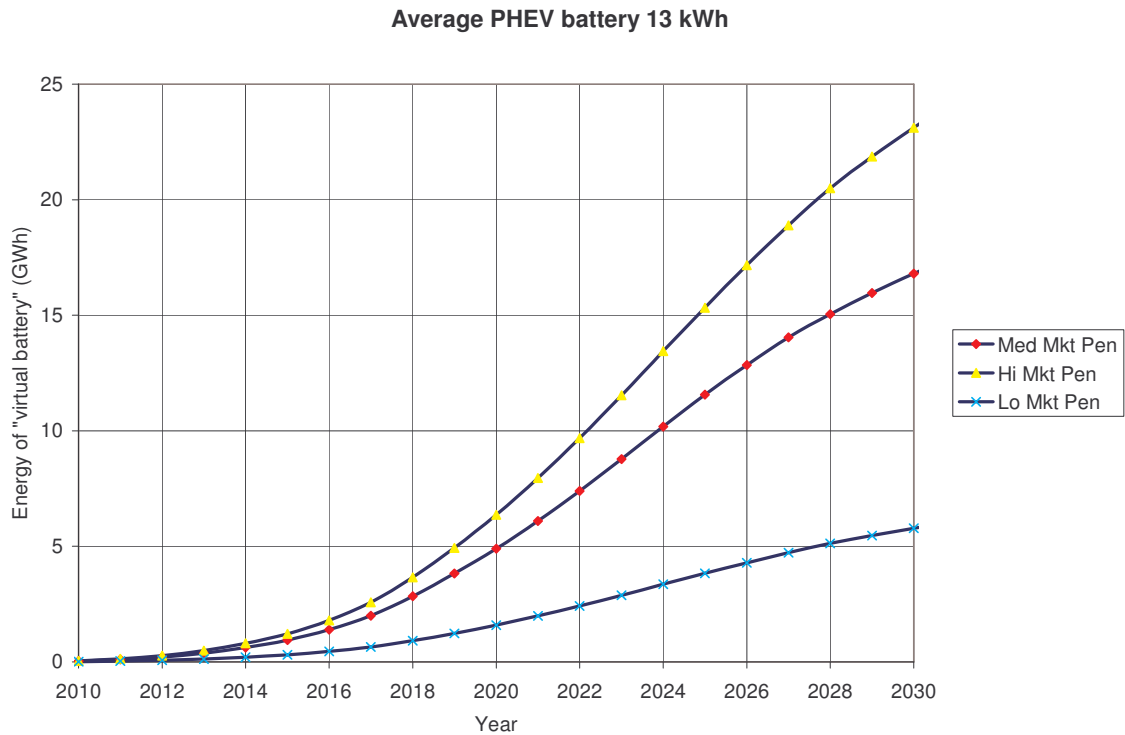
**Table 3-4: Summary of virtual battery model input parameters (created by authors).**

<b>Parameter</b>	<b>Value</b>
Population of BC (2007)	4.35 Million
BC Population Growth	1.9%
Number of vehicles per person	0.6
Average lifetime of vehicle	10 years
Average PHEV battery energy storage (in 2020)	13 kWh
Percentage of plugged-in vehicles connected to the grid at anyone time	90%
Percentage of battery storage capacity available to the grid or home	80%

Figure 3-4 shows the results from our model for the total PHEV battery energy storage available to the electrical grid from 2010 to 2030 for the scenarios outlined in EPRI, 2007. From Figure 3-4 it can be seen that BC’s virtual battery in 2020 will be between 1.6 and 6.4 GWh. If this virtual battery were fully cycled (80%) every day then the yearly energy would be 584 to 2,336 GWh/year. It can be seen from Figure 2-1 that the energy requirement in 2020 in BC will somewhere between 64 TWh and 76 TWh, if we assume the 50% demand sided management (DSM) saving is attained. Under these

assumptions, the PHEV energy capacity represents 1 to 3.6% of the total energy requirement in BC by 2020.

**Figure 3-4: Size of virtual battery present on BC's electrical grid in the 2010-2030 time period for the 3 market penetration scenarios outlined in EPRI, 2007 (created by authors).**



### 3.5 Battery charging characteristics

The charging characteristics of the batteries are important when trying to ascertain the effect they will have on the load demand to the grid - especially at peak times.

Knowing the extra demand is important because it determines how much extra capacity will be demanded from BC Hydro's power generation and distribution facilities. If this capacity cannot be met then it could result in power cuts or the excess demand having to be met by importing energy from outside the province. If energy has to be imported then



BC Hydro could miss their goal of energy self-sufficiency by 2016. The duration of the load drain is dependent upon the energy storage capacity of the battery and its state of charge (SOC) at plug-in time. The amplitude of the power demand is dependent upon the circuit's voltage and current rating. Hadley (Hadley, 2006) has outlined the load for each of the likely circuit voltage and current scenarios. These scenarios are summarized in Table 3-5.

**Table 3-5: Circuit load dependence upon circuit voltage and current (created by authors).**

<b>Scenario</b>	<b>Voltage (Volts)</b>	<b>Current (Amperes)t</b>	<b>Load (kW)</b>
Low Power	120	15	1.4
Medium Power	120	20	2
High Power	208/240	30	6

Hadley (Hadley, 2006) also presented data for the average charging time for various PHEV-20 vehicles as well as their temporal power requirements from plug-in time. Hadley's data is reproduced in Table 3-6 and Table 3-7. Charging time varies from a low of 3.9 hours for the shortest time to charge a compact sedan to a high of 8.2 hours for the maximum time to charge a full-size SUV. It can be seen from examination of Table 3-6 and Table 3-7 that the kilowatt-hour demand in Table 3-7 is greater than the battery pack sizes shown in Table 3-6. No reason is given in the reference for this, but it is assumed that this difference is due the charging process having a 10 – 20% efficiency loss.

Table 3-6: Charging requirements for PHEV-20 vehicles (Hadley, 2006).

PHEV 20 Vehicle	Pack Size	Charger Circuit	Charging Time 20% SOC
Compact Sedan	5.1 kWh	120 VAC / 15 A	3.9 – 5.4 hrs
Mid-size Sedan	5.9 kWh	120 VAC / 15 A	4.4 – 5.9 hrs
Mid-size SUV	7.7 kWh	120 VAC / 15 A	5.4 – 7.1 hrs
Full-size SUV	9.3 kWh	120 VAC / 15 A	6.3 – 8.2 hrs

*1.2 – 1.4 kW power, 1 or 2 hours conditioning*

Table 3-7: Power requirements by hour for PHEV-20 vehicles at 120 V / 15 A (Hadley, 2006).

Hour	1	2	3	4	5	6	7	8	kWh Demand
Compact Sedan	1.4	1.4	1.4	1.4	0.91	0	0	0	6.51
Mid-size Sedan	1.4	1.4	1.4	1.4	1.4	0.21	0	0	7.21
Mid-size SUV	1.4	1.4	1.4	1.4	1.4	1.4	0.35	0	8.75
Full-size SUV	1.4	1.4	1.4	1.4	1.4	1.4	1.4	0.35	10.15

Figure 3-5 shows the calculated hourly demand due to our average vehicle 13 kWh capacity in 2020. From Figure 3-5 it can be seen that if a high power circuit was available to charge the PHEV then it would take approximately 2 hours to fully charge a depleted 13 kWh PHEV battery. Obviously, if this high power circuit charging were available to all PHEVs, then the power draw on the grid would be far higher than would be necessary if the PHEVs were charged using the lower power circuits. It would take approximately 6 to 8 hours to charge a depleted 13 kWh PHEV battery using a low power circuit.

**Figure 3-5: Hourly demand for average 2020 battery with 20% SOC at initial plug-in ( $0.8 \times 13 \text{ kWh} = 11.56 \text{ kWh}$ ) (created by authors).**

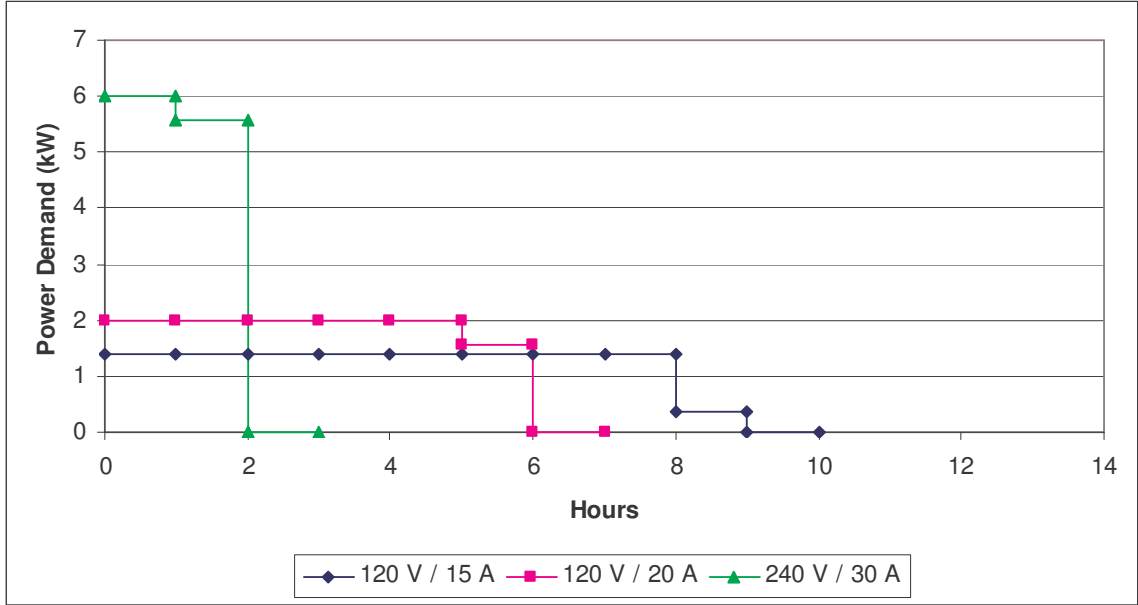


Figure 3-6, Figure 3-7 and Figure 3-8 show the total hourly system demand in 2020 for our 3 market penetration scenarios. These figures are all built on the worst possible case where all vehicles are plugged in simultaneously and they are all at a 20% SOC. To put the capacity numbers in the graphs into perspective, the current combined capacity of BC in 2007 is approximately 11.3 GW. Table 3-8 summarizes the maximum increase over 2007 capacity that would be required to charge the PHEV vehicles in BC in 2020. It can be seen from Table 3-8 that if high power circuit charging was allowed (240 V / 30 A) then the grid would be extremely taxed and capacity would have to be significantly increased. It can therefore be concluded that that BC Hydro is likely wanting to prohibit mass charging of PHEVs using high power circuitry and in all likelihood they may want to either limit PHEV users to low power circuitry or ensure that

the plug-in time is spread out throughout the day. Another alternative is to utilize power regulation within the SMI.

Figure 3-6: 2020 total BC hourly system demand for a 20% SOC 13 kWh average battery in the low market penetration scenario (created by authors).

