Cornell University

College of Engineering

Engineering Management

Plug-In Hybrid Vehicles

Critical Analysis and Los Angeles Regional Feasibility Study

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Critical Analysis and Los Angeles Regional Feasibility Study

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Executive Summary

This report is the product of a team project conducted at Cornell University for the Master of Engineering degree in Engineering Management. The project goal was to study the potential transition of light duty passenger vehicles to the Plug-In Hybrid Electric Vehicle (PHEV) concept, using the Los Angeles basin as the feasibility focus region. The analysis and findings should prove useful to governments, consumers, utilities, vehicle manufacturers, and other stakeholders.

PHEVs incorporate both an electric motor and an internal combustion engine, with a battery pack that can be recharged externally. This vehicle concept has been gaining attention due to its potential ability to reduce petroleum consumption and carbon emissions, especially when combined with sustainable, low-carbon electricity generation. A mass transition toward PHEVs has been seen as one possible measure for addressing concerns related to climate change, global peak oil, dependence on foreign oil, urban smog, and air pollution.

The team began by conducting a literature review in order to gain background information on the PHEV. The scope of the literature review was limited to the existing PHEV technology in Europe, Asia and North America; the PHEV battery with a focus on the Lithium-ion battery; electrical infrastructure including charging stations, smart grid systems, and renewable energy; and finally a section summarizing government, consumer and other points of view regarding PHEVs. The purpose of the literature review was to collect existing information about PHEVs as well as to identify potential areas of research.

A Streamlined Life Cycle Analysis (SLCA) was performed to evaluate how environmentally responsible the PHEV is when compared to Internal Combustion Engine Vehicles (ICEVs). All five stages of the life cycle were studied: premanufacture, manufacture, delivery, use, and disposal. Though the ICEV showed better results in both the manufacture and disposal stages, overall the PHEV achieved a better score and proved to be the better environmental choice.

A regional analysis of electrical infrastructure was performed to determine whether the local utility had sufficient generation capacity to support PHEVs. The analysis considered available capacity, existing electricity demand, and hypothetical PHEV charging demand. These were compared on an hourly basis in the context of the hottest day on record, when the infrastructure would be under maximum stress. Several scenarios were considered for determining available capacity. These include currently existing generation resources; hypothetical resources that meet 2020 targets for increased renewables; and increased renewables in conjunction with a vehicle-to-grid system that uses PHEV batteries as a form of grid storage. A Solver analysis was able to calculate maximum PHEV fleet penetrations under the various scenarios, using both default assumptions for PHEV electricity usage and theoretical maximums. It was found that LA's existing generation resources can support a 100% transition under default assumptions, and that the 2020 target resources can support a 98% transition if a vehicle-to-grid system is implemented.

The team also performed a cost analysis, focusing on the costs incurred by the customer. The study was concerned with both direct and indirect costs. The indirect cost consisted of a qualitative analysis, and the PHEV proved to incur lower indirect costs. The direct costs were subdivided into two major components: the capital costs and the operating costs. The capital costs consisted of the initial costs to own the car and the operating cost consisted of costs from maintaining and driving the car over its lifetime (a period of 15 years). The results of this analysis determined that the PHEV has higher capital

costs compared to the ICEV but that the overall costs over the lifetime of the car were similar for both. The following table summarizes the findings of the cost analysis.

	ICEV	PHEV
Capital Costs	$21,180	$33,500
Operating Costs	$24,838	$14,209
Total Costs	$46,018	$47,709

A review of current government incentives found that the government of California promotes PHEVs and other low emission vehicles through legal regulations, offering various advantages to their drivers. The Climate Change Program AB32, passed in 2006, sets annual goals for the reduction of greenhouse gas emissions until 2020. This program requires manufacturers to reduce the emissions of their fleets significantly year by year, starting in 2010. Meanwhile, by purchasing a PHEV, the consumers are granted tax credits that are worth between $2,500 to $7,500 depending on the size of the battery. In addition, PHEV owners enjoy the advantage of free parking in certain areas in LA and are allowed to use carpool lanes in the greater LA area.

Overall, this research project reveals that PHEVs are the more environmentally friendly solution for private transportation when compared to ICEVs. The infrastructure analysis demonstrates that generation capacity is not a limiting factor for PHEV penetration in Los Angeles. However, other utilities should do their own local analysis to determine whether additional generation resources are needed to support the charging of PHEVs. Utilities can optimize the use of the existing generation resources by implementing a smart-grid system that allows them to control the timing of PHEV charging. Wind generation is highly compatible with PHEVs, as both peak at night, and PHEV batteries can act as form of distributed storage that would help mitigate the intermittency of wind. Utilities with access to wind resources should therefore promote PHEVs and consider implementing vehicle-to-grid systems.

Various stakeholders including manufacturers, consumers and utilities influence the transition from ICEVs to PHEVs in the LA area. To increase and expedite PHEV penetration, the government should consider service-based incentives in addition to the existing financial incentives. Private organizations such as entertainment facilities, car wash companies and auto shops could be required to offer exclusive service and ticket booth lanes for PHEV owners. Such service-based incentives raise public awareness and make PHEVs more attractive while minimizing revenue losses for the government. The government should also consider introducing PHEVs in their fleets as police cars or ambulances to raise public awareness and increase demand.

PHEVs can help car manufacturers comply with the emission reduction requirements in California. Therefore, they should extend their product portfolio and consider the introduction of luxury PHEVs and SUV PHEVs. Key promotional values that can be used for manufacturers' marketing campaigns include lower noise pollution, less emissions and significantly lower operating costs. In addition to promoting these values through creative advertisements, they should also be communicated via bi-directional promotion strategies which allow consumers to easily inquire for more information about PHEVs.

At this early stage of the PHEV development, there are already strong arguments for consumers and other stakeholders to support this alternative form of light duty passenger transportation. It is shown that PHEVs are cost competitive, more environmentally friendly and energy efficient. In addition, cost savings can be expected as the technology matures. The current capacity of LA's energy infrastructure is able to support the maximum penetration rate of PHEVs, and with effective promotional efforts from the government, manufacturers and other stakeholders, a transition to PHEVs in LA is achievable.

Team Roster

The following map shows the countries of origin of the eleven team members who worked on the PHEV project. The backgrounds and interests of each group member are discussed below.

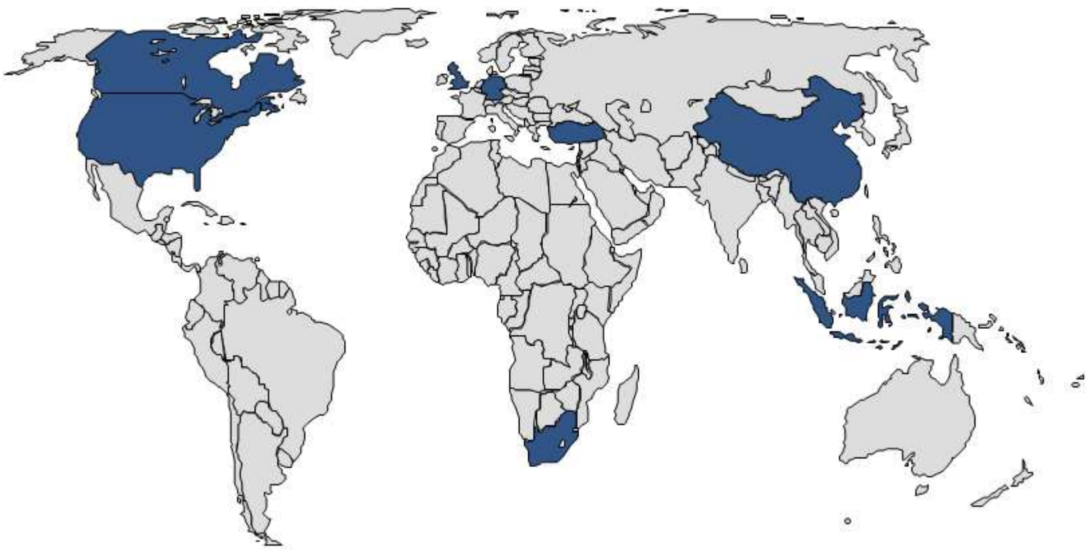

Figure 1 – Countries of Origin of the PHEV Team Members

Auret Basson studied Civil Engineering during his undergraduate education in South Africa, after which he completed a Master's degree in Renewable and Sustainable Energy. While completing his studies, he has worked for a Consulting Engineering firm (BKS Engineering and Management) for almost 5 years in their Water & Power Division. Auret has worked on various water treatment plants all over Africa. He was the deputy project manager for a cooling water pipeline currently being constructed for two coal-fired power stations in South Africa. In the last two years, Auret has become more involved in renewable energy projects and last worked as the project engineer on a 40MW community wind farm project.

Auret was particularly interested in the grid integration aspects of the PHEV project. Specifically, he was interested in the impact that increased PHEV penetration could have on the electric grid in terms of added storage and its subsequent impact on renewable energy integration. He also wished to gain understanding about the Smart Grid's role in a high-penetration PHEV system and explore possibilities for achieving a dynamic, integrated system between energy supply and the PHEV user.

Mert Berberoglu was born and grew up in Ankara, Turkey. He studied Environmental Engineering at the Middle East Technical University. Before coming to Cornell, Mert was working at a Membrane Bio-Reactor (MBR) Wastewater Treatment Facility as an Environmental Engineer. His concerns about the environmental issues increased his interest in the renewable energy field. Moreover, he was also interested in the managerial aspects of engineering. Accordingly, during his research for the PHEV project, Mert participated in both, infrastructre and business sub-teams. He describes his experience in the PHEV team as unique and unforgettable. Aside his contrubutions, he developed a deeper knowledge about wind energy. He also had a chance to put his theoretical knowledge about team dynamics in to practice and improved his facilitation skills.

Weijia Bi was born in China and completed her undergraduate studies in Shanghai, majoring in Material Science and Textile Engineering. In addition, she completed various summer internships in the financial services sector and worked for foreign trading companies in China. Weijia continued her studies at Cornell and was very interested in the PHEV project, as she is herself an owner of a hybrid vehicle. Weijia appreciates that hybrid vehicles are more efficient, less polluting and less noisy, thus protecting the environment. She considers PHEVs to be a meaningful topic for research, given their potential for improving quality of life. Weijia was also interested in the project as a way to develop her communication skills, presentation skills and other "soft skills."