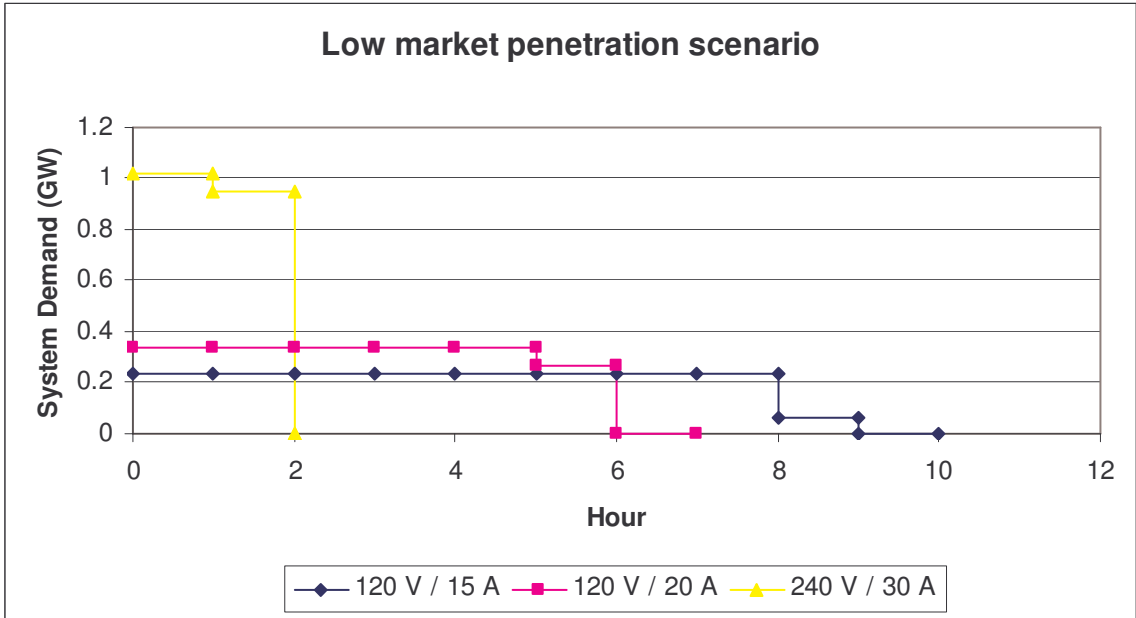
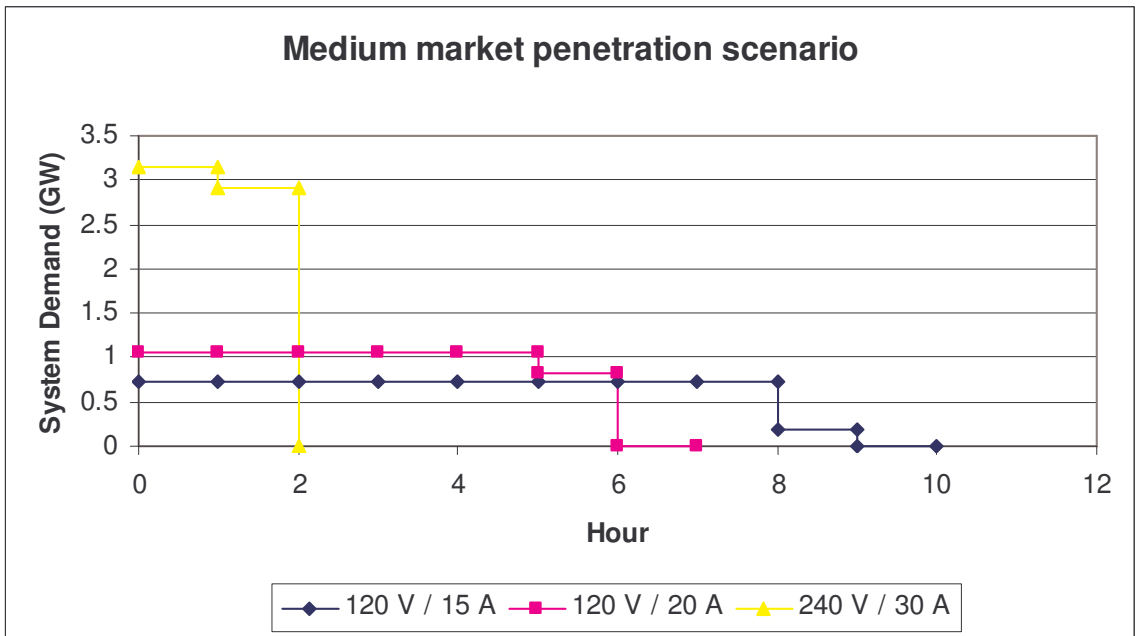
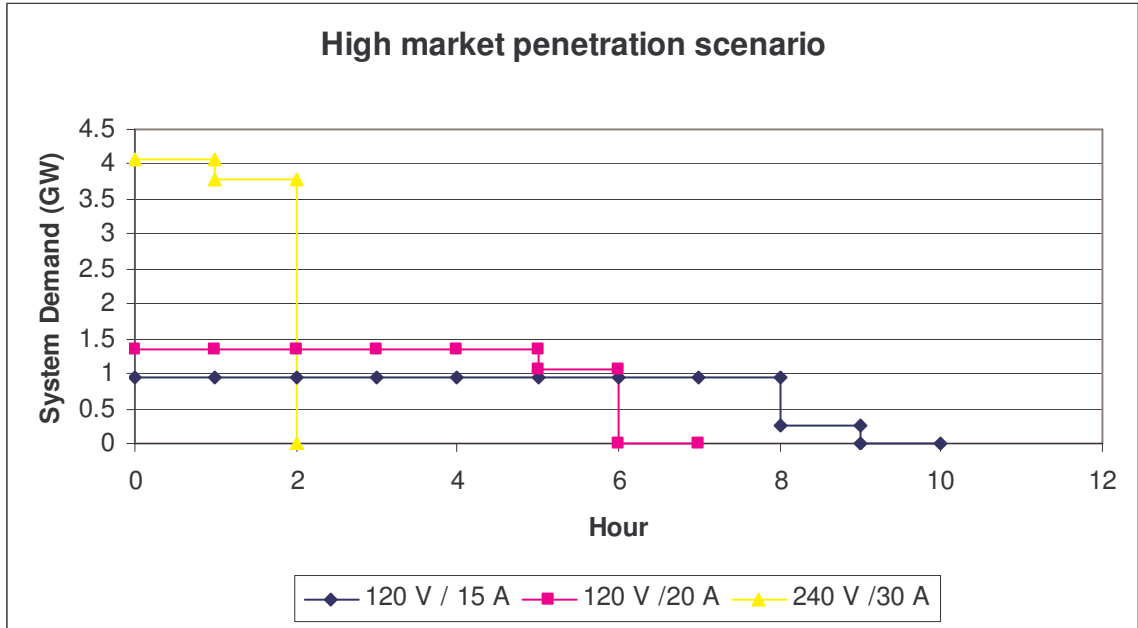


Figure 3-7: 2020 total BC hourly system demand for a 20% SOC 13 kWh average battery in the medium market penetration scenario (created by authors).



**Figure 3-8: 2020 total BC hourly system demand for a 20% SOC 13 kWh average battery in the high market penetration scenario (created by authors).**



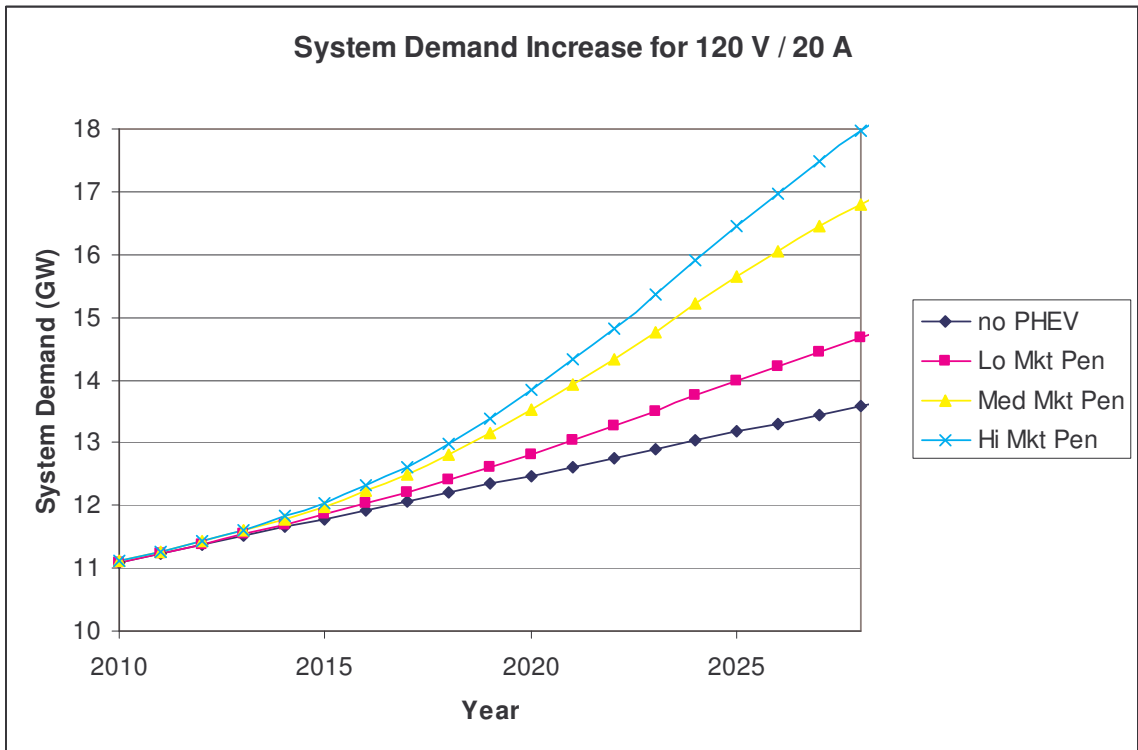
**Table 3-8: Maximum increase to capacity due to PHEVs over 2007 capacity (table created by authors).**

Market Penetration Scenario	Circuit Power Increase		
	Low (120 V / 15 A)	Medium (120 V / 20 A)	High (240 V / 30 A)
Low	2.1%	3.0%	9.0%
Medium	6.5%	9.3%	28%
High	8.4%	12%	36%

Figure 3-9 shows how the three market penetration scenarios impact the peak capacity requirement over the 2010 to 2030 time frame. In this case, we assume that all PHEVs are plugged in and drawing power. It can be seen from Figure 3-9 that this has a very significant impact on peak demand, especially as we look at longer time horizons. One method of lessening the impact of PHEVs on the peak demand is to ensure that

PHEVs are plugged in during off peak hours, which will require BC Hydro to incentivize their customers to do so: strategies for achieving this are outlined in section 8.2.

**Figure 3-9: Effect of PHEV uptake on the integrated peak demand requirement before DSM for the 3 market penetration scenarios with medium power circuitry (created by authors).**



### 3.6 Timing of plug-in

The impact that PHEVs will have on BC Hydro will be very much dependent upon the habits of vehicle owners as well as the measures put in place by BC Hydro to manage the re-charge timing. If the decision is left to PHEV owners when to plug-in to the grid and nothing is done to control the power demand timing, then, in all likelihood, the PHEV demand would occur at peak time around 6 or 7 pm at night. PHEV owners would plug-in when it is most convenient for them, which, on average, would be when they return from work in the evening. BC Hydro would prefer for the battery re-charging

to occur at off-peak times - from 11 pm to 6 am. In-order for this to occur, the consumer has to be either forced or incentivized to do so. The consumer could be forced by including intelligence in either the vehicle or the wall plug providing the power to allow the PHEV battery to charge only at the preferred time. Consumers could be provided monetary incentives if BC Hydro could introduce a variable rate where the car owner would get cheaper power at 11 pm than at 6 pm. A further incentive for consumers could be to allow them to use the energy purchased at a low off-peak rate and stored in their PHEV at peak times in their home. The details of these strategies are discussed in Section 8.2.



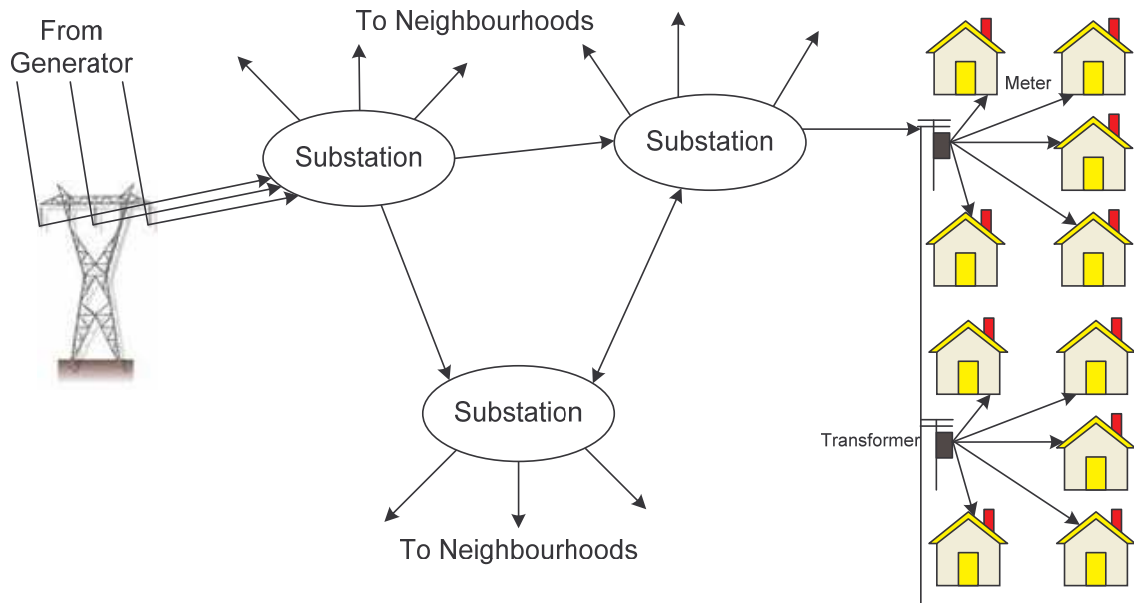
## **4: UTILITY DISTRIBUTION GRIDS**

Since the introduction of centralized electrical utilities nearly a century ago, the fundamental elements and structural design of distribution networks have been unchanged. BC Hydro is currently in the process of evaluating competitive bids for a major Smart Metering Infrastructure (SMI) initiative (BC Hydro, 2007) which will facilitate new flexibility and monitoring features. This project is planned for implementation to be completed in 2012 with pilot projects already underway.

### **4.1 Existing Infrastructure**

The standard interconnected distribution design is a variation of the hub and spoke model where power first arrives by high voltage transmission lines at transformer substations, then is fed at lower voltage to a number of other substations distributed throughout the service region. These substations in turn feed electricity to the block transformers which finally step the voltage down to the lines which enter the customers' premises as shown in Figure 4-1. Redundant linkages between substations are used to provide alternative paths and improve system resilience against downed lines and failed equipment.

**Figure 4-1: Traditional Distribution Network (created by authors).**



The traditional interconnected distribution design (figure 4-1) involves a series of stages stepping down voltages and distributing power to regional hubs. Measurements of power flow can be made at substations and read from customer meters. This traditional model has three serious shortfalls namely: weak communication of power usage throughout the system, weak fault detection and diagnosis, and limited load balancing flexibility.

The first shortfall exists because the flow of power can be monitored in real time only at the major transformer and substation facilities. The consumption of power by individual customers is measured by meters physically located on site, and to collect the data from these meters requires a site visit by an employee. If, as happens for various illicit activities, the meter is physically bypassed, then the utility company is unable to determine where in the community the lost power (represented by the difference between the substation reading and the sum of the site readings ) has been used.

The second shortfall of the system is weak fault detection and diagnosis. If a service interruption occurs at any point downstream of a substation, the distribution system has no inherent way to alert service crews of this event. The utility company must rely on service complaints from customers to identify that there is a problem, and then use a process of triangulation from multiple complaints in order to localize the site of the problem.

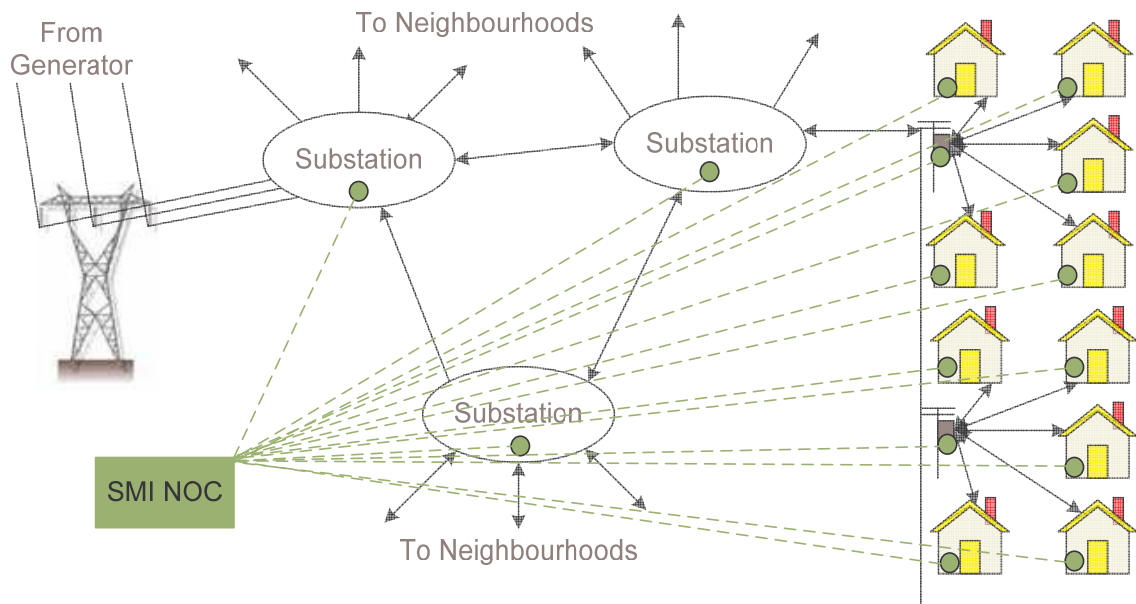
The third major shortfall of the existing system is limited load balancing flexibility. In order to respond to the dynamic demand of the customer base in any neighbourhood, the system must be built to supply the estimated maximum possible demand wattage to each substation at all times. This model is inefficient compared to the alternative of dynamically balancing the power delivered to each substation as appropriate for its actual demand at each point in time. For related reasons, the reverse flow of power from customers is not a practical option.

## **4.2 Smart Metering Infrastructure (SMI)**

The Smart Metering Infrastructure will use one or a combination of technologies to embed a network of two way communication devices at all relevant points throughout the system and potentially reaching into the customer's site as seen in Figure 4-2 (BC Hydro). In addition to resolving the limitations listed above, the SMI allows for new service features. These include real time usage metering, "smart" appliance management, and safe reverse power flow management (BC Hydro, 2008). As SMI technologies have matured, many major North American utility companies have embarked on similar initiatives to BC Hydro's, notably the Ontario Energy Board which plans to have their infrastructure fully upgraded for all customers by December 21, 2010 (Ontario Energy

Board, 2008). The capital costs of providing and installing the new metering devices will be carried by the utility company; but equipment specific to the site's occupant, such as the smart appliances and power conversion units used to interface with on-site energy sources (photovoltaics, wind, batteries), will be carried by the customer.

**Figure 4-2: Distribution Grid with Smart Metering Overlaid. Source: Created by authors based on RFQ System Integration Model (BC Hydro, 2008).**



With the implementation of the SMI, real time monitoring and control of power flow is centralized to the network operations centre. With real time metering, the customer's consumption of power by time of day can be accurately measured. This opens the door technologically to the establishment of a rate policy whereby the customer is billed differently per kWh consumed when the utility's supply is more expensive than when it is less. This matter is further developed in Section 8.2.

Smart appliances can be any electrical device at the customer's site with the ability to interface using a standard protocol such as TCP/IP with the SMI Network Operations Centre (NOC). The type of data which could be communicated in such a scenario includes real time power consumption of the appliance, cues from the utility to adjust appliance consumption patterns up or down (e.g., turning off hot water heater for 5 minutes every half hour during peak periods) signals for when and at what rate the utility will buy power from the customer, and billing account authentication at an appliance specific level.

### **4.3 Distribution Infrastructure and PHEVs**

The Use Case component of BC Hydro's SMI request for quote that addresses PHEV interface functionality defines five Primary Models under which a customer will be able to charge their vehicle from the utility grid. (BC Hydro, 2008) These models are:

1. PHEV charges without interaction with the SMI.
2. PHEV charges at a designated service location outside of home premises.
3. PHEV charges directly through the utility via SMI at home premises.
4. PHEV charges/discharges at designated service location. (bidirectional)
5. PHEV charges/discharges via SMI at home premises. (bidirectional)

We will assume that the 2012 SMI infrastructure will support each of these five scenarios.

An application of appliance level metering would be charging a vehicle battery at a non-home site while having the bill for the charge assigned to the appropriate customer account. The technological means for offering such a service is built around a unique digital identifier embedded within the charging circuit of each vehicle. In much the same

way as a cellular telephone identifies itself uniquely to the wireless network it connects to, PHEVs could likewise be associated with the owner's account regardless of which charging station to which they were physically connected. Furthermore, this feature creates a business opportunity for either BC Hydro or third party firms to install publicly accessible charging stations at parking facilities away from the home. These stations would distribute energy and presumably exact a "convenience fee" in addition to the energy bill to justify their installation and maintenance costs.

While connected to charging stations, whether home or public, it is technically feasible (Fung et al., 2002) for power to flow in the reverse direction from the battery to the grid. Such a situation would be of value to the utility in the case of a local area distribution failure or at a time when the marginal cost of energy supplying the grid was extremely high. Owners of PHEVs and owners of public charging stations could be financially incentivised to make some of the battery stored energy available to the grid by setting a high enough "buy-back rate" during these emergency conditions.

We have identified two major challenges to the implementation of reverse power flow models. The predominant issue is safety as service personnel must be certain as to whether the equipment they are working on is live. With reverse power flow, it is possible to have islands within a service area that are live even when the utility supplied power is interrupted. Even more dangerous is the possibility of such an island suddenly becoming unexpectedly live as the result of other than utility personnel throwing a switch. It is also possible that the utility would wish to capitalize on reverse power flow to sustain service to an area when the primary sources are unavailable or limited. For these reasons, it is critical that a highly reliable system of communication be in place so

that the utility always, regardless of the current state of the local grid, has absolute control over the operation of all assets outside of the customer's site. The impact of this is that the third party equipment used by customers to connect energy sources with the SMI will need to meet rigorous functional standards. They must be fail safe, tamper proof, and robust against all realistic adverse conditions (fire, flood, lightning strike) which significantly raises the costs for these units. A typical example from the current market for a grid-tie inversion unit is the Xantrex Single Phase GT 3.0 system rated at 3,000W capacity, which carries a retail price of \$1,899 (Xantrex, 2008). We expect that prices for similar units will fall over the next decade but will always remain a non-negligible financial expense for customers who wish to use the SMI's bidirectional functionality.

The second major issue to be considered when allowing large scale reverse power flow is the original source of the energy. As energy itself cannot contain an identifier or tracking mechanism, it is not possible to determine whether the battery connected to a reverse enabled charging station was filled with energy from a legitimate source. Two cases where this would be undesirable are; i) if the energy did not rightfully belong to the seller, such as if it were a stolen battery or a battery charged from the grid by bypassing a meter in a non SMI controlled network, and ii) if the energy had been generated using unacceptably polluting means. There is also the danger that an incentive is created for a potential seller of stored energy to force demand for their power by actively sabotaging distribution assets. A careful consideration of the potential scale of these vulnerabilities to abuse and the enforcement mechanisms which might be applied is worthy of further investigation, but left beyond the scope of this paper.

An intermediate approach to using V2G energy is the Vehicle to Home (V2H) model in which the energy stored in a PHEV's battery is connected to the household power system and merely supplements the grid supplied power. This model effectively offsets the retail utility grid energy to the customer with power drawn from the battery. Though this model does not provide protection against service outages at the neighbourhood level, it would provide a temporary emergency energy supply to the directly connected building. The equipment needed to allow this functionality is marginally simpler than the grid tie equipment referred to above, and so would be expected to retail at a comparable price.