Vincent DeRosa was born and raised in the United States. He studied at the Pennsylvania State University and graduated in 2010 with a Bachelor of Science in Civil Engineering. His interests in the PHEV project were primarily related to the infrastructure associated with PHEV technology, particularly the systems related to an increase in penetration following the initial takeoff, such as commercial and/or public charging stations.

One of Vincent's goals in choosing this project was to become familiar with recent advances in green technology. He also hoped to gain experience with the business aspect of PHEVs and their financial feasibility. One of the reasons he decided upon the Engineering Management program was to gain experience with the less technical business and managerial aspects of engineering projects, which was left out of his undergraduate education.

Sara Lachapelle was born and raised in Calgary, Canada and attended Cornell University for her undergraduate degree in Chemical Engineering. She was primarily involved in research regarding the PHEV technology, including a life-cycle analysis, cost analysis and societal analysis. After she finishes the Master of Engineering program, Sara plans to work in the financial services industry.

Christina Lu was born in China and came to the U.S. about ten years ago. She received her undergraduate degree in Chemical Engineering at Cornell in May 2010 and has had internships in the petroleum industry and in a multi-industry company. Over the course of her studies, however, she has become more interested in the financial services industry and the consulting industry. Christina saw this project as an opportunity to gain experience in the consulting process, allowing her to combine her technical capabilities with her interest in finance and consulting. She also considers herself a big advocate of renewable energy. This project has allowed Christina to gain a better understanding of the evolving PHEV technology and how it can create a healthier environment when combined with a sustainable power grid. Christina was mainly involved with researching the vehicle technology as well as the business aspects of a market transition.

Torio Risianto was born in Jakarta, Indonesia, and lived in Bali, Indonesia for eight years. He studied Industrial Engineering and Operations Research at the University of California, Berkeley, specializing in operations and supply chain management. Torio pursued his Master's degree in Engineering Management at Cornell University and discovered his interest in renewable energy when he read and watched related background information for this project. He is especially concerned about the catastrophic global effects of oil scarcity if comparable renewable energy technologies have not been developed. His goal in the project was to learn about the societal significance of renewable energy and technology. In addition, he has gained experience in working with a large team and was able to relate it to project management concepts.

Torsten Steinbach studied Industrial Engineering and Business Management at Nordakademie University in Hamburg, Germany. During his undergraduate studies he focused on operations research and project management. Torsten has completed various internships in the automotive industry and worked for Mercedes-Benz after his graduation. He has been continuing his studies at Cornell University since August 2010, with a focus on manufacturing management. Upon completion of his Master's degree Torsten wishes to continue working in the automotive industry. The PHEV project was attractive as an opportunity to extend his knowledge of sustainable transportation technologies. Torsten is particularly interested in the business aspects of a transition from internal combustion engine vehicles to PHEVs and the market potential of the new technology for car manufacturers. He wishes to understand the roles of different stakeholders of a PHEV introduction and study possibilities for promoting and marketing PHEVs.

Adam Stevens grew up and studied in the UK before moving to the US and studying at Cornell. His undergraduate degree was a Bachelor of Engineering in Electronic Engineering and Music Technology Systems. The PHEV project was a perfect match for Adam because of his career goals relating to renewable energies and evolving technology markets. Aside from this fact, Adam also enjoys driving. His personal goals for the project were mainly centered around the impact that such a technology would have on electricity infrastructure, and Adam was very interested in the Vehicle-to-Grid possibilities that were studied. Adam plans to keep an eye on this evolving technology as he hopes to see it become a mainstream transportation choice in the coming years.

Alice Yu's background is unusually local, being both a US-born citizen and a recent graduate of Cornell University. She received her Bachelor of Science from CALS in May 2010, having majored in Environmental Engineering Technology. Throughout her undergraduate career, Alice pursued a strong interest in issues of environmental sustainability, particularly as they relate to the sustainable energy challenge. The PHEV project has been very relevant to these interests, allowing Alice to deepen her understanding of sustainable transportation, renewable energy, electricity infrastructure, and smart-grid systems.

Naji Zogaib was born and raised in Lebanon. He attended the University of Toronto for his undergraduate degree in Mechanical Engineering. While completing his undergraduate studies, he worked for a Consulting Engineering firm (SNC-Lavalin Nuclear Inc.) for two summer internships. He was in charge of drafting technical and commercial proposals for the different work packages of one of the major projects the company was involved in. This experience led him to choose to pursue a Masters degree in Engineering Management.

Naji's work on the PHEV project focused primarily on the research of the technology including a life cycle analysis, a cost analysis and a PHEV penetration forecast. Naji has particular interest in all topics related to energy and the environment and hopes to re-enter that field of work professionally upon graduation.

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1 PROBLEM DESCRIPTION AND STATEMENT OF SCOPE

This project is a study of Plug-In Hybrid Electric Vehicles (PHEVs) as a sustainable transportation energy concept. Its scope includes a critical analysis of the vehicle technology, a regional feasibility study of the electrical infrastructure necessary for the vehicle fleet, and a business-focused transition analysis.

1.1 Background

Cheap fossil fuel energy has been one of the most important drivers of economic growth in the 20th century. However, the US dependence on fossil fuel is becoming an ever-growing concern due to looming challenges such as climate change, air pollution, and global peak oil. There is also public and political interest in reducing dependence on foreign oil and supplying a larger portion of US energy needs with renewable energy.

The transportation sector currently relies heavily on the Internal Combustion Engine Vehicle (ICEV), which necessitates the burning of petroleum in the form of gasoline or diesel. This releases carbon dioxide – a greenhouse gas that constitutes a major contributor to global warming. Other pollutants in the exhaust are harmful to urban air quality and constitute a major contributor to smog in densely-populated cities.

PHEVs are increasingly recognized as a highly efficient and environmentally attractive form of sustainable light duty passenger transportation (cars, minivans, sport-utility vehicles, etc). PHEVs are powered using an electric motor and battery pack that is recharged using an external electricity source. The vehicle also incorporates a traditional internal-combustion engine which recharges the battery when needed and provides back-up power and range extension. This technology drastically reduces the average amount of petroleum consumed per vehicle-mile, and the efficient electric power-train results in less energy consumed overall. This reduces the marginal carbon footprint per vehicle-mile, an effect that is maximized when the batteries are charged using low-carbon electricity. Low-carbon electricity generation includes sources such as wind, solar, hydroelectric, geothermal, and nuclear.

Due to these considerations, the PHEV transportation concept is receiving a great deal of interest from regional and national governments, as well as from energy companies and vehicle manufacturers. The successful adoption of the technology will depend on many factors, as will its impact on society. These factors include environmental performance, cost competitiveness, availability of electrical infrastructure, consumer behavior, government initiative, and marketing strategy.

1.2 Project objectives

This project seeks to understand the potential transition of light duty passenger vehicles from ICEVs to PHEVs in a specific geographic region. The Los Angeles basin serves as the focus region due to its large transportation demand and the various energy resources available, including wind and solar.

Due to the range of critical issues associated with such a transition, the scope of this project is organized into three major components. The first component explores issues relating specifically to the vehicles themselves; the second component explores issues relating to the local electrical infrastructure; and the third component explores issues relating to business feasibility and transition.

The combined objective is to achieve a well-rounded, system-level perspective on the desirability and feasibility of this move away from incumbent ICEVs toward the new PHEVs, as well as identifying what kinds of investments and adaptations may be required of various stakeholders. This analysis should provide useful insight to governments, consumers, utilities, vehicle manufacturers, and other stakeholders.

1.3 PHEV technology

The main objective of this component of the project is to determine how the PHEV compares against the ICEV in terms of environmental performance, cost competitiveness, and local societal acceptance.

1.3.1 Streamlined LCA

Because the negative environmental impact of ICEVs is such a primary motivator for the transition toward PHEVs, a life cycle analysis (LCA) was performed in order to compare the two technologies. The purpose was to determine whether the PHEV is actually the “greener” alternative. The scope of this LCA was comparative rather than absolute; thus, the analysis overlooked the vehicle components that were common to both vehicle-types and focused instead on differences such as the battery, electric motor, energy source, etc.

Rather than attempting to quantify absolute measures of environmental performance such as carbon footprint, this project used a streamlined approach developed by Yale professor T.E. Graedel. This approach assigns weighted rankings to five different environmental stressors over five different life stages of the vehicle. [1]

1.3.2 Cost analysis

The LCA determines whether or not the PHEV is the more environmentally friendly alternative, but eventually, the price the end-user is willing to pay is the deciding factor. The cost analysis took into consideration both direct and indirect costs. Direct costs consist of capital costs, operating costs and end-of-life (disposal) costs. The indirect costs focus more on aspects that will affect society as a whole and thus tax payers. The cost analysis plays a major role in determining whether or not the PHEV is a feasible alternative to the ICEV. If costs are too high, customers will not buy-in to the idea of the PHEV, even if it is the environmentally friendlier choice.

1.3.3 Societal analysis (background on LA)

This analysis is concerned with how the PHEV would fit into the local Los Angeles society. This includes a study of driving trends of the community, including average driving distances, highway vs. city mileage,

[1] (Graedel, 1998)

daily peak hours, seasonal trends, surrounding topography, etc. In addition, the analysis will evaluate LA's perception of PHEVs and green transportation as suggested by indicators such as the rate at which people are buying hybrid vehicles. The study will also assess the demographics of the LA population, particularly with respect to disposable income and the effect of PHEVs across society's various income segments.

1.3.4 Assumptions

The following are some of the assumptions that the above studies will be based on:

- Lithium Ion (Li-Ion) is to be used as the battery of choice for the PHEV. The literature review determined that the Li-Ion battery exhibited the best performance, showing the best results in terms of efficiency, capacity, weight and size when compared to the alternatives (see Section 2.2 on page 23).
- The project assumes that the average PHEV drives 80% on electricity and 20% on gasoline. This simplification will allow for a better understanding of the LCA and of the cost incurred on the customer by each technology.
- The study will be focused on a mid-size light duty passenger vehicle. A Honda Accord is a good example of such a type of car.
- The technology is already feasible in terms of performance and safety. Assessment of the technology's risks, such as a failure modes and effects analysis (FMEA analysis), is outside the scope of the project.

1.4 Electrical infrastructure in the Los Angeles basin

A large transition toward PHEVs will result in a proportionally large increase in electricity demand. The main objective of the infrastructure component of the project is to determine whether this increased demand can be feasibly supported by the electrical generation resources available to the local utility – the Los Angeles Department of Water and Power (LADWP).