## **5: INTERNAL CHARACTERISTICS ANALYSIS OF BC HYDRO**

In this chapter, we present an internal analysis of BC Hydro, which includes a description of their infrastructure, their organizational structure, and their integration of partners. Finally, we discuss the corporation's self defined short term priorities as they relate to the PHEV market introduction. Four of the six short term priorities outlined in this chapter are used in the balanced scorecard analysis developed in section 8: make the trade-offs that drive our strategic recommendations to BC Hydro.

### **5.1 Power generation and distribution**

BC Hydro has an extensive electrical power generation and distribution network that includes 33 generating facilities. 30 of these generating facilities are hydroelectric installations mainly located on the Peace and Columbia river systems and on the Pacific coast. These hydroelectric facilities can currently produce between 43,000 and 54,000 GWh per year. The range in the yearly electrical energy production is dependent upon the water levels in the dams, which is snow pack and rain fall dependent. The 30 hydroelectric facilities provide over 90% of BC's energy requirements with the remaining 10% coming from BC Hydro's three thermal plants. The thermal plants are a last resort for energy supply and are typically only used for marginal capacity at times of peak demand.

BC Hydro is part of the WECC (Western Electricity Coordinating Council) and trades with its members when they have electricity purchasing needs or have excess

energy to sell. In recent years, BC Hydro has become a net importer of energy by 10 to 15% of consumption. It is a goal of BC Hydro to become a net exporter of power by 2016.

Figure 5-1: Summary of BC hydro's generation and distribution system.

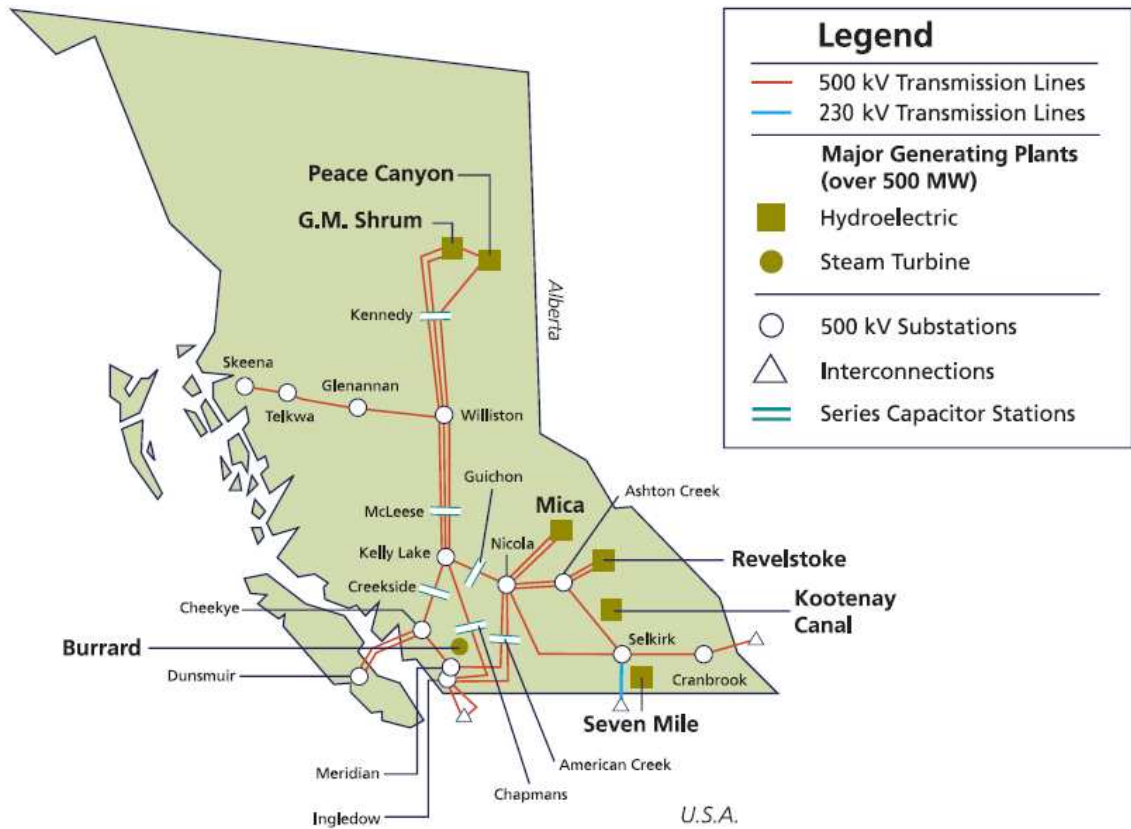


Figure 5-1 summarizes some of the major electrical generating facilities within BC as well as the electrical distribution system. BC Hydro owns a network of 74,000 km of transmission and distribution lines within BC. The planning, operating and management of BC Hydro's transmission and distribution network is the responsibility of

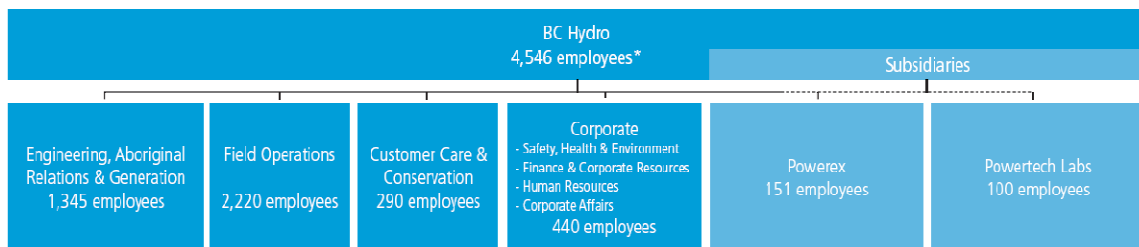
the British Columbia Transmission Corporation (BCTC). Like BC Hydro, the BCTC is regulated by BCUC.

## 5.2 Independent power providers

BC Hydro contracts with Independent Power Providers to meet their customers' needs: this is in compliance with the Province's 2002 energy plan. As outlined in BC Hydro's 2008/09 – 2010/11 Service Plan, approximately 87 Electricity Purchase Agreements (EPAs) with IPPs account for 15,000 GWh per year. IPPs provided the province with 1,500 MW of capacity in 2006 (BC Hydro, 2007).

## 5.3 Organizational Structure

Figure 5-2: Summary of BC Hydro's employee numbers, groups and subsidiaries (BC Hydro, 2007).



\*total number of employees as of March 31, 2007

As of March 31, 2007, BC Hydro had 4,546 employees. The organization includes three operational business groups, a corporate group and two subsidiaries (Powerex and Powertech labs). The employee distribution within these groups and subsidiaries is summarized in Figure 5-2. The responsibility of each of these groups is:

- Engineering, Aboriginal Relations & Generation. Generation manages and operates the companies generation facilities. Engineering provides maintenance

and construction services to both BC Hydro and BCTC. Aboriginal relations builds relationships and negotiates with the aboriginal peoples of BC in any decisions that may effect them.

- Field Operations delivers power safely and reliably to customers. It manages the distribution system as well as providing connection and emergency services.
- Customer Care and Conservation is responsible for providing long-term planning and ensuring adequate future resources (via acquisition for example) for BC's energy needs. This group is also responsible for Power Smart DSM initiatives.
- Corporate is responsible for such things as finance, regulatory affairs, risk management, legal, etc.

## **5.4 Short Term Priorities**

Throughout the organization, BC Hydro bases all decision making on six clearly defined priorities that are detailed in the Annual Report along with the metrics, the reporting/data collecting practices, and the major activities related to each. These priorities are listed below with a brief outline of their relevance to the approaching PHEV market introduction.

### **1. Safety**

The authors feel that activities related to providing energy to PHEVs will not affect the safety priority either negatively or positively. This is because technology is, or will be available at an acceptable cost that is capable of alleviating all incremental safety risks brought about by the expansion of the distribution infrastructure.

## 2. Reliability

Reliability of service provided to customers is measured on two scales. The first is the need to have supply (capacity) available to meet any moment's demand. BC Hydro has not failed to meet demand with supply, though the cost of purchasing energy from external markets at spot rates to meet extreme peak demand is uncertain, as is the availability of this emergency resource. The second scale of reliability is the distribution system performance. One of the measures of this is the Customer Average Interruption Duration Index (CAIDI) which is measured in hours and represents the total amount of time during the year when the average customer is un-serviced due to interruption. A significant fleet of PHEVs could positively impact both of these facets of reliability. The specific range of impact is calculated in Section 8.3.

## 3. Financial

As financial priorities are most often involved in decision making and performance is so easily measured through managerial accounting, we have expanded on this area in Chapter 6. The impact of PHEVs on the financial operation of BC Hydro is potentially very significant as it could result in a net cost increase or savings depending on how the issue is managed. This is also calculated in Section 8.3.

## 4. Environment / Sustainability

This is a broad category of issues grouped under one general priority title. By their definition, Plug-in Hybrid Electric Vehicles displace liquid hydrocarbon fuels with electricity for the bulk of their energy needs. If the electricity is

produced from clean, sustainable sources, as 90% of BC's grid power is, then a major environmental GHG advantage is available from a significant sized fleet. Conversely, if the liquid fuels are displaced by peak capacity electricity generation sources such as natural gas or coal fired thermal plants, this advantage is lost. Section 8.3 presents calculations for this range of GHG emissions based on the largest PHEV uptake scenario.

#### 5. Customer Satisfaction

BC Hydro's residential customers are composed of a very wide range of market segments, each with very different specific priorities and expectations of the company. There are a few general themes, however, that can reliably be assumed to be common to the vast majority of BC Hydro's customers. These would include low rates, high reliability, and simplicity. Rates and reliability are independently addressed, but the concept of simplicity represents an impact that had been previously unchanged throughout the history of the company. The introduction of the PHEVs and the SMI provide the opportunity and motive for a new, more complex rate structure than the simple flat rate currently used. This will require some learning and some adaptive behaviour on the part of the residential customer segment, which can be expected to be unwelcome, even in light of potentially lower average rates and environmental benefits. A full and precise determination of this impact would be worthy of a market research study but is left beyond the scope of this report.

## 6. People

The implementation of a more complex rate structure and an expansion of distribution infrastructure to interact with PHEV battery charging/discharging controls would involve some level recruitment beyond the status quo but would not affect the working conditions or benefit structures in the company. We do not feel that the PHEV market introduction significantly affects this priority.

## **6: CORPORATE PERFORMANCE OF BC HYDRO**

BC Hydro has adopted the concept of a “Triple Bottom Line” which addresses financial, environmental and social considerations in all levels of decision making and planning. In order to effectively manage and report on their performance in these areas, a range of objective metrics has been adopted by BC Hydro. For each metric, a target is set at the beginning of each period calculated to be aggressive yet attainable with the resources available and in light of the projected external factors. Metrics are tracked across reporting periods to identify trends and support projections.

### **6.1 Financial**

Table 6-1 is from the 2007 Annual Report, showing the scale of the corporation and the returns on equity it provides to the BC Government. These key financials are presented here to allow the reader to more effectively understand the gravity of the financial implications developed in Section 8.3. The corporation is currently a \$13 Bn asset that returns in the order of \$300m in annual profit to the province.



**Table 6-1: BC Hydro Key Financials for 2006 and 2007 (BC Hydro, 2007).**

<b>(dollar amounts in millions)</b>	<b>2007</b>	<b>2006</b>	<b>Change</b>
Total Assets	\$ 12,845	\$ 12,484	\$ 361
Retained Earnings	\$ 1,783	\$ 1,707	\$ 76
Net Income	\$ 407	\$ 266	\$ 141
Payment to the Province	\$ 331	\$ 223	\$ 108
Return on Equity	13.44%	9.26%	4.18%
Debt to Equity	70:30	70:30	–
Number of Domestic Customers	1,736,741	1,704,671	32,070
GWh Sold (Domestic)	52,911	52,440	471
Property, Plant and Equipment and Intangible Asset Expenditures	\$ 807	\$ 610	\$ 197

Table 6-2, also from the 2007 Annual Report, identifies the generation and trade amounts of the energy and corresponding dollar values for electricity managed by BC Hydro during the past 2 years. The values to make specific note of from this table are the costs of energy production from hydro generation at \$5.82/MWh in comparison to the costs for IPP, thermal and trade energy at \$60, \$73, and \$64 per MWh. This makes the case very clearly that there are tremendous economic advantages to maximizing hydro generation in cases where it can be substituted for other sources.

**Table 6-2: Energy Sources and Costs for 2006 and 2007 (BC Hydro, 2007).**

	(\$ in millions)		(GWh)		(\$per MWh)	
	2007	2006	2007	2006	2007	2006
Hydro generation	\$259	\$272	44,886	46,219	\$5.82	\$5.81
Purchases from Independent Power Producers and other long-term contracts	363	449	6,041	6,741	60.09	66.61
Other electricity purchases– Domestic	248	350	5,698	5,853	43.52	59.80
Gas for thermal generation	78	53	1,060	375	73.58	141.33
Transmission charges and other expenses	22	79	112	109	–	–
Allocation from (to) trade energy	67	(68)	656	(1,321)	64.32	71.75
<b>Total Domestic</b>	<b>\$1,037</b>	<b>\$1,135</b>	<b>58,453</b>	<b>57,976</b>	<b>\$17.74</b>	<b>\$19.57</b>
Other electricity purchases– Trade	\$438	\$565	33,815	28,405	\$50.34	\$65.21
Remarketed gas	480	494	8,320	6,912	57.67	71.54
Transmission charges and other expenses	229	226	–	–	–	–
Allocation (to) from domestic energy	(67)	68	(656)	1,321	64.32	71.75
<b>Total Trade</b>	<b>\$1,080</b>	<b>\$1,353</b>	<b>41,479</b>	<b>36,638</b>	<b>\$56.52</b>	<b>\$72.07</b>
<b>Total Energy Costs</b>	<b>\$2,117</b>	<b>\$2,488</b>	<b>99,932</b>	<b>94,614</b>	<b>\$33.84</b>	<b>\$39.90</b>

## 6.2 Environmental

BC Hydro uses the International Standards Organization (ISO) 14001 compliant Environmental Management System within which performance is partially measured by means of Environmental Incident Reporting (EIR). A subset of the total EIR incidents qualify as Environmental Regulatory Compliance (ERC) incidents which must be reported to external regulatory agencies and are considered preventable. ERC incidents

and the reparatory/compensatory measures taken are one metric used by BC Hydro to determine and improve their performance under the triple bottom line model.

GHG emissions are a major concern when producing power from hydrocarbon sources. The 2007 BC Government Greenhouse Gas Reduction Targets Act (B.C., 2007) requires Crown corporations including BC Hydro to be carbon neutral after offset measures by 2010. This policy will have the resultant affect that fossil fuel based thermal energy sources will increase in cost beyond the rate at which input materials are increasing in price. At present, the GHG emissions of vehicles which would be offset by substituting hydrocarbon fuels with electricity are not factored into the calculation for BC Hydro's net GHG emissions. The GHG emissions and sources for 2003 to 2006 are presented in Table 6-3.

**Table 6-3: BC Hydro Greenhouse Gas Emissions from 2003 to 2006 (BC Hydro, 2007).**

<b>Calendar Year</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>
<b>BC Hydro Direct GHG Emissions (tonnes of CO<sub>2</sub>)</b>				
BC Hydro Facilities	259	448	283	577
Fugitive Sulphur Hexafluoride (SF <sub>6</sub> )	77	70	55	51
Buildings	14	8	7	8
Vehicles	18	16	15	17
Subtotal direct GHG Emissions	368	542	360	653
<b>Indirect GHG Emissions</b>				
B.C.-based Independent Power Producers	809	943	863	734
Customer-Based Generation and Load Displacement	N/A	27	27	28
Subtotal indirect GHG Emissions	809	970	890	762
<b>Offsets</b>				
Island Cogeneration Project	(260)	(327)	(296)	(244)
<b>Total GHG Emissions</b>	<b>917</b>	<b>1,185</b>	<b>954</b>	<b>1,171</b>

### **6.3 Social**

Social concerns address the interests and priorities of the three human stakeholder groups (customers, employees and community). The numeric metrics used to monitor performance in this area are largely generated through surveys and similar mechanisms. Feedback is systemically solicited from these groups in order to seek innovative solutions to existing concerns and to identify priorities and values which are evolving with time.

BC Hydro employs an extensive range of education and outreach programs, such as PowerSmart, to help the corporation and the communities where it operates work together toward common goals. Along with these directly impacted groups, BC Hydro maintains formal liaison activities with peripheral industries which are impacted by their service and rate policies. These industries would include suppliers of micro scale power generation products such as photovoltaic panels and power converters and in the future

this group will expand to include suppliers and servicers of PHEVs. Liaison activities such as partnership in research and development programs and technology evaluations will ensure that a smooth implementation of services to support future market needs is possible.

## 7: FULCRUM ANALYSIS

The preceding chapters have presented foundational descriptions of three major factors that will be coming together over the 2012 – 2020 period. In brief, these are; i) the introduction to the market of mass produced plug-in hybrid electric vehicles and the batteries they carry (Chapter 3), ii) the smart metering infrastructure with the real time data monitoring and bidirectional energy flow (Chapter 4), and iii) the top level mandates of BC Hydro to not only provide financial returns on equity but to maintain alignment of its activities with environmental sustainability and community interests (Chapters 5 and 6). The information available at this time is not sufficient to make highly certain predictions about the future values of key variables. None the less, in order to establish the viability of all reasonable strategic actions before the time of the anticipated demand impact, it is appropriate to analyze the potential future scenarios today and plan the optimal actions for each case.

Existing research literature has predicted the market adoption of PHEVs and their key performance characteristics over the period of interest based on technological trends combined with economic and political factors roughly similar to today. Such assumptions provide, at best, a most-probable estimation of the type and scale of impact powering the provincial PHEV fleet will have over the period of interest. In Chapter 8, we will define this as the *moderate* level of market adoption and then identify the major assumptions which could conceivably unfold differently. After identifying some

hypothetical factors that would significantly change these assumptions, we will then use these scenarios to outline a *low* range and a *high* range of PHEV market uptake.

Before we begin to define the range of strategic alternatives available to BC Hydro, we will briefly address the option of acting to block the licensing of PHEVs in the province or on the grid. The motive to take such a position is found in the demand gap outlined in Section 2.2, where the use of aggressive demand side management to reduce the projected rate of electrical energy use is depended upon in order for BC Hydro to meet capacity demands. This approach would almost certainly be futile as societal perceptions of both the consumer and the greater environmental and societal benefits would drive BC Hydro's regulator and shareholder to force support of these vehicles and so we will not present refusal as an option. BC Hydro will become a supplier of energy to the transportation sector beginning in 2010 and then with increasing significance for the foreseeable future. It must plan for that role.

The legitimate range of actions that BC Hydro can take fall into two categories, they can control the services and features they offer to their customers and they can set rate policies for the energy they trade. As a regulated company, they must seek and be granted permission from the BCUC to apply changes in both of these areas. We will present four fundamentally different strategies that engage these actions and provide the rationale behind each.

The four strategic responses we will investigate as they would be applied to each of the three PHEV market adoption levels are:

1. No fundamental change in demand side policies. This will mean power must be supplied at the times customers choose to charge their batteries without any policy

incentives. This may however include advertising to discourage charging during peak times.

2. Simple peak and off-peak rate structure. This option would use the SMI to differentiate power drawn during peak periods from that drawn during off peak. Different rates for energy would be assigned to each period. This policy would provide incentive for customers to schedule high energy demand activities, specifically PHEV charging, to times when the utility is operating on the least expensive energy sources.
3. Peak and off peak with reverse metering. In this case, the SMI will be used to allow customers to supply energy stored in their PHEV batteries to the grid at peak demand times, and be credited for this amount at a rate equivalent to the utility's offset costs during this time. Functionally, this would simply mean that the customer's household would be drawing less power during peak periods but this stored energy could also be called upon if a distribution interruption occurred.
4. Dynamically variable rates with reverse metering. This would entail a larger capital investment for smart equipment at the customer's site, after which a real-time communication would be available between the utility and the customer's PHEV battery. This technology platform would allow the utility to respond to low or high instantaneous demand by signalling a spot "buy" and "sell" rate to the collective pool of batteries connected to the grid. Individual customers would be able to pre-program the threshold rates they wish to both buy and sell energy.



## 8: SOLUTION ANALYSIS

To transparently and objectively provide recommendations for action, this report uses the balanced scorecard technique for addressing priority tradeoffs. The machinery of this technique as applied to this case is as follows:

1. Three external scenarios are defined, one of which will apply in the future. Collectively, these scenarios span the spectrum of reasonable potential PHEV uptake models. This report uses low, moderate, and high uptake of PHEVs as the net outcomes of the scenarios which are developed in detail in section 8.1.
2. Four internally controllable categories of strategic actions are defined which also collectively span all reasonable courses of action constrained by the time frame, technologies and resources available. These four strategies are developed in detail in section 8.2.
3. With the above information in place, a table is drawn with scenarios presented as columns and strategies as rows. Four fundamental priorities which are or may be impacted by the scenarios and the strategic actions applied are reliability, sustainability, financial strength, and customer convenience. At each intersection of the table, one of twelve potential futures is represented and for each future it is possible to roughly estimate a level of impact on each of the defined priorities. This report uses a

standard scale of 5 impact levels consisting of (--), (-), (.), (+), (++) which represent; most negative, somewhat negative, neutral, somewhat positive and most positive. The impact levels for each priority at each intersection are provided by the authors based on analysis explained in section 8.3.

4. The selected priorities are intrinsic to the mandate of the corporation and used to drive decisions throughout the organization at all levels. Section 8.4 looks at the development of these weighting values as percentages which sum to 100 for each intersection.
5. With the impact level and weight for each priority now available at every intersection of the table, a total score for that box is calculated by multiplying these together then summing over all 4 priorities. This is the final step in the process and presents the optimal strategy for each scenario as the row containing the highest score.
6. The completed balanced scorecard identifies the degree to which optimal strategies are scenario dependent or not. This then provides the justification to delay actions pending more information where they are scenario dependent, or to act sooner where they are not.

## **8.1 Scenario Development**

The three possible scenarios for PHEV up-take in BC are named low, medium and high and were detailed in section 3: Figure 8-1 summarizes the impact of our scenarios on BC hydro from the point of view of increased energy and capacity requirements for the year 2020. Under the high scenario, there will be an additional

6.4 GWh of energy storage available to BC Hydro and an extra capacity of 1.36 GWh for which BC Hydro must plan.

**Figure 8-1: Impact summary of our scenarios on BC Hydro for 2020 (created by author).**

<b>Scenario</b>	<b>Number of PHEVs on BC roads</b>	<b>Total Available Energy Storage, GWh</b>	<b>Maximum Capacity Required to Charge PHEVs, GW<sup>a</sup></b>
Low	170,000	1.6	0.34
Medium	520,000	4.9	1.05
High	680,000	6.4	1.36

<sup>a</sup> assumed a 120 V/20 A circuit.

It is difficult to predict exactly what the PHEV adoption in BC will be in 2020, but current events are leaning towards a much different world in 2020. Currently, gas prices are spiralling upwards with no indication that the trend will reverse. If we have not already hit peak oil production then we will surely experience it by 2020: this will make it extremely unlikely that we will ever again see the cheap oil prices of yesteryear. Although the major price driver for the price of gas at the pump is the cost of a barrel of oil, both provincial and federal governments are introducing or have introduced carbon taxes. These taxes are only likely to have increased by 2020, hence adding further to the retail price of hydrocarbon fuels. A third factor that will increase the adoption of PHEV technology will be peoples' increased concern over the effect of green house gases (GHG) on global warming.