1.4.1 Available generation capacity

The project considers both the current available generation resources and potential future generation resources. The current status of the power grid must be analyzed to serve as a basis for comparison before researching the added energy requirements of PHEVs. We are interested in both the total available capacity and the nature of those resources. The study investigates the LADWP's current electricity generation mix, determining the use of fossil fuels versus renewable energy sources. The current existing infrastructure serves as a valuable context for scenario analysis.

In addition, our project also considers potential changes to the generation mix. In particular, the utility's stated goals for 2020 serve as a useful reference point. Increased wind and solar energy will result in changes to the hourly availability of dependable capacity, which is important to consider when performing scenario analysis.

1.4.2 Electricity demand

The project considers both existing demands on the electrical system and the hypothetical added demand from PHEVs. Seasonal, daily, and hourly patterns are considered when evaluating these demands. Based on these patterns, we can calculate what penetration levels are feasible and theoretically possible under various supply scenarios. It is important to determine what additional generation capacity must be added (if any) in order to support the total combined electricity demand.

1.4.3 Smart grid and vehicle-to-grid

One of the reasons PHEVs have been receiving interest is the potential for vehicle-to-grid applications in the context of a smart grid. The concept of vehicle-to-grid (V2G) is that PHEVs can be left plugged-in whenever they are not being driven. Whenever there is a sudden drop in supply or a spike in demand, the grid can draw power from the car batteries. Conversely, whenever there is a spike in supply or a dip in demand, the grid can load the excess supply into the batteries. Thus V2G can act as a form of backup storage and load following for the grid. This can help mitigate the intermittency of resources such as wind energy.

V2G would require a "smart grid" in which there is real-time digital communication and control between the grid operators and the vehicle charge points. The objective of this study is to determine how such systems can maximize renewable potential, reduce costs, and facilitate the integration of PHEV demand into the existing electrical supply and demand picture.

1.4.4 Assumptions

The following are some of the assumptions that the above studies will be based on:

- There exists a public preference for renewable electricity over electricity generated from fossil fuels.
- Some form of carbon economy will exist in the study region that will help incentivize improvements that will result in reduced carbon emissions. (e.g. cap-and-trade, carbon tax, or emissions constraints such as those found in California's AB32 legislation)
- It is outside the scope of our project to study the political and regulatory difficulties associated with the installation of additional transmission and distribution infrastructure. We will assume that any necessary, financially-viable infrastructure can be constructed without issue.
- It is outside the scope of our project to assess potential sites for renewable electricity generation. It is assumed that the targets published by the utility are physically achievable given the wind and solar resources of the region.
- It is outside the scope of our project to propose potential sites for public charging points and outline an implementation schedule. It is assumed that the availability of public charging will not be a binding constraint on PHEV penetration, as it is a convenience rather than a primary source of electricity, with the majority of recharging taking place at the owner's home.

1.5 Business and transition analysis

The objective of this component of the project is to critically evaluate the business case for the PHEV and analyze how a transition could take place. This analysis is necessary because the PHEV is competing against an incumbent technology – the ICEV. Even if this project concludes that PHEVs are superior to ICEVs and that the infrastructure can support them, it is important to study how the move away from ICEVs can take place.

1.5.1 Stakeholder analysis

This analysis was performed in order to identify which stakeholders are most relevant to the possible transition from ICEVs to PHEVs. In addition to consumers, these stakeholders include the government, vehicle manufacturers, utility companies, and providers of financial services. The project analyzes each of these stakeholders in order to determine how they would be impacted by the PHEV transition, how they can stand to benefit, and how they might exert influence on the transition.

1.5.2 Government initiatives

The project performed a review of existing government initiatives that serve to support PHEVs, whether directly or indirectly. In addition, we assessed potential new initiatives that could be introduced in order to expedite the adoption of PHEV technology, including both financial and non-financial incentives. The project analyzed how the federal, state and local governments could help educate the public on the environmental benefits of PHEVs and facilitate the transition until capital costs can be reduced.

1.5.3 Marketing analysis

This analysis sought to determine how to optimize the marketability of PHEVs. The question was analyzed from the manufacturer's perspective under the classic 4P marketing framework (product, price, place, and promotion). In addition, we explored potential opportunities to use PHEVs to address challenges faced by the stakeholders, such as emissions regulations and a desire for vehicles that are large yet fuel-efficient. The analysis also identified several non-obvious consumer benefits of the PHEV that can be used to advertise it to the customer and make it more attractive compared to the ICEV.

2 LITERATURE REVIEW

2.1 PHEV Technology

A plug-in hybrid electric vehicle (PHEV) is a hybrid vehicle with rechargeable batteries that can be connected to an external electric power to restore to full charge. A PHEV combines an electric motor, an internal combustion engine, and a plug to connect it to the electrical grid. PHEVs have several important advantages over the conventional vehicles. Firstly, it can reduce air pollution by eliminating greenhouse gas emissions that contribute to global warming. Secondly is the convenience of recharging the vehicles at home. Notable automakers in three major continents include Toyota in Japan; Volvo, Audi, and Peugeot in Europe; and General Motors, Chrysler, and Ford in the United States. All of these companies are currently undertaking extensive research and development to produce the next generation of "green" vehicles. This review has been divided to recognize the three distinct markets.

2.1.1 Asia

Toyota's Prius PHEV vehicle is based on the third-generation Prius. The vehicle is an expansion of Toyota's Hybrid Synergy Drive technology that comes with an external power source that allows the lithium-ion battery to be recharged from a household electrical outlet. When it's fully charged, Toyota's PHV can be in electric vehicle mode with zero greenhouse emissions for about 12.4 miles (20km) and is capable of achieving highway speeds up to 60 mph in electric-only mode which is sufficient enough for shorter distances or city commute, while for long-distance journeys, the vehicle has to be operated as a full hybrid.

According to the pressroom of Toyota website, in late December 2009, a total of 350 vehicles were delivered to Japan and Europe to support the model as well as to raise social awareness. In early 2010, 150 vehicles arrived in the U.S. where they were placed in regional clusters for market/consumer analysis and technical demonstration. All vehicles that were released for test were equipped with data retrieval devices which monitor activities such as how often the vehicle is charged and when, whether the batteries are depleted or being topped off during charging, trip duration, mpg in electric mode and so on. In October 2009, Toyota finalized its partnership with Xcel Energy's SmartGridCity program in Boulder, Colorado to test ten PHVs with Boulder residents whom are participants in an interdisciplinary research project coordinated by the University of Colorado at Boulder Renewable and Sustainable Energy Institute to better understand the vehicle by gathering data on performance and charging patterns, consumer behavior and preferences, as well as customer-electric utility interaction[2]. In February 2010, Toyota in Norway signed a partnership agreement with the City of Oslo to run a demonstration project with two plug-in hybrid vehicles for three years starting in June 2010[3].

[2] (Toyota Environmental, 2009)
[3] (Abuelsamid, Toyota to test Prius PHEV in Oslo, Norway, 2010)

2.1.2 Europe

In Europe, PHEVs appear to be an immature technology. Many recent advances have taken place concerning hybrid vehicles, but the combination of a plug-in option has yet to be established in the market. Also, new European regulation dictates that automakers' fleets must not exceed an average greenhouse emission of 130 g CO2/km starting in 2015[4]; this is bound to have a large reaction from all of the automotive companies.

The Geneva motor show in March 2010 provided the industry with many exciting announcements for future releases. Notably, Peugeot have given details on their 2011 model, the 3008 Hybrid4[5]. This 5-person 2.0 litre Diesel hatchback offers 163bhp from the efficient diesel engine and an addition of 37bhp from an all-electric motor (200bhp comb.). Overall, they are predicting a possible fuel economy as high as 74.4mpg with 99g/km CO_2 emissions. On top of this, the 3008 Hybrid4 will come with 4 possible drive modes, including a Zero Emissions (ZE) mode where it will operate solely on the electric motor, which offers exciting possibilities for inner-city users especially. The system layout allows for 4x4 drive possibilities and also the electric motor can be used as a 'boost' option for hard acceleration times. An energy recovery system (the electric motor becomes a generator) enables kinetic energy created by the vehicle to be transformed into electrical energy to recharge the Nickel Metal Hybrid batteries during deceleration. This recovery system can be used to reduce fuel consumption accordingly. On top of this, it was announced that a Plug-In version will be released the following year, with expectedly similar performance parameters.

Volvo is also making their impression on the PHEV market. The V70 hybrid combines the popular features of the original ICE model with the ability of a 30 mile (50km) range on electricity alone[6]. It is expected for release in 2012. No formal details have yet been released, but the company will be teaming up with Swedish energy utility Vattenfall to create a new plug-in hybrid. They plan to use a lithium-ion battery pack whose batteries, once depleted would charge in about five hours from a household socket. Their vehicle will also use regenerative braking to maintain charge.

Audi's A1 E-Tron was also unveiled at Geneva, but remains only a concept as of yet[7]. The A1's lithium-ion battery pack has a capacity of 12 kW-hours, which can provide up to 30 miles (50km) of range per charge. This combines with a gas-engine to provide an additional 125 miles (200km) of range after the electric charge has run out. This is relatively small as the fuel tank holds only 3.17 gallons. Overall, this car is expected to offer a 124 mpg fuel efficiency. On Sept 9th 2010, Audi started testing its fleet of A1 E-Tron Mega City Vehicle (MCV) in Munich[8].

In the luxury market sector, Porsche has released details of the PHEV 918 Spyder[9]. This super car has a top speed of nearly 199mph, and can accelerate from 0 to 62mph in just 3.2 seconds: all for a $650,000

[4] (International Council on Clean Transportation)
[5] (Abuelsamid, Auto Blog Green)
[6] (Berman, Volvo V70 Plug-in Hybrid)
[7] (Berman, Audi A1 E-Tron)
[8] (Yvkoff)
[9] (Porsche Approves 918 Spyder Hybrid Supercar)

price tag. The high-end automaker says that it has received 2,000 non-binding submissions of interest for the 918 - more than twice the required level of interest for the board to vote on production of a new vehicle. The Spyder will have a total of 718bhp - 218bhp coming from a pair of 160kW electric motors and 500bhp coming from a 3.4 liter V8 engine. The electric drive train will provide about 16 miles range from the fluid-cooled lithium ion battery. It is claimed that the car will produce just 79g/km CO_2 emissions and achieve 78mpg.

2.1.3 North America

In the American automobile market, the Ford Escape PHEV uses a Series-Parallel power-train similar to that of the Toyota Prius[10]. While Ford used some of Toyota's Prius's Solomon patents[11], the Escape was designed independent of the Prius, and therefore its technical specifications are very different. Ford is in partnership with Microsoft on new energy management software that will help customers determine when and how to most efficiently and affordably recharge PHEVs.