## **8.2 Strategic Alternatives Development**

As the range of potential positive and negative impacts are chiefly determined by the actions of the customer base, the control BC Hydro has over these actions is exercised through incentives that align the customers' interests with the corporation's. This section describes four levels of rate policy management that collectively encompass the full range of technically feasible alternatives. We have not addressed non-rate based alternatives such as subsidizing capital equipment purchases as these would only be practical as secondary matters within a reformed rate structure.

### **8.2.1 Strategy 1 – No Change in Policies**

The null alternative is to maintain the existing flat rate structure for energy purchases. To date, the determination of what this rate is has been calculated as the rate which will produce a required return on equity for the shareholder after energy generation/acquisition costs and operating overhead costs. While overhead costs are fixed in the short term, the value used for energy costs is an average of the inexpensive hydroelectric energy which forms the base of the supply and the much higher and more volatile rates paid on the margin to supply peak demand. As such, the fixed rate which must be charged to the customer will be higher when a larger percentage of marginal sources is used in the supply mix. Functionally, this means the peak time energy consumption is subsidized by the off peak consumption. BC residential customers have always purchased energy at the same rate regardless of the time, and, in turn, use energy as is convenient without regard to the differential cost or environmental impact of the energy's source at that time.

### **8.2.2 Strategy 2 – Peak and Off-Peak Rates**

The offering of two tier energy rates is commonplace in many parts of the world with a close analog of the BC energy environment found in Scotland. In such cases, the tariff structure for energy sold to customers is time dependant. The bill to the customer charges a daily service charge (a nominal fixed fee comparable to the price of 1 KWh), a Day rate times the KWhs consumed during day hours and a Night rate multiplied by the KWhs consumed during the hours defined by the utility as off peak. The timing of the rate periods and the specific rates charged vary from company to company in this privatized competitive market, but an example would be ScottishPower (ScottishPower, 2008).

In jurisdictions where two tier rate structures are used, it is typical that the Day rate is roughly double the Night rate. This 100% difference in rate provides incentive for customers to shift non time sensitive demand activities such as laundry and dishwashing to the periods when inexpensive base power is used by the utility. Furthermore, devices which store energy collected during the night for use during the day are often employed to capitalize on the the economy available. A popular low-tech example is a volume heater that stores heat energy in a stone or concrete block and then radiates the heat to the building over the following day. At the higher technology level, this rate structure would incentivise the use of batteries in PHEVs to charge during off-peak rate hours and through the use of home based power inverters, provide some of this electrical energy back at a later time to a building. This model is commonly referred to by the term Vehicle to Home or V2H (Kramer, 2006). Such stored energy would offset the consumption of grid power at the peak rate, saving both the customer and the utility on energy costs.

### **8.2.3 Strategy 3 – Peak and Off-Peak Rates with Reverse Metering**

This case is functionally very similar to the one above with the significant difference being that in addition to the V2H functionality, the stored energy in charged PHEV batteries connected to the home can be called on for use in the wider network. The common label for this model is Vehicle to Grid or V2G. Although the amount of usable energy stored in a PHEV battery is less than that consumed by a typical household during a typical day's peak period, there are many situations where surplus energy would be available in these remotely distributed locations to provide short term emergency power in the event of a distribution or transmission system failure. Although these situations are rare and extensive measures are taken to minimize them, weather and other uncontrollable causes will always produce some level of service interruption. Three cases where this virtual battery would be practical are; i) where multiple PHEVs and possibly other batteries are attached to a common location such as in a commercial parkade, ii) for short periods of perhaps less than thirty minutes where power needs can be met by the battery's capacity, and iii) if the current rapid advancement of energy density in batteries exceeds currently predicted levels, PHEV battery storage could be multiples of what we have assumed otherwise in this report.

A combination of SMI and distributed PHEV batteries throughout a service area provide the technical ability to form a functional uninterruptable power supply. To make this emergency resource work, owners of PHEVs need to be incentivized to sell some of the energy they have stored back to the utility when called upon. This would almost certainly need to be at a premium rate, above the daily peak rate charged by the utility but not so high as to motivate criminal sabotage of BC Hydro assets. The specifics of such a

policy are beyond the scope of this paper as it is the intent here only to explain how service interruptions would be mitigated via this strategic alternative. The grid-tie inverter equipment needed to support this model would be more complex and therefore expected to be more expensive than V2H equipment. We estimate this premium to be in the neighbourhood of \$500, based on current market offerings (Xantrex, 2008).

#### **8.2.4 Strategy 4 – Dynamically Variable Rates with Reverse Metering**

In this case, rather than the two or possibly three tier tariff policy used in Strategy 3, BC Hydro's residential rate would float based on the cost of energy they are paying. To facilitate this, the SMI would be integrated with the generation/acquisition systems to calculate a real time cost for the energy they sell. The retail rate charged to the customer would be adjusted in real time also to cover BC Hydro's costs plus a margin for overhead and return on equity requirements. Outside of base generation times, customers would have the right to sell energy to the utility at a floating rate below the marginal rate that the company would have to pay for an alternate source. "Smart" appliances interfaced with the SMI would be programmed to operate at energy price thresholds, for instance, a clothes drier might be set to only begin a load when the spot retail rate for electricity is below 6 cents/KWh. More importantly, a PHEV charger might be set to charge the battery when the *retail* rate is below 5 cents/KWh and to power household demand (V2H) when the *retail* rate is above 5.5 cents. Furthermore, it could be programmed to sell up to 60% of the usable battery charge to the utility (V2G) when the *buy* rate is above 6 cents/KWh. All of these values would be specified by the customers to match their individual preferences.

This model would have two profound effects on the daily load demand seen in Figure 2-3. The first effect is optimal “valley filling” where any load demand which can reasonably be put off to late evening will be, thus making use of base hydroelectric capacity that would otherwise be wasted through spill over or sold at even lower rates to external markets. The second effect is optimal “peak shaving” where not only is much of the demand shifted to the valley as described above, but less expensive energy is made available to the company during the remaining peaks from the collective virtual battery of PHEVs connected to smart chargers. This model represents an ideal efficiency strategy for levelling the daily demand load cycle and consequently replacing peak sources with base sources. For the customer, it offers financial incentives to align their energy consumption patterns with the interests of the utility, possibly to the extent of supplying battery resources beyond their vehicles.

There are two primary drawbacks to this strategy. The first is the extensive infrastructure development that would be required in addition to the current SMI plans. Internal to BC Hydro, data linkage with the power generation stations and transmission systems to the SMI network operations centre must be developed and implemented at a cost that we roughly predict in the order of half a million dollars. Furthermore, third party smart devices not currently on the market would need to be incorporated, through a commitment from BC Hydro to support Strategy 4 would incentivise industry to develop them. The second and more daunting drawback is the potential reaction of the segment of customers who would not immediately benefit from this change, but who would feel compelled to learn a more complex trade relationship with the power utility. BC Hydro would likely not gain authorization for this or any of the above changes from their



regulator if opponents of the changes successfully argue that they are negatively impacted.

### **8.3 Priority Impact Levels**

This section presents the justification for the level of impact assigned to each combination of future scenarios and response strategies. The valuation of each intersection is calibrated by defining all impacts for low uptake and no policy change as zero. By this means, any net loss in priority value will be represented by a negative value and a net improvement by a positive one. Appendix A shows the calculations used in each case.

#### **8.3.1 No Policy Change Impacts**

##### **8.3.1.1 Low Uptake**

As described above, this section is calibrated to be represented by a 0 value. In terms of priority metrics, this means:

Reliability: (.) Demand requires 3.0% increase in maximum capacity on highest usage days. This 3.0% capacity increase corresponds to medium circuit power (120 V / 20 A) in Table 3-8. It is assumed that this small increase in capacity will have minimum impact on Customer Average Interruption Duration Index (CAIDI).

Sustainability: (.) Vehicular carbon emissions reduced by 2.5% (see Appendix A).

Financial: (.) \$0, with savings measured against this value.

Customer Service: (.) Not impacted.

### **8.3.1.2 Medium Uptake**

Reliability: (-) Required capacity increase of 9.3% on highest days. This 9.3% capacity increase corresponds to medium circuit power (120 V / 20 A) in Table 3-8.

Sustainability: (+) Vehicular carbon emissions reduced by 7.9% (see Appendix A).

Financial: (.) \$0, with savings measured against this value.

### **8.3.1.3 High Uptake**

Reliability: (--) Requires capacity increase of 12% on highest days. This 12% capacity increase corresponds to medium circuit power (120 V / 20 A) in Table 3-8.

Sustainability: (+) Vehicular carbon emissions reduced by 10.2% (see Appendix A), an estimated 5% of which is replaced by non-renewable marginal sources leaving a net reduction of 5.2%. The reasons we feel that 5 of the 10.2% will be transferred from gasoline emissions to other thermal emissions is the combination of the expectation that only 3/5 of charging will be migrated to off peak periods, and the fact that rainfall patterns may limit the total energy available from clean sources.

Financial: (.) \$0, with savings measured against this value.

## **8.3.2 Simple Tiered Rate Policy**

### **8.3.2.1 Low Uptake**

Reliability: (.) Relative reduction over null strategy of 3.0% from peak demand.

Sustainability: (.) Comparable to all low uptake scenarios.

Financial: (+) \$18M savings. We estimate this strategy will capture of 60% of the potential savings as per the calculations in Appendix A.

Customer Service: (-) Some inconvenience to the customers must be expected for this strategy over the *status quo*, i.e. strategy 1 or no change in policy.

### **8.3.2.2 Medium Uptake**

Reliability: (.) Relative reduction over null strategy of 9.3% from peak. We consider less than 10% to be within uncertainty of neutral for this priority.

Sustainability: (+) Same as no response.

Financial: (+) \$34M savings. We estimate this strategy will capture of 60% of the potential savings as per the calculations in Appendix A.

### **8.3.2.3 High Uptake**

Reliability: (-) Relative reduction over null strategy of 14% from peak.

Sustainability: (+) Vehicular carbon reduced by 10.2%, 3% of which is anticipated to come from non-renewable marginal sources leaving a net carbon reduction of 7.2%. The reasons we feel that 3 of the 10.2% will be transferred from gasoline emissions to other thermal emissions is the combination of the expectation that only 4/5 of charging will be migrated to off peak periods, and the fact that rainfall patterns may limit the total energy available from clean sources.

Financial: (+) \$43M savings. We estimate this strategy will capture of 60% of the potential savings as per the calculations in Appendix A.

### **8.3.3 Tiered Rates with Reverse Metering**

#### **8.3.3.1 Low Uptake**

Reliability: (+) Virtual battery as connected to grid able to support each average residential customer for 0.3 average hours. (daily demand divided by 16)

Sustainability: (+) Same as section 8.3.2.1.

Financial: (+) Same as section 8.3.2.1.

Customer Service: (-) Some inconvenience to the customers must be expected for this strategy in all scenarios.

#### **8.3.3.2 Medium Uptake**

Reliability: (+) Virtual battery as connected to grid able to support each average residential customer for 0.9 average hours.

Sustainability: (+) Same as section 8.3.2.1.

Financial: (+) Same as section 8.3.2.1.

#### **8.3.3.3 High Uptake**

Reliability: (+) Virtual battery as connected to grid able to support each average residential customer for 1.1 average hours.

Sustainability: (+) Same as section 8.3.2.1.

Financial: (+) Same as section 8.3.2.1.

### **8.3.4 Dynamically Variable Rates with Reverse Metering**

#### **8.3.4.1 Low Uptake**

Reliability: (+) Same as section 8.3.2.1.

Financial: (+) Savings of \$31M. (Appendix A)

Customer Service: (--) Customers will need to have new equipment installed in their homes and learn new and significantly more complicated practices relating to their use of electricity. Customers with PHEVs will appreciate the advantages integration of their car with their home energy use will provide, but the majority of residential customers will not own these units. For these customers, the inconvenience of switching to a dynamic variable rate policy will be a negative impact.