The Ford Escape PHEV, a research vehicle using high voltage lithium-ion batteries can deliver up to 120mpg[12] resulting in a reduced need for refill. Full charge of the battery takes six to eight hours from a standard power outlet. On a full charge, the Ford Escape has a 30 mile[13] range running solely on the electric mode. Once the battery charge has depleted, the vehicle continues to operate as a fuel efficient, standard Ford Escape Hybrid. The transition is automatic and unnoticeable to the driver.

Ford Motor Company is partnered with Progress Energy, a regional utility company, who is adding a Ford Escape PHEV to its Florida operations. Ford was the first automotive manufacturer to partner with the utility industry in a shared effort to understand all of the issues related to PHEV technology and its interconnectivity with the electric grid. Ford started the program in mid-2007 when it formed its first utility partnership with Southern California Edison. Ford's utility partners have already conducted more than 160,000 miles of road testing with a fleet of 21 Escape PHEVs[14].

The Chevrolet Volt Hybrid propulsion system is based on General Motor's new Voltec (formerly known as E-Flex) electric automobile platform, which differs significantly from GM's earlier BAS Hybrid and Two-Mode Hybrid systems. For the first 40 miles, the Volt is powered by electrical energy, a distance longer than the daily commute for 75% of Americans (who average 33 miles). After depletion, a small 4-cylinder internal combustion engine (ICE) using premium-grade gasoline creates electricity on-board using a 55 kW generator to extend the Volt's range to more than 300 miles[15].

[10] (Coperation, 2010)
[11] (Alternative Fuel Vehicles(AFVs) and Hybrid Electric vehicle report, 2010-03-09)
[12] (2005 Ford Escape Hybrid Electric Vehicle, 2005)
[13] (2005 Ford Escape Hybrid Electric Vehicle, 2005)
[14] (Ford delivers E85 hybrid vehicles, 2007)
[15] (Stenquist, 2010)

2.2 PHEV Battery

This section discusses current development of li-ion battery technologies for plug-in hybrid electric vehicle (PHEV) applications. In any PHEV architecture the battery plays a crucial role in storing energy from the electric grid as well as passing energy back and forth with the electric motor to maximize efficiency. Ultimately, the commercial success of the PHEV depends on the development of appropriate battery technology due to its expensive price.

2.2.1 Battery R&D

AFS Trinity, an American company that develops PHEV technology, has recently invented a more efficient battery. By combining Lithium-ion battery, which has high storage but low power, and ultra capacitors, which have low storage and high power, the overall battery system has a longer life, higher energy density and it also weighs less. This is due to the fact that energy output fluctuation will be more controlled by such combination and less lithium will be required. These batteries will be equivalent to current batteries with a higher energy capacity. GM will apply the technology for its future SUV PHEV fleets. One issue with this product on the market is that since its required energy capacity is lower, it receives less tax credit from the government[16].

Electrovaya, developer and manufacturer of portable power solutions based in Ontario, has signed a Memorandum of Understanding (MOU) to form a joint venture with Visionary Vehicles, a PHEV developer and manufacturer in New York. The joint venture will result in a creation of a separate company, owned equally by both firms, that focuses on battery research and development. Electrovaya is known for its SuperPolymer technology, which provides longer battery life span. Visionary Vehicles, on the other hand, develops vehicles that are targeted to luxury consumers and its products are comparable to German and Japanese luxury car models[17].

BYD, a Chinese manufacturer, still remains the largest battery producer in the world. Based in Shenzhen, the company has built an additional factory worth $732 Million in Huizhou in the Guangdong province. This expansion is supported by Berkshire Hathaway, through which Warren Buffet invested $230 Million. BYD, also a successful PHEV manufacturer, claimed its proprietary battery technology called “lithium-ion ferrous phosphate” although the ability to apply this new technology at full scale while maintaining low cost is still questionable[18].

Argonne National Laboratory, one of the US science and engineering research national laboratories, had its lithium-ion battery commercialized by BASF. Argonne signed a licensing agreement that allows its patented composite cathode materials to be used by BASF, which planned to manufacture advanced lithium-ion batteries. Consequently, the company also planned to build a manufacturing plant in Elyria,

[16] (AFS trinity)
[17] (Abuelsamid, Auto Blog Green)
[18] (BYD)

Ohio, to start the battery mass production.[19] The technology results in high performing, longer lasting and safer than current battery products for EVs, HEVs and PHEVs[20].

Ford is currently working with academia and battery suppliers to improve the efficiency of lithium-ion batteries. It found that lithium-ion batteries are 5% more energy efficient than the nickel-metal hydride and they are also 30% less expensive. It also announced that all of its green vehicle models would use lithium-ion instead of nickel-metal hydride. Ford estimated that its battery system technology could support PHEV fleets by 2012. One of the challenges in this development stage is safety issue related to extreme hot or cold temperature, which has been an issue for li-ion batteries used in laptops and other consumer electronics. To accelerate Ford's research, Michigan Economic Development Corporation granted a $55 Million tax credit to the company. Moreover, Ford established partnerships with eight regional electrical utility companies to test their battery-powered Ford Escape[21].

Other companies who are developing more effective and cheaper li-ion batteries are the following: A123 Systems, Johnson Controls – Saft Advanced Power Solutions, China BAK Battery, Lishen, Wanxiang, Shuzhou, Phylion, and Exponent. [22]They were present at the Vehicle Battery Summit in Shanghai in September 2010 along with major automakers (e.g. Toyota, Ford, Chrysler) to discuss the current development of battery technologies and how it would impact the penetration of green-vehicles in the market[23].

A Massachusetts company named A123 Systems uses a technology initially developed at MIT called low impedance Nanophosphate electrode, which is used to produce low cost/watt batteries due to their higher voltage compared other long-life battery systems. This year, the company developed battery packs for Shanghai Automotive Industry Corporations, the largest automaker in China. [24]In addition, the company also signed a supply contract with Fisker Automotive for battery systems of Fisker Karma model[25].

Smaller companies and academic institutions also contribute in li-ion battery development. For example, ActaCell, a spin-off company from University of Texas, Austin, has received funding from the Texas Emerging Technology Fund for their research in li-ion batteries. Supported by the university's Material Science and Engineering Laboratory, the company created a manganese spinel formulation that might solve decreasing capacity over time problem[26].

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[19] (Argonne National Laboratory)
[20] (Argonne National Laboratory)
[21] (Red Orbit)
[22] (PR Newswire)
[23] (SAE International)
[24] (A123 Systems)
[25] (A123 Systems)
[26] (Green Car Congress)

2.2.2 Li-ion Battery Recycle

Recycling batteries create an extra hassle to consumers because there are regulations to treat each type of battery. For example, car owners have to dispose lead acid batteries at designated places such as Autozone or Sears, and would otherwise be penalized by the government[27]. Presently, Toxco, based in California, is still the only company in the world that can recycle large size of lithium batteries, which include Li-Ion PHEV batteries[28]. Due to this reason, Toxco is awarded 9.5 Million by the Department of Energy to increase their operation capacity to meet the growing demand of EV, HEV and PHEV in the United States. Using the fund, Toxco built an exclusive lithium battery recycling facility in Lancaster, Ohio[29].

2.3 PHEV Infrastructure

2.3.1 Charging Station Infrastructure

Even though it is possible to charge a PHEV from a standard electricity outlet, they can also be charged at higher voltages and higher currents for faster charging. Society of Automotive Engineers (SAE) categorizes these fast-charging opportunities as Level 1, Level 2 and Level 3[30]. Level 1 charging is essentially the standard 110 volt power supply. Level 2 recharging point charges the vehicle with a voltage 240 V alternative current and it can be installed in homes. Level 3 charging points supply electricity with 500 Volts direct current. Mostly because of the safety issues, Level 3 charging is not used as a domestic charging opportunity. Additionally, battery swapping is also another alternative charging opportunity, which is offered and has been fully tested by Better Place - a global provider for EV networks.

Charging time and power supply demand are two main concerns in vehicle recharging. It requires several hours for a level 2 charging station providing 3.3kW of power to charge an electric vehicle. This method is the most preferable charging manner as it can be carried out while the car is at home or work. On the other hand, level 3 charging stations reduce the charging time remarkably and allow refueling at any stage of a journey. The Nissan Leaf can be charged in only 30 minutes[31] by a level 3 station providing 500 Volts and 125 Amperes of DC current. This would take 7 hours[32] in a level 2 charging station. However, fast charging requires larger sized electrical power services.

In Battery swapping business model of the better place, discharged batteries can be exchanged at ‘swap points’ for charged batteries. In this system the battery pack is owned by the network operator company rather than the customer. With a three month field test in Tokyo, Better Place showed that their

[27] (Health and Safety Online Environment)
[28] (Toxco Inc)
[29] (Toxco Inc)
[30] (Tennessee Valley Authority)
[31] (Nissan)
[32] (Nissan)

technology works as promised. During the test the battery powered Nissan Rogue crossovers were used as taxis, and made over 25,000 miles having their batteries swapped a total of 2,122 times[33].

2.3.2 Smart Grid Infrastructure

Unmanaged PHEV charging could mean a significant increase in demand on the existing electrical infrastructure. Utilities have designed their systems to accommodate such impacts only up to a point before system upgrades and new investments are required. Utility generation, transmission and distribution systems are designed to meet the highest expected peak demand, which in most cases occurs for less than a few hundred hours a year. The rest of the time, in off peak time, up to a third or more of the power plants are idle, ready to respond to part-time duty, or shut down altogether if there is no scheduled requirement.

Based on research conducted by Pacific Northwest National Laboratories, this idle capacity in the U.S. grid could supply the equivalent energy needs of over 70% of the cars, trucks and SUVs that are on U.S. roads today. That equals approximately 175 million PHEVs. However, achieving this requires the charging of PHEVs to be managed in a centralized fashion to ensure that charging takes place during off-peak periods. By making use of Smart Grid principles the additional demand that PHEVs will imply on the grid system can be provided for without making major investments in additional electricity generation, transmission or communication systems[34].

Smart grid applications improve the ability of electricity producers and consumers to communicate with one another and make decisions about how and when to produce and consume electricity. One advantage of a smart grid application is time-based pricing. Customers who traditionally paid a fixed rate per kWh each month will be able to set their threshold and adjust their usage to take advantage of fluctuating prices and even sell electricity from their PHEV battery of they feel the price is right and they won't be using their battery capacity before being able to recharge again[35].

Large numbers of PHEVs connected to such a Smart Grid then create a "distributed storage" resource that can be used to absorb excess energy that routinely occurs in utility systems. Such excess energy, for example, occurs moment to moment as the system operators attempt to match generation supply with demand and keep the system in balance. Perhaps more significant is the "excess energy" associated with renewable energy. Renewable energy is inherently variable and in many places is mostly available at times when energy is least in demand (i.e., off-peak; midday, as with solar and mostly wind as well). Without energy storage, the ability of electricity systems to absorb increasing amounts of intermittent renewable energy is significantly impacted. A recent study indicated that without energy storage, achieving 50% renewable portfolio standards in California would result in over 3,000 GWh of energy "dumped" annually – energy that could otherwise charge the equivalent of 1 million vehicles for that year[36].

[33] (Motavalli, 2010)
[34] (Kevin Morrow, 2008)
[35] (Chris Farmer, 2009)
[36] (Jim Lazar, 2008)

PHEV Smart Grid software similar to the EV Smart Grid Software developed for the Better Place Project will be able to monitor all the batteries in the network, aggregating data on each battery's state of charge and anticipated energy demand. Smart Grid network software can then communicate this data to utility partners in real-time, allowing them to optimize the allocation of energy based on available supply and PHEV drivers' demand. In this way utilities can ensure that PHEVs serve as a distributed storage mechanism, absorbing under-utilized, off-peak electricity, while at the same time meeting driver expectations in terms of charging time and pricing[37].

The technology already exists to allow customers to feed excess power from their own electricity supply systems back onto the grid by digital net / bi-directional metering systems. This PHEV-to-grid supply will reduce the amount of spinning reserve or backup capacity that electric utilities have to keep on stand-by further firm up the grid system.

2.3.3 Energy Sources

2.3.3.1 Wind Energy

Capacity factor (as % of installed capacity) is a measure of the actual energy produced by a generator as a percentage of that which would be achieved if the generator were to operate at maximum output for 100% of the time. Capacity factor for baseload thermal generators can be above 85%. As the electricity production from wind turbines depend on the intermittent wind resource, wind energy plants achieve capacity factors of 25% - 45%.

Capacity credit (as % of installed capacity) is a measure of the amount of load that can be served on an electricity system by an intermittent plant with no increase in the loss-of-load probability (LOLP), which is often expressed in terms of conventional thermal capacity that an intermittent generator can replace. The LOLP is in other words a measure of reliability/dependability of an energy resource. In simple terms there must be minimal probability that a period of high demand coincides with the failure/unavailability of conventional energy source or low output from intermittent resources. Since the risk of low output from a wind farm during high demand periods is often higher than for conventional generators it is necessary to hold more “backup” capacity on the system in order to maintain LOLP (reliability/dependability). This reduces the capacity credit which could be given to an intermittent renewable energy source[38]. For example; a 10% capacity credit means that by adding a 100 MW wind installation allows you to remove 10 MW of “on demand” generation capacity without compromising grid reliability.

Because the variance in supply from a wind resource at peak demand is larger than for conventional stations, the capacity credit of intermittent sources tends to be significantly lower than their installed capacity. This is due to the fact that the capacity credit will always be less than the capacity factor, as you cannot give a resource a higher capacity credit than for the amount of electricity it actually produces (capacity factor).

[37] (Better Place)
[38] (UK Energy Research Centre, 2006)

The California Public Utilities Commission (CPUC) calculates the monthly net qualifying capacity credit of wind by determining the three-year average of monthly hourly production between noon and 6:00 p.m. on weekdays. This calculation is method was based on a 10% penetration of wind as percentage of total produced energy[39].

The capacity credit data of 19 studies conducted by the UKERC, 2006 in Europe are summarized in the graph below. Their findings concluded that wind energy does have a capacity credit value greater than zero, and also clearly shows that the capacity credit, expressed as a percentage of installed wind capacity, declines as the penetration of wind energy increases. Penetration is stated as a percentage of total produced electricity per resource for the total grid supply[40].

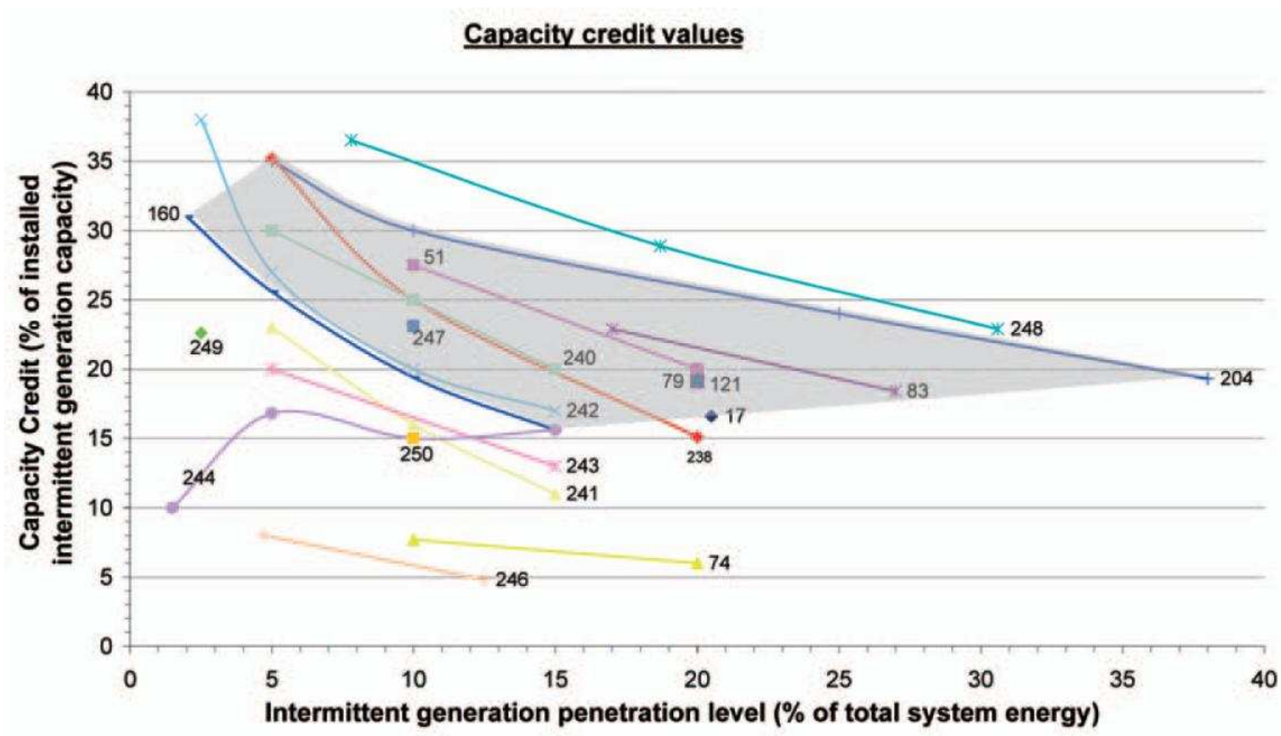

Figure 2 - Capacity Credit Values (Source: UK Energy Research Centre, 2006)

2.3.4 Stakeholders

2.3.4.1 Government

For decades, national and regional governments have recognized the benefits of PHEVs and Plug-In Electric Vehicles (PEVs). There has been interest from as early as 1990 to further their introduction into the market in order to reduce dependence on petroleum, improve urban air quality, and reduce overall greenhouse gas emissions. Various initiatives have been introduced in the US and abroad that directly or indirectly support their research, development, and deployment. The strength of these initiatives vary

[39] (Laboratory, 2008)
[40] (UK Energy Research Centre, 2006)

widely from region to region and change over time in response to public interest, industry pressures, and the balance of political power.

This review is not an exhaustive summary of the history and nature of government attitudes and activities relating to PHEVs and PEVs. Rather, it seeks to organize and group the various forms that government support has taken. A few examples have been selected to illustrate these various forms of support, chosen from a vast body of relevant literature. Examples are drawn primarily from the US Federal government, though some have been drawn from other countries or from state-level initiatives.

Below is a categorization of government support for PHEVs:

Specific support:

1) Mandates or goals stating that PHEVs must reach a certain number or fleet percentage by specified time targets.
2) Per-car monetary incentives for end-consumers who purchase PHEV technology.
3) Per-car monetary incentives for manufactures who produce and sell PHEV technology.
4) Funding for the research and development of PHEV technology.

General support:

1) Funding for the manufacture of PHEV components.
2) Funding for transportation electrification.
3) Funding for "advanced vehicle" development.
4) Mandates to reduce petroleum use.

<u>Examples of government activities that specifically support PHEV technology</u>

1) Mandates or goals stating that PHEVs must reach a certain number or fleet percentage by specified time targets.

One of the earliest initiatives was the "Zero-Emission Vehicle Mandate" (ZEV Mandate) created in 1990 by the California Air Resources Board (CARB) as part of Low-Emission Vehicle (LEV) Regulations. It required increasing the percentage of ZEVs to 2% of new car sales by 1998 and 10% by 2003. This was effectively a mandate to produce electric cars, which were then the only viable vehicle technology with zero tailpipe emissions. This mandate was eventually repealed under pressure from car manufacturers, the petroleum industry, and shifting interest to hydrogen fuel cells[41].

More recently, on March 19, 2009, Barack Obama articulated his "New Energy for America" plan, which includes a goal stating that 1 million PHEVs be on the road by 2015[42].

2) Per-car monetary incentives for end-consumers who purchase PHEV technology.

[41] (Korthof)
[42] (Obama for America)

Such incentives do not appear to exist in the US at the moment. However, numerous governments in other countries offer these incentives to their citizens in various forms.

In 1996, Japan introduced its first incentive program for electric vehicles, which was integrated with the Clean Energy Vehicles Introduction Project in 1998. The project subsidized up to 50% of the incremental costs of a clean energy vehicle (electric, hybrid electric, natural gas, or methanol) as compared with the price of a conventional ICEV. The program was extended until 2003[43].

In Canada, Ontario established a rebate for new plug-in electric vehicles purchased or leased after July 1, 2010, available to the first 10,000 applicants that qualify. The rebate ranges from CAD 5,000 to CAD 8,500 depending on battery size (~ US $4,956 - $8,425)[44].

3) Per-car monetary incentives for manufactures who produce and sell PHEV technology.

On October 3, 2008, the US "Energy Improvement and Extension Act of 2008" was signed into law. One of its features grants tax breaks of $2,500 to $7,500 per car for manufacturers of up to 250,000 plug-in hybrid vehicles[45].