#### **8.3.4.2 Medium Uptake**

Reliability: (++) In this scenario, users are incentivised to charge their vehicles more while at non-home locations. As such, the amount of time when the PHEV is fully charged and on-line is higher, resulting in an increase of average reserve time to a total of 1.1 hours.

Sustainability: (+) Same as section 8.3.2.1.

Financial: (++) Savings of \$56M.

#### **8.3.4.3 High Uptake**

Reliability: (++) By the same reasoning as in Medium Uptake, the average reserve time in this case would be 1.4 hours.

Sustainability: (++) The incentive to PHEV owners to offset supply from marginal sources means essentially all non-renewable energy sources are averted. This represents a 10.2% (see Appendix A) reduction of carbon emissions over hydrocarbon fuelled vehicles.

Financial: (++) Savings of \$71M.

## **8.4 Priority Weighting**

In order to evaluate a meaningful net advantage or disadvantage in the case of priority tradeoffs, it is necessary for the principal stakeholder (i.e. BC Hydro), to assign a relative weighting to each priority in light of the range of impacts to which they are exposed. Weightings are currently not available but it is worthwhile illustrating how the tool works so that when weightings do become available the procedure can be easily followed. For the purposes of illustration, we have assigned placeholder values of 25% to each priority.

We can now use the 25% relative weightings assigned to each of the priorities in combination with the impact levels that PHEVs will have on these priorities for the three PHEV uptake scenarios in the context of the four strategies that we have outlined in section 8.2 to address the PHEV impact on the electrical grid. A balanced scorecard (Kaplan & Norton, 1992) was used to choose the best strategy for each of the PHEV uptake scenarios and the results are presented in Table 8-1. It can be seen from examination of the balanced scorecard that the optimum strategy is dependent upon the market penetration of PHEVs. For the low market penetration scenarios the balanced scorecard shows that the best strategy is to implement tiered rates with reverse metering.

The tiered rates with reverse metering strategy only narrowly beats the dynamic rates with reverse metering strategy and only came out on top because it was perceived that the tiered rate strategy would be simpler to understand and require less customer involvement.

For both the medium and high uptake scenarios the balanced scorecard recommends the dynamic rates with reverse metering strategy. It is believed that the dynamic rates strategy will allow BC Hydro to engineer the daily and annual energy cycle to their best advantage. For example, if BC Hydro were finding it difficult to meet a peak in capacity, then, instead of purchasing power from expensive marginal sources, they could increase the energy price to their customers and hence encourage customers to use the power in their PHEV batteries. A counter example may be if BC Hydro were experiencing excess energy surplus due to a large fall rain they could store energy in their customers' PHEVs instead of allowing water to spill over spill ways; this would be achieved by dropping the price of energy and having customers charge up their PHEV batteries. It is believed that the instigation of a dynamic rate will also encourage PHEV owners to have their vehicles plugged-in to a power outlet as often as possible, hence ensuring that a higher proportion of the virtual battery is available to BC Hydro as a capital free resource – BC Hydro did not have to outlay any capital to purchase this virtual battery.

**Table 8-1: Results of the PHEV balanced scorecard analysis (created by authors).**

Policy Category	Priority	Low Uptake			Medium Uptake			High Uptake		
		Impact	Weight	score	Impact	Weight	score	Impact	Weight	score
No Change	Reliability	.	25	0	-	25	-25	--	25	-50
	Sustainability	.	25	0	+	25	25	+	25	25
	Financial	.	25	0	.	25	0	.	25	0
	Inconvenience	.	25	0	.	25	0	.	25	0
	<b>Total</b>			<b>0</b>	<b>Total</b>		<b>0</b>	<b>Total</b>		<b>-25</b>
Tiered Rates	Reliability	.	25	0	.	25	0	-	25	-25
	Sustainability	.	25	0	+	25	25	+	25	25
	Financial	+	25	25	+	25	25	+	25	25
	Inconvenience	-	25	-25	-	25	-25	-	25	-25
	<b>Total</b>			<b>0</b>	<b>Total</b>		<b>25</b>	<b>Total</b>		<b>0</b>
Tiered with Reverse	Reliability	+	25	25	+	25	25	+	25	25
	Sustainability	.	25	0	+	25	25	+	25	25
	Financial	+	25	25	+	25	25	+	25	25
	Inconvenience	-	25	-25	-	25	-25	-	25	-25
	<b>Total</b>			<b>25</b>	<b>Total</b>		<b>50</b>	<b>Total</b>		<b>50</b>
Dynamic rates with Reverse	Reliability	+	25	25	++	25	50	++	25	50
	Sustainability	.	25	0	+	25	25	++	25	50
	Financial	+	25	25	++	25	50	++	25	50
	Inconvenience	--	25	-50	--	25	-50	--	25	-50
	<b>Total</b>			<b>0</b>	<b>Total</b>		<b>75</b>	<b>Total</b>		<b>100</b>



#### **8.4.1 Weighting Sensitivity Analysis**

As discussed above, it was not possible to obtain priority impact weightings at the time of writing this report, therefore a sensitivity analysis was done using our balanced scorecard tool. It was found from this sensitivity analysis that the only priority weighting that had any significant impact on the recommended strategy for PHEV management was the inconvenience weighting. For example, when the weighting on the inconvenience was raised to 40% and the remaining 60% was equally divided among the other 3 priorities, then the medium market penetration strategy switched over from dynamic rates with reverse metering to tiered rates with reverse metering - this is illustrated in Table 8-2. As the weighting on inconvenience was further increased to 50% then the high uptake recommended strategy also switches from dynamic rates with reverse metering to tiered rates with reverse metering - this is illustrated in Table 8-3.

It is worth noting that it is unlikely that the inconvenience priority will take on a 40% weighting relative to the other BC Hydro priorities. With this knowledge, it can be concluded that the balanced scorecard analysis recommends a tiered rate system with reverse metering in the low uptake scenario and a dynamic rates system with reverse metering in the medium and high uptake scenarios.

**Table 8-2: Result of balanced scorecard sensitivity analysis where the recommended medium uptake scenario strategy switches from dynamic rates with reverse to tiered rates with reverse, i.e. at a inconvenience weighting of 40% (created by authors).**

Policy Category	Priority	Low Uptake			Medium Uptake			High Uptake		
		Impact	Weight	score	Impact	Weight	score	Impact	Weight	score
No Change	Reliability	.	20	0	-	20	-20	--	20	-40
	Sustainability	.	20	0	+	20	20	+	20	20
	Financial	.	20	0	.	20	0	.	20	0
	Inconvenience	.	40	0	.	40	0	.	40	0
	<b>Total</b>			<b>0</b>	<b>Total</b>		<b>0</b>	<b>Total</b>		<b>-20</b>
Tiered Rates	Reliability	.	20	0	.	20	0	-	20	-20
	Sustainability	.	20	0	+	20	20	+	20	20
	Financial	+	20	20	+	20	20	+	20	20
	Inconvenience	-	40	-40	-	40	-40	-	40	-40
	<b>Total</b>			<b>-20</b>	<b>Total</b>		<b>0</b>	<b>Total</b>		<b>-20</b>
Tiered with Reverse	Reliability	+	20	20	+	20	20	+	20	20
	Sustainability	.	20	0	+	20	20	+	20	20
	Financial	+	20	20	+	20	20	+	20	20
	Inconvenience	-	40	-40	-	40	-40	-	40	-40
	<b>Total</b>			<b>0</b>	<b>Total</b>		<b>20</b>	<b>Total</b>		<b>20</b>
Dynamic rates with Reverse	Reliability	+	20	20	++	20	40	++	20	40
	Sustainability	.	20	0	+	20	20	++	20	40
	Financial	+	20	20	++	20	40	++	20	40
	Inconvenience	--	40	-80	--	40	-80	--	40	-80
	<b>Total</b>			<b>-40</b>	<b>Total</b>		<b>20</b>	<b>Total</b>		<b>40</b>

**Table 8-3: Result of balanced scorecard sensitivity analysis where the recommended high uptake scenario strategy switches from dynamic rates with reverse to tiered rates with reverse, i.e. at a inconvenience weighting of 50% (created by authors).**

Policy Category	Priority	Low Uptake			Medium Uptake			High Uptake		
		Impact	Weight	score	Impact	Weight	score	Impact	Weight	score
No Change	Reliability	.	16.6	0	-	16.6	-16.6	--	16.6	-33.3
	Sustainability	.	16.6	0	+	16.6	16.6	+	16.6	16.6
	Financial	.	16.6	0	.	16.6	0	.	16.6	0
	Inconvenience	.	50	0	.	50	0	.	50	0
				<b>Total</b>	<b>0</b>		<b>Total</b>	<b>0</b>		<b>Total</b>
Tiered Rates	Reliability	.	16.6	0	.	16.6	0	-	16.6	-16.6
	Sustainability	.	16.6	0	+	16.6	16.6	+	16.6	16.6
	Financial	+	16.6	16.6	+	16.6	16.6	+	16.6	16.6
	Inconvenience	-	50	-50	-	50	-50	-	50	-50
				<b>Total</b>	<b>-33.3</b>		<b>Total</b>	<b>-16.6</b>		<b>Total</b>
Tiered with Reverse	Reliability	+	16.6	16.6	+	16.6	16.67	+	16.6	16.6
	Sustainability	.	16.6	0	+	16.6	16.6	+	16.6	16.6
	Financial	+	16.6	16.6	+	16.6	16.6	+	16.6	16.6
	Inconvenience	-	50	-50	-	50	-50	-	50	-50
				<b>Total</b>	<b>-16.6</b>		<b>Total</b>	<b>0</b>		<b>Total</b>
Dynamic rates with Reverse	Reliability	+	16.6	16.6	++	16.6	33.3	++	16.6	33.3
	Sustainability	.	16.6	0	+	16.6	16.6	++	16.6	33.3
	Financial	+	16.6	16.6	++	16.6	33.3	++	16.6	33.3
	Inconvenience	--	50	-100	--	50	-100	--	50	-100
				<b>Total</b>	<b>-66.6</b>		<b>Total</b>	<b>-16.6</b>		<b>Total</b>

## **9: RECOMMENDATIONS AND CONCLUSIONS**

The balanced scorecard analysis recommends that, for a low market penetration in the year 2020, BC Hydro should implement a tiered rate system with reverse metering and that, for the medium and high market penetration scenarios, they should implement a dynamic rate system with reverse metering. Although the authors feel that a dynamic rates system may be a good solution for the long-term (>10 years), where it is inevitable that electrical energy displace the chemical energy stored in gasoline for vehicular transportation, it is still felt at this point that such a radical change to the BC rates system is too radical for their customers and of too high a risk. It is therefore recommended that a simple two-tiered rates system be initially implemented. Although tiered rates will be new to British Columbians, there is much precedence around the world where two-tiered, peak and off-peak rates have been in place for a long time. This tiered system is thought to be of low risk and should be easily accepted by customers. However, it is also recommended that a feasibility study be conducted by BC Hydro on a dynamic rates system and, if this feasibility study proves that dynamic rates are feasible, then a pilot program be instigated.

As well as the rates system itself, reverse metering will further add to the customers' incentive to exploit the tiered rates system and hence allow BC Hydro to maximize the benefits of the free energy storage device. The reverse metering essentially allows the customer to maximize his energy cost savings by utilizing the electrical energy stored in their PHEV during off-peak times at the peak times of the day.

The final aspect of BC Hydro strategy that needs to be in place is that the system has to be automatic and intelligent so as to be of minimal inconvenience and complexity to the customer. It is believed that the SMI should include programming capabilities similar to programmable thermostats which will allow customers to easily ensure that vehicles are only charged during off peak times. Although the SMI should be simple enough to be totally intuitive to the vast majority of BC Hydro's customers, we believe that the SMI roll out should also be supplemented by an extensive advertising and educational campaign.