In 2009, the "American Recovery and Reinvestment Act of 2009" modified the tax credits. It included a new credit for plug-in electric drive conversion kits and for 2- and 3-wheel vehicles[46].

Many other countries offer similar incentives to companies. On June 1, 2010, the Chinese government announced a trial program that would provide incentives of up to 50,000 yuan (~US $7,507) for new PHEVs in five cities. The subsidy would be reduced after 50,000 units are sold[47].

4) Funding for the research and development of PHEV technology.

Barack Obama's "New Energy for America" plan (announced March 19, 2009) included programs that would direct $2.4 billion toward electric vehicle development[48].

Meanwhile, the "FreedomCAR" program of the USDOE announced that it would give $30 million to three companies over three years to further develop electric vehicles. (Longley, 2008) The USDOE also announced the selection of Navistar Corporation for a cost-shared award of up to $10 million to develop and deploy PHEV school buses[49].

Examples of government activities that generally benefit PHEV technology

5) Funding for the manufacture of PHEV components.

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[43] (Incentives for EV & HEV, 2003)
[44] (Queen's Printer for Ontario)
[45] (IRS, 2009)
[46] (IRS, 2009)
[47] (Motavalli, 2010)
[48] (Obama for America)
[49] (EERE Network News, 2009)

The "American Recovery and Reinvestment Act of 2009" includes two competitive solicitations for up to $2 billion in federal funding for cost-shared agreements to manufacture advanced batteries and other drive components[50].

6) Funding for transportation electrification.

The "American Recovery and Reinvestment Act of 2009" also includes up to $400 million for demonstration and deployment projects of transportation electrification, which includes PHEVs in addition to PEVs, electric rails systems, etc[51].

7) Funding for "advanced vehicle" development.

The US House of Representatives has passed house bill H.R.3246 – the Advanced Vehicle Technology Act of 2009. This bill has not yet been passed by the Senate or signed into law, but it includes $2.85 billion for "advanced vehicle" development, 39% of which would go toward retrofitting medium- and heavy-duty commercial vehicles for advanced vehicle technologies (including PHEVs)[52].

8) Mandates to reduce petroleum use.

On October 5, 2009, Barack Obama signed Executive Order 13514 on "Federal Leadership in Environmental, Energy, and Economic Performance." It would require a 30% reduction in petroleum use by 2020 among the 600,000-vehicle federal fleet. Agencies with 20 or more vehicles would be required to reduce petroleum 2% annually through 2020[53].

2.3.4.2 Consumer

According to a new survey conducted by Pike Research, plug-in hybrid electric vehicles are one of the most highly anticipated new product categories. Approximately 48% of prospective consumers in the U.S. would be either "extremely" or "very" interested in purchasing a PHEV. The survey results indicated that the needs of the vast majority of drivers would be met by the PHEV, since 82% of those surveyed drove 40 miles or less on a given day with an average of 27 miles[54].

Research revealed several other factors that were noted as being important for consumers choosing their next vehicle. Improved fuel efficiency was one of the main criteria according to 85% of consumers. A total of 65% of survey respondents indicated a willingness to pay a premium over and above the price of standard gasoline car, with an average premium of 12%. This last statistic is particularly relevant, considering the early stages of the PHEV technology and, as a result, the relatively high prices compared

[50] (U.S. Department of Health and Human Services, 2009)
[51] (U.S. Department of Health and Human Services, 2009)
[52] (California Cars Initiative, 2009)
[53] (California Cars Initiative, 2009)
[54] (Pike Research, 2009)

to gasoline cars. It is expected that in the future, once PHEVs become more popular and the demand for them increases, the cost will drop.[55]

One of the primary issues with the commercialization of PHEVs is the charging infrastructure that is needed. A massive effort would need to be set forth to make charging stations available in public urban areas, workplaces and homes. Many prospective consumers will not consider purchasing a PHEV unless the appropriate infrastructure has been put in place that makes driving the vehicle convenient[56].

Some critics also believe that, in some cases, PHEVs may not result in lower CO_2 emissions than a standard gasoline car. The source of the electricity used to charge the vehicle is in question. In locations where the local power grid is relatively clean, such as California, the CO_2 emissions would certainly be reduced. However, in states that used coal-fired grids, such as North Dakota and Wyoming, the PHEV may emit more CO2 per mile than the conventional gasoline car[57]. There is not a consensus on this issue, and other sources claim that is the PHEV battery is charged entirely on electricity from coal-fired plants, there is still a net reduction in CO_2 emissions of at least 50%[58].

Overall, it appears that many prospective consumers in the US would be willing to purchase a plug-in hybrid electric vehicle, provided that the necessary infrastructure was put in the place even though the PHEV may be initially more expensive than the standard gasoline car.

2.3.4.3 Other Stakeholders

Besides consumers and governments, there is a sizeable list of “other” stakeholders involved with PHEVs. While often times they may be considered an afterthought in the discussion, there are a few particular industries that have much to gain (or lose) with an increase in PHEV production.

Power utility companies are one of the primary benefactors from an increase in PHEVs. With multiple PHEVs scheduled to launch in the upcoming year, coal power will still dominate current electricity generation. However, the extra demand will pave the way for other power technologies, perhaps the continued development of nuclear power or the expanded use of renewable resources like solar and wind. As it stands currently, a report by the Department of Energy's Pacific Northwest National Lab (PNL) estimates that if the national power grid were optimally utilized at all hours of the day, it could provide enough power for plug-in hybrids to comprise up to 73 percent of the nation's cars[59]. However, the same study also mentions that while certain parts of the country could handle this burden, other areas such as California and Nevada would have to build more power plants to accommodate the additional load. This increased use of the nation’s power supply would mean profitable gains for the power utility companies.

Electronic manufacturing is another industry that stands to make a substantial profit with an increase in PHEVs. The increase in computerized electronics in a PHEV will have a ripple down effect to various

[55] (Pike Research, 2009)
[56] (Taylor & Van Doren, 2010)
[57] (Hybrid Cars, 2009)
[58] (County of Sonoma Green Transportation Alternatives, 2010)
[59] (Gartner, 2007)

manufacturers. While it may be more obvious to mention the companies that produce the larger parts of the car, the ripple effect will mean switch, circuit, and chip vendors will show increased profits as well. In fact, even at relatively modest production volumes, the additional $500 - $1,500 worth of electronics used by each of these vehicles would constitute an additional $25 - $150 million opportunity for automotive electronics vendors[60]. Unfortunately however, the corollary remains that the vendors who supply parts to traditional ICE vehicles may lose their market share if they do not modify their product line. In this way, the potential benefit- drawback analysis will be based primarily on the volume of PHEVs produced.

Finally, an interesting theory of some of the other stakeholders involved with PHEVs includes an almost infinite list of "to be announced" names. This list will begin to be filled as the various research and development programs take shape. In 2008, the British automaker Lotus created a new research and development group solely devoted to electric and hybrid vehicles. This has led to the creation of lighter weight materials and improved aerodynamics[61]. In this way, there will be countless stakeholders that will come as a result of the various findings from research and development teams.

There are many stakeholders with something to gain with an increase in production of PHEVs. Power utility companies, electronic manufactures and the vast list of "to be announced" names all stand eagerly awaiting the development of PHEVs.

[60] (Goldberg)
[61] (Lotus Creates Hybrid R&D Center, 2008)

3 PHEV TECHNOLOGY

The plug-in hybrid vehicle can be thought of as a combination of an internal combustion engine vehicle and an electric motor vehicle. The vehicle includes two propulsion systems, an IC engine powered by gasoline that's stored in the fuel tank and an electric motor powered by electricity that is stored in the battery. The battery can be recharged by plugging it to an electricity source.

The battery plays a crucial role in storing energy from the electric grid as well as passing energy back and forth with the electric motor to maximize efficiency. The state of charge of the battery is one of the factors that determines which propulsion system is used.

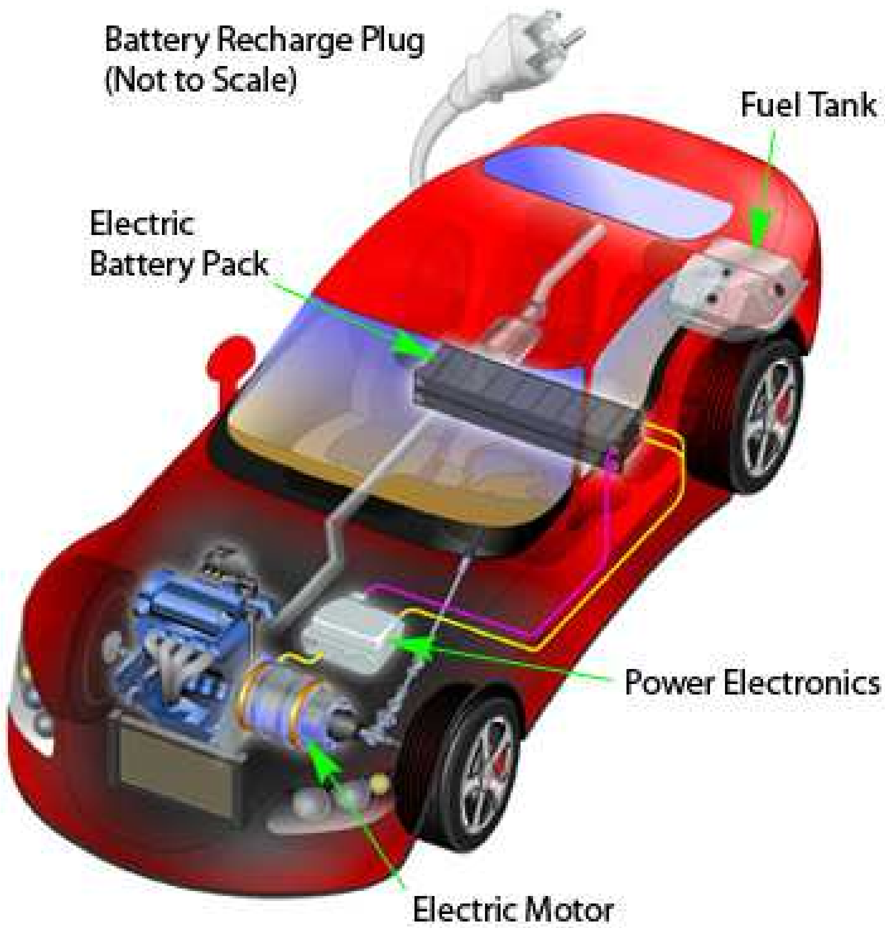

Figure 3 - The PHEV Propulsion Systems

3.1 Two Cycles of the Battery

PHEV operates in either one of these modes: Charge Depleting (CD) or Charge Sustaining (CS)[62].

Initially, once the battery is fully charged, the vehicle will run in CD mode, which gradually depletes the battery's state of charge. In this mode, gasoline can either be used or not. After reaching a certain charge

[62] (Axsen, Burke, & Kurani, 2008)

level, the vehicle runs in CS mode and the battery's state of charge is sustained by using gasoline. In CD mode, the battery state of charge will slightly oscillate due to receiving energy from the regenerative battery and using energy to improve engine efficiency. The vehicle remains in this mode until the battery is recharged from an off-board source, while the vehicle is at rest

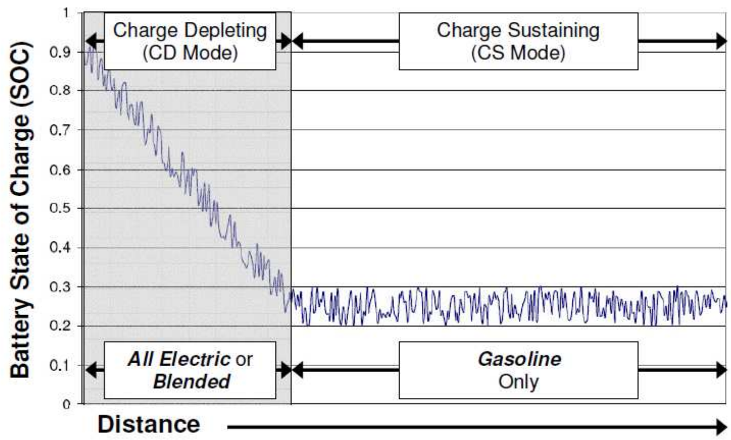

Figure 4 - Illustration of Typical PHEV Discharge Cycle(Axsen & Kurani, 2008)

3.2 Performance Criteria

According to the US Advanced Battery Consortium (USABC), battery performance criteria or "goals" consists of power, energy capacity, life, safety, and cost.

Power is the rate of energy transfer, measured in kilowatts (kW). Specifically, it is the rate at which mechanical energy can be transferred from the engine to the tires via the drivetrain, which is especially significant for acceleration. While for ICEV the speed of gasoline transfer is not the only factor for acceleration rate, it is particularly critical for PHEV[63].

Energy capacity is related to the maximum energy storage capacity (in kWh) and the energy density (Wh/kg). This translates to how far the PHEV can travel in the Charge Depleting mode. Maximum energy storage capacity is not the only factor to determine the distance travel capability. Depth of discharge (DOD) determines how much of that energy (in percent) can actually be used in the Charge Depleting mode. For example, a 100 kWh energy capacity with a 50% DOD means that we can only deplete the energy up to 50 kWh before the system will change to a Charge Sustaining mode[64].

For **battery life**, the most common metrics to measure the performance is calendar life, which is the time it takes to degrade the battery independent to the usage frequency. USABC aims 15 years at a temperature of 35 degrees Celsius as an ideal battery life. Another measure is called deep cycle life, which is the total number of charge cycles in CD mode. USABC aims for 5,000 deep cycles. There are many other criteria such as shallow cycles, which calculate electric regeneration using gasoline and

[63] (Axsen, Burke, & Kurani, 2008)
[64] (Axsen, Burke, & Kurani, 2008)

brakes, and survival temperature range, which is the range of temperatures a battery can be subjected to while not in operation[65].

Battery safety is an important factor. Batteries contain energy and chemicals, which can harm people and damage the vehicle if they behave in an uncontrollable manner. Overall, battery safety depends on battery chemistry, design, and manufacturing quality control[66].

Battery cost is very critical to PHEV market expansion. USABC estimates a cost of $3,400 (not including mark-ups) for an Li-Ion battery with 17 kWh capacity which translates to $200/kWh. Such a battery would allow the PHEVs to travel up to 40 miles in the CD mode. Another performance metric for cost is called dollars per total kWh, which is aimed to be $800/kWh to $1,000/kWh[67].

3.3 Types of Batteries

Lead-Acid Batteries: The safe and affordable lead-acid batteries have low energy storage capacity. They have been used for decades as the starter batteries of conventional automobiles so their performance is already proven. The lead-acid batteries don't store as much energy as alternative batteries, so larger, heavier packs must be used to supply enough energy. The lead-acid battery in today's Prius based PHEVs allow around 8 to 12 miles in all-electric mode driving at low speeds[68].

Lithium Ion Batteries: The expensive Li-ion battery has high energy storage capacity. It is not a proven technology and its safety and performance are questioned when it comes to using it in a PHEV. The high energy storage allows a PHEV Prius to drive as much as 30-40 miles in all-electric mode[69].

Nickel Metal Hydride Batteries: The NIMH battery has moderate energy storage capacity. Their safety and performance has been proven in current Hybrids. Since these batteries store less energy than Li-ion batteries, they aren't being considered for use in PHEVs[70].

Table 1 - Battery Module Specifications (Tara, Shahidineja, Filizadeh, & Bibeau, 2010)Table 1 summarizes the characteristics of each of the 3 battery types.

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[65] (Axsen, Burke, & Kurani, 2008)
[66] (Axsen, Burke, & Kurani, 2008)
[67] (Axsen, Burke, & Kurani, 2008)
[68] (Plug-in Hybrid Batteries: Type Matters, 2007)
[69] (Plug-in Hybrid Batteries: Type Matters, 2007)
[70] (Plug-in Hybrid Batteries: Type Matters, 2007)

BATTERY MODULE SPECIFICATIONS

Battery Type	Lead Acid	NiMH	Li-Ion
Cell Voltage [V]	6	1.2	3.6
No. of cells per module	2	6	3
Capacity [Ah]	12	6.5	6
Module weight [kg]	4.79	1.04	0.99
Specific energy density [Wh/l]	90	175	200
Efficiency* [%]	70	80	95
SOC swing range [%]	20	70	70
Cost [$/kWh]	145	365	1000

*The efficiency values are for the energy efficiency of the modules.

Table 1 - Battery Module Specifications (Tara, Shahidineja, Filizadeh, & Bibeau, 2010)

The table below summarizes the advantages and disadvantages of each of the 3 batteries:

Key (relative to each other): Poor / Fair / Good

Attribute	Lead Acid	NiMH	Li-Ion
Weight (kg)	Poor	Fair	Good
Volume (lit)	Poor	Good	Good
Capacity/Energy (kWh)	Poor	Fair	Good
Discharge Power (kW)	Good	Fair	Good
Regen Power (kW)	Poor	Fair	Good
Cold-Temperature (kWh & kW)	Good	Fair	Poor
Shallow Cycle Life (number)	Fair	Good	Good
Deep Cycle Life (number)	Poor	Good	Fair
Calendar Life (years)	Poor	Fair	Fair
Cost ($/kW or $/kWh)	Good	Poor	Poor
Safety- Abuse Tolerance	Good	Good	Fair
Maturity - Technology	Good	Good	Fair
Maturity - Manufacturing	Good	Fair	Poor

Table 2 - Qualitative Comparison of batteries(Pesaran, 2006)

From the above analysis, we can conclude that the Li-Ion battery is the better choice to be used in PHEVs. Assuming all car manufacturers precede with Li-ion for all of their PHEVs, its cost, safety and maturity can all be eventually improved.

4 LIFE CYCLE ASSESSMENT

For a transition from an ICEV market to a PHEV market to be beneficial, it is important to determine first if the PHEV is better than the ICEV in minimizing the negative impacts on the environment and society over the entire life cycle. This is done by performing a life cycle assessment (LCA) for both alternatives and their respective sources of energy. The life cycle of the vehicle is cut down to five distinct stages. Each stage is governed by environmental stressors. These can be classified as inputs and outputs as follows:

Inputs		**Life Stage**		**Outputs**
		Premanufacture	→	Gaseous Residues
Materials Choice	→	Manufacture		
		Delivery	→	Liquid Residues
Energy Use	→	Use		
		Disposal	→	Solid Residues

Each life stage will be evaluated for each of the 5 environmental stressors creating a 5x5 matrix[71]. In order to perform the study, the team chose T.E. Graedel's Streamlined LCA (SLCA) model. The SLCA is a semi-quantitative LCA method. Each stage is given five scores, one for each environmental stressor. The scoring is based on a formalized scoring system published by Graedel.

The SLCA is widely used in the marketplace to evaluate how environmentally responsible products and processes are. The SLCA is a rapid but still rigorous alternative to the traditional expensive and time consuming LCAs. One is able to identify 80% of the issues in a fraction of the time using the SLCA[72].

Since the main purpose of this study is to compare the ICEV to the PHEV, it can be deemed reasonable to use a semi-quantitative LCA rather than a quantitative one. The scoring of each alternative is done comparatively and thus the final result is sufficient enough to determine which vehicle is more environmentally responsible.

Rather than discussing each alternative separately, the team chose to compare them for each life stage of the LCA while also studying their respective sources of energy. Each section will start with a table portraying the scores awarded to the different alternatives over the specific life stage.

[71] (Graedel, 1998)
[72] (Benmar, 2010)

The analysis will focus on the differences between the two vehicles and not on the vehicles as a whole. In other words, no research will be done on the vehicle's chassis since it is the same for both cases. The main components of the research are the IC engine, the electric motor and the Li-Ion battery.

4.1 Premanufacture

When doing the research on the premanufacture stage, the team focused on the resources extracted, the processes of extraction and the transport of the resources.

		Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	Total
Vehicle	ICEV	3	2	2	3	2	12
	PHEV	1	1	1	2	2	7
Energy Source	Gasoline	1	0	1	2	1	5
	Electricity	3	2	2	3	2	12

Table 3 - Premanufacture SLCA Scoring

Materials Choice

The ICEV scored higher than the PHEV due to the use of lithium and cobalt in the Li-Ion battery. Both lithium and cobalt are scarce materials but they are both recoverable. Since there are other alternatives for batteries that don't use scarce materials, the PHEV was awarded a lower score for materials choice[73].

The bulk of LA's electricity generation comes from coal and natural gas. Both these natural resources are more abundant than petroleum from which gasoline is produced. Also the supply of coal and natural gas in the US is more stable[74]. For these reasons gasoline was awarded a lower score in material choice over electricity.

Energy Use

The ICEV scores a bit higher than the PHEV because more energy is put into extracting the Lithium and the cobalt. The remaining resources used to manufacture either vehicle are common to both.