It is very hard to tell what the world will be like in 2020; however, it is conceivable that employers or external agents may offer to sell power for PHEVs at the work place and other away from home sites. Also, it is not known at this time how much computing power and intelligence may be in the SMI or in PHEVs in 2020. However, one function that could possibly be available would be individual vehicle identification, which would allow the PHEV owner to plug-in their vehicle almost anywhere while having the power charged to them individually; this would be similar to today's mobile phone roaming capability. If this roaming charging is a reality for PHEVs, then it means that vehicles are likely to always have a higher average charge in their batteries, which means that more power is available from the battery in times of emergency. With the average household consuming 30 kWh/day and the average PHEV battery in 2020 having an energy storage capacity of 13kWh, home owners will have enough energy to run their household for ½ a day - hence increasing reliability.

It is also believed that, since the use of dynamic rates with reverse metering maximizes the use of the PHEV battery as well as allowing BC Hydro to optimally use

the PHEV virtual battery to minimize the use of the often “dirtier” marginal power sources, this strategy has the greatest beneficial impact on BC’s GHG footprint. As BC Hydro is a crown corporation, and the BC provincial government has recently demonstrated a commitment to reducing vehicular GHG emissions, then a strategy that results in a maximal reduction of GHG emissions is in alignment with this policy.

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## APPENDIX A - CALCULATIONS

This appendix shows the calculation done to support the ranges given in section 8.3. The purpose of this section is to show the reasoning behind our calculations and to give our approximations. By showing our calculations, it should be a reasonably simple matter for the reader to construct their own spreadsheet and vary the inputs to their effect on the output. We feel this is necessary because of the uncertainty and hence debate that is often present between individuals when trying to predict the situation in 2020.

### Reliability

**Table A- 1: Reliability Example Calculation Values (created by authors).**

Parameter	Symbol	Value	Units
Low market penetration virtual battery size <sup>c</sup>	$VB$	1,592	MWh
Medium market penetration virtual battery size <sup>c</sup>	$VB_m$	4,901	MWh
High market penetration virtual battery size <sup>c</sup>	$VB_h$	6,368	MWh
Total residential energy consumption <sup>a</sup>	$E_{res}^{08}$	17,000	GWh
Fraction of vehicle connect to grid during outage	$\epsilon_0$	0.5	

<sup>a</sup> 2007 numbers (Ince, 2008)

Average hours that BC residential client can be supported from virtual battery:

$$H = 16 \cdot \frac{VB}{(E_{res}^{08}/365)} \cdot 0.5$$

For example for low market penetration:

$$H_l = 16 \cdot \frac{1,592}{(17,000,000/365)} \cdot 0.5$$

$$= 0.27 \text{ hrs}$$

## Sustainability

**Table A- 2: Sustainability Example Calculation Values (created by authors).**

Parameter	Symbol	Value	Units
Average yearly CO <sub>2</sub> emissions from a CV	$E_{CV}$	6200	kg/vehicle
Average yearly CO <sub>2</sub> emissions from a PHEV	$E_{PHEV}$	3100	kg/vehicle
Number of PHEVs for low market penetration <sup>a</sup>	$n_l$	170,100	vehicle
Number of PHEVs for medium market penetration <sup>a</sup>	$n_m$	523,600	vehicle
Number of PHEVs for high market penetration <sup>a</sup>	$n_h$	680,300	vehicle
Total number of vehicle on the road	$n_t$	3,330,000	vehicle

<sup>a</sup> 2020 numbers

$$CE = n_t \cdot E_{CV}$$

Yearly CO<sub>2</sub> emissions if all vehicles were conventional:

$$= 3,330,000 \times 6,200$$

$$= 20,646 \text{ million kg}$$

$$\begin{aligned}
 CR_l &= n_l \cdot (E_{CV} - E_{PHEV}) \\
 &= 170,100 \cdot (6,200 - 3,100) \\
 \text{Low market penetration yearly CO}_2 \text{ reduction:} &= 170,100 \times 3,100 \\
 &= 527 \text{ million kg}
 \end{aligned}$$

$$\text{Percentage CO}_2 \text{ reduction} = (527/20,646) \times 100\% = \mathbf{2.55\%}$$

$$\begin{aligned}
 CR_m &= n_m \cdot (E_{CV} - E_{PHEV}) \\
 &= 523,600 \cdot (6,200 - 3,100) \\
 \text{Medium market penetration yearly CO}_2 \text{ reduction:} &= 523,600 \times 3,100 \\
 &= 1,623 \text{ million kg}
 \end{aligned}$$

$$\text{Percentage CO}_2 \text{ reduction} = (1,623/20,646) \times 100\% = \mathbf{7.86\%}$$

$$\begin{aligned}
 CR_h &= n_h \cdot (E_{CV} - E_{PHEV}) \\
 &= 680,300 \cdot (6,200 - 3,100) \\
 \text{High market penetration yearly CO}_2 \text{ reduction:} &= 680,300 \times 3,100 \\
 &= 2,109 \text{ million kg}
 \end{aligned}$$

$$\text{Percentage CO}_2 \text{ reduction} = (2,109/20,646) \times 100\% = \mathbf{10.2\%}$$

## Financial

For the purposes of assigning dollar values to the impact calculations, we focussed our calculations on the year 2020, as we feel meaningful values can be developed for this year and the differences between strategies are distinctly demonstrated. We have not adjusted for inflation as the purpose here is primarily to demonstrate comparisons.

Financial differences between different strategies for each uptake scenario are composed of two parts. The first part is the direct savings in energy costs found by moving demand from high cost sources to low.

**Table A- 3: Financial Energy Cost Example Calculation Values (created by authors).**

Parameter	Symbol	Value	Units
Hydro energy cost <sup>a</sup>	$C_H$	5.82	\$/MWh
Cost of marginal supply <sup>a, b</sup>	$C_M$	88	\$/MWh
Low market penetration virtual battery size <sup>c</sup>	$VB_l$	1,592	MWh
Medium market penetration virtual battery size <sup>c</sup>	$VB_m$	4,901	MWh
High market penetration virtual battery size <sup>c</sup>	$VB_h$	6,368	MWh
Percentage of year when we have to use marginal supply	$\eta_y$	25	%
<i>Percentage of vehicles charging during peak time</i>	$\eta_v$	80 <sup>d</sup>	%

<sup>a</sup> 2007 numbers

<sup>b</sup> estimation of today's cost

<sup>c</sup> 2020 numbers – as calculated in section 3.4 (see Figure 3-4)

<sup>d</sup> This is dependent upon the strategy implemented by BC Hydro to manage PHEV charging. For simplicity we have fixed this value. We feel this is justified since the financial impact of PHEVs has turned out to be minimal.

Yearly cost savings due to using power generated at base rather than marginal rate:

$$Cs = 365 \cdot VB \cdot \eta_y \cdot \eta_v \cdot (C_M - C_H)$$

For example the yearly cost increase due to buying power at a marginal rate for the case of low market penetration is:

$$\begin{aligned} C_s &= 365 \cdot VB \cdot \eta_y \cdot \eta_v \cdot (C_M - C_H) \\ &= 365 \times 1592 \times 0.25 \times 0.8 \times (88 - 5) \\ &= \$9.6 \text{ million} \end{aligned}$$

The second part reflects the financial impact of switching to a strategy where the power demand peaks can reliably be shaved. It is based in delaying the time before which an increase in base capacity must be made through a major investment. For this calculation, we identify the year when a major capital asset would be needed in each uptake scenario without peak load management policies and assign the asset a cost. We then identify the year when a managed peak strategy will climb to the same peak threshold. The cost savings is calculated as the time value of money for the amount of the capital investment over the intervening period.

**Table A- 4: Financial Asset Investment Delay Sample Calculation Values (created by authors).**

Scenario	Parameter	Symbol	Value	Units
Low Uptake	Unmanaged Capacity Demand	$t_1$	2021 <sup>a</sup>	Date
	Managed Capacity Demand	$t_2$	2023	Date
Medium Uptake	Unmanaged Capacity Demand	$t_1$	2019	Date
	Managed Capacity Demand	$t_2$	2022	Date
High Uptake	Unmanaged Capacity Demand	$t_1$	2018	Date
	Managed Capacity Demand	$t_2$	2021	Date
	Cost of Asset	$A$	100M <sup>b</sup>	Dollars
	Work Annual Interest Rate	$r$	10	Percent

<sup>a</sup> The dates used in this table indicate the years that capacity demand is projected to first exceed 13 MW.

<sup>b</sup> This is an order of magnitude value for an incremental capacity increasing asset such as an additional turbine added to an existing dam.

For the case of low market penetration

$$As = A \times \left( (1 + r)^{(t_2 - t_1)} - 1 \right)$$

$$As = 100,000,000 \times \left( (1.1)^{(2023 - 2021)} - 1 \right)$$

$$As = \$21 \text{ million}$$

Total Financial Impact

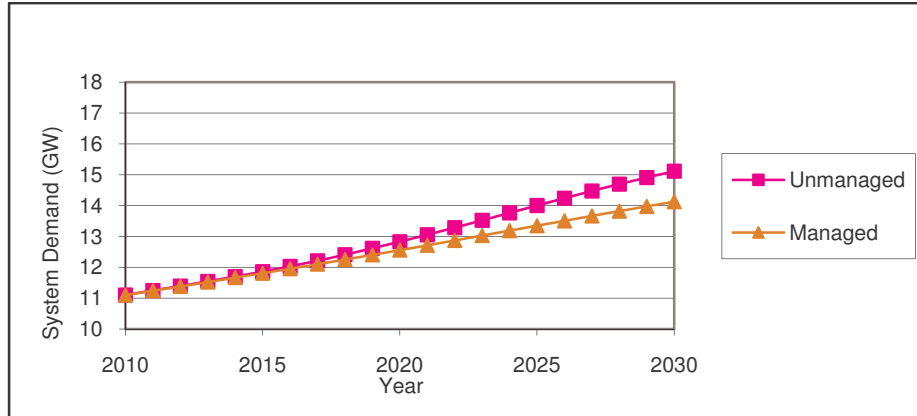
$$F = Cs + As$$

$$F = \$9.6 \text{ million} + \$21 \text{ million}$$

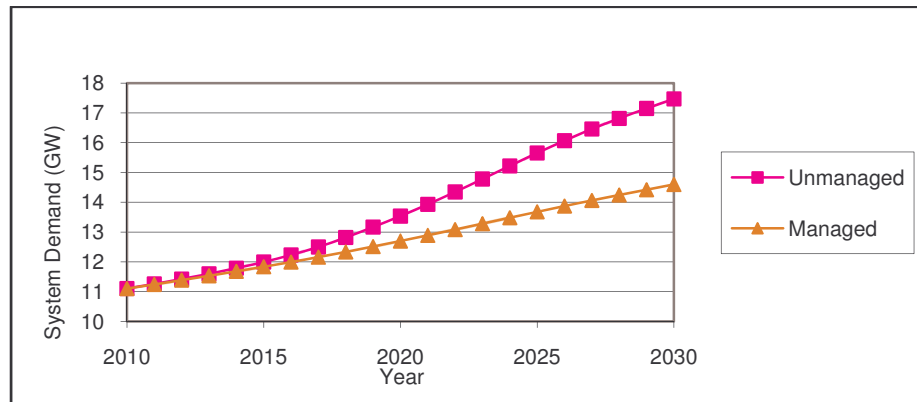
$$F = \$30.6 \text{ million}$$

The dates for the above calculation are read from the following figures which show the total projected peak capacity demand profiles after the inclusion of both an unmanaged customer daily charging model, and a managed one where 80% of the PHEV charging power draw is shifted off the daily peak.

**Figure A- 1: Capacity Demand Increase Range – Low Market Penetration (created by authors).**



**Figure A- 2: Capacity Demand Increase Range - Medium Market Penetration (created by authors).**



**Figure A- 3: Capacity Demand Increase Range - High Market Penetration (created by authors).**