The energy used to extract petroleum is significantly higher than that used to extract natural gas and coal[75].

Residues

The residues generated from the premanufacture stage of the ICEV get higher scores than those of the PHEV because the PHEV involves the extraction of more materials. Also, lithium and cobalt reserves are located in areas that will require additional transport and thus generate additional residues[76].

[73] (Jungst, 1999)
[74] (Fossil Fuels - Coal, Oil and Natural Gas)
[75] (Graedel, 1998)

The extraction of petroleum requires the implementation of a pump system powered by the combustion of coal which results large amounts of residues[77].

4.2 Manufacture

In this life stage, the research was focused on the manufacturing processes utilized and the components being produced.

		Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	Total
Vehicle	ICEV	3	3	3	3	2	14
	PHEV	1	2	2	1	1	7
Energy Source	Gasoline	1	1	3	2	1	8
	Electricity	2	2	2	3	1	10

Table 4 - Manufacture SLCA Scoring

Materials Choice

The ICEV ranks relatively high in the material choice as there are no toxic or virgin materials used to manufacture the IC engine. On the other hand, PHEV requires toxic compounds such as lithium cobalt oxide ($LiCoO_2$) to produce the Li-ion battery[78]. Moreover, the motor's interior is insulated using fiberglass. The fiberglass is applied by spraying toxic chemicals[79].

The scoring of the energy source was done using the same arguments as those of the pre-manufacture life stage.

Energy Use

The casting and machining of the ICEV's engine block and its components is an energy intensive process. The process has evolved greatly over the years and its energy requirements have substantially decreased by implementing techniques that utilize otherwise waste energy. The PHEV's IC engine is manufactured in the same way. The manufacture of the motor is less energy intensive then the engine. The rotor and stator casings of the motor are produced in the same way as the IC engine block. Since the PHEV requires both a motor and an engine to be manufactured, it was scored lower than the ICEV in the energy use phase.

Though both processes are energy intensive, the energy that goes into refining petroleum to produce gasoline is significantly greater than the energy that goes into burning the coal to produce electricity.

Residues

76 (Abuelsamid, Bolivia may hold the keys to lithium battery cars, 2009)
77 (Petroleum)
78 (Thackeray, Thomas, & Whittingham, 2000)
79 (Halm, 1975)

Through the years, IC engine manufacturers have found ways to cut down scrap production in the manufacturing of the engine. On the other hand, the manufacturing process of the motor generates large amounts of harmful residues. The spraying of the toxic compound to apply the fiberglass insulation to the interior of the motor produces both liquid and gaseous residues. Moreover, once assembled, the motor is coated with polyester varnish which is another source of liquid residue. Solid and gaseous residues are produced by hardening the varnish in large ovens[80]. Also the manufacturing of the Li-Ion battery involves toxic compounds such as lithium cobalt oxide ($LiNiCoO_2$).

The generation of electricity by burning coal produces significant quantities of waste by-products such as ash and sludge. Refining petroleum on the other hand creates by-products that can be converted into higher value products[81].

4.3 Delivery

In this life stage, the research was focused on the methods used to deliver the products to the customer and on the packaging involved.

		Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	Total
Vehicle	ICEV	3	2	3	3	2	13
	PHEV	3	2	3	3	2	13
Energy Source	Gasoline	4	2	3	3	2	14
	Electricity	4	2	4	4	4	18

Table 5 - Delivery SLCA Scoring

The rank for both ICEV and PHEV for all environmental stressors is the same because the same delivery process is used for both vehicles. The same transportation system, such as trains and trucks, is applied to deliver both vehicles. Potential liquid residue could result from cleaning supplies, such as detergents and waxes. The low gaseous residue score comes from the use of trucks to deliver the vehicles, leading to increased emissions.

Materials Choice

Since no packaging is used for the delivery of either gasoline or electricity, both alternatives score 4.

Energy Use

The gasoline is delivered using truck and rail transportation. These account for a high energy use over long distances. Electricity is transported through power lines and there is no direct energy input in the process. However, there are losses of electricity due to the resistance of the power lines over long

[80] (Halm, 1975)
[81] (Petroleum Refining, 2006)

distances. The losses can be up to 30% and must be compensated for by producing more to meet the demand[82].

Residues

Transporting electricity in power lines doesn't generate any major residues. On the other hand, transporting the gasoline to the gas station by trucks contributes heavily to the greenhouse gas emissions and thus scores lower than electricity.

4.4 Use

In this life stage, the research was focused on what goes into operating and maintaining the vehicle while taking into consideration their respective efficiencies. The use stage of the SLCA was done for both the vehicle and the energy source simultaneously. It is not reasonable to study them separately since the vehicle cannot be used without using up the energy source

		Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	Total
Vehicle	ICEV	1	1	2	2	1	7
	PHEV	3	3	3	3	3	15

Table 6 - Use SLCA Scoring

Materials Choice

The ICEV has a rank of 1 because it exclusively uses gasoline which is not renewable. Fuel contains various chemical components that are hazardous to the environment and dangerous to human health. The potential spill of fuel could result in contamination of the environment. The PHEV has a rank of 3 because it uses a combination of gasoline and electricity. Since the PHEV uses less gasoline, the potential contamination to the environment is reduced.

Energy Use

The ICEV uses the IC engine as its source of torque. As the gasoline SI engine is used over its lifetime, its efficiency decreases. Energy-conservative design features have been implemented; however they still have not been able to significantly increase the efficiency to more than 20%[83].Since the PHEV uses both the IC engine and the electric motor as the sources of torque, the overall efficiency of the vehicle is improved and the energy used for the same distances is lower. Electric motors have varying efficiencies depending on the load used but it is usually near 75%[84]. Also the regenerative breaking system available in the PHEV allows it to recover otherwise lost energy when breaking.

Residues

[82] (Hokin)
[83] (Johnson, 2010)
[84] (U.S. Department of Energy)

According to the EPA, over the lifetime of the Honda Civic DX engine use, there would be over 756kg of CO released alone (assuming 15 years with 12,000 miles per year)[85]. Gaseous residues such as CO_2, SO_2, VOCs, and CFCs, although released on a small level, are a significant contributor to GHG over the engine's lifetime. The use of electricity will not produce any tailpipe residues but it does produce emissions such as CO_2 and NO_x at the power plant; still, it is considered the cleaner than burning gasoline. The highest score was not awarded in this case since the PHEV still uses gasoline in its SI engine. However the amount of gasoline used is lower than that of the standard engine and hence the emissions are lower.

4.5 Disposal

In this life stage, the research was focused on how the vehicle is disposed of, taking into consideration how much is recycled and what is reused.

		Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	Total
Vehicle	ICEV	3	2	2	3	2	12
	PHEV	1	1	1	2	2	7

Table 7 - Disposal SLCA Scoring

Materials choice

The IC engine is mainly made out of steel which is recycled and reused for the manufacture of new IC engines. The electric motor of the PHEV can be broken up into two main components: the steel casings and the fiberglass insulation. Both are recycled. Recycling the Li-Ion battery is a newer process. The lithium can be fully recovered but it is not economically viable since producing lithium carbonate from raw materials is cheaper than extracting it from the recycled batteries. This is expected to change once the market evolves and the price of lithium carbonate rises due to demand[86].

Energy Use

An estimated 85 million barrels of oil are saved every year by using recycled car parts to manufacture new parts[87]. More energy is put into the disposal of the PHEV since it has two additional components that need to be taken care of. Recycling the electric motor and the battery will use up energy and thus the PHEV scores lower than the ICEV. The overall low scores of both come from the high usage of energy in the reuse of the steel.

Residues

The low scores awarded to the PHEV come from the disposal of the Li-Ion battery. Since, as discussed above, the recycling rates are not currently high; the battery is mainly being disposed of in landfills. Such

[85] (EPA, 2008)
[86] (Green, 2009)
[87] (Automotive Recyclers Association, 2006)

a practice poses major issues; there is high potential for soil contamination from the toxic compounds within the battery such as lithium hydroxide[88]. It is assumed that as the PHEV market grows, the lithium carbonate market will become more competitive and thus the recycling of the Li-Ion battery will become economically profitable.

4.6 Discussion & Conclusions

Having performed the life cycle assessment for both the ICEV and the PHEV and compared them in each life stage separately, the team will now evaluate these results and come up with conclusions that compare the two alternatives over the full life. In order to do that, we need to combine the scores of the different life stages into one score. The SLCA is designed in a way where weights should be given to the different stages according to their importance, their environmental impact on the whole life cycle and their duration[89]. These weights are to be chosen after having performed the research and having understood the impact of each stage. In the automobile case, the use phase gets the highest weight since it uses up a significant amount of energy and emits large amounts of residues over a 15 year period. The delivery gets the lowest weight considering that on average it takes 1 month to deliver the automobile from the plant to the dealer and the process doesn't impact the total life cycle as much. The tables below summarize the overall results of the SLCA.

Vehicle SLCA Scores				
Life stage	**Weight**	**Max Score**	**ICEV**	**PHEV**
			Weighted total	**Weighted total**
Premanufacture	2	40	24	14
Manufacture	3	60	42	21
Delivery	1	20	13	13
Use	5	100	35	75
Disposal	1	20	12	7
Grand Total	**12**	**240**	**126**	**130**

Table 8 - Vehicle overall SLCA Scores

Energy Source SLCA Scores				
Life stage	**Weight**	**Max Score**	**Gasoline**	**Electricity**
			Weighted total	**Weighted total**
Premanufacture	2	40	10	24
Manufacture	3	60	24	30
Delivery	1	20	14	18
Grand Total	**6**	**120**	**48**	**72**

Table 9 - Energy Source SLCA Scores

88 (Jungst, 1999)
89 (Graedel, 1998)

From the two SLCAs summarized above, it can be concluded that the PHEV/Electricity combination wins over the ICEV/Gasoline combination. The results can be combined to give one final score for each alternative. Since the PHEV drives 80% on electricity and 20% on gasoline, the same ratio will be given to the scores of each energy source. The table below summarizes the final scores of the SLCA.

Overall SLCA Scores			
	Max Score	**ICEV / Gasoline**	**PHEV / 80% Electricity / 20% Gasoline**
Vehicle	240	126	130
Energy Source	120	48	67
Grand Total	**240**	**174**	**197**

Table 10 - Overall SLCA Scores

After performing the SLCA, the team can confidently conclude that the PHEV is an environmentally feasible alternative to the ICEV. It is indeed a more environmentally responsible product than the ICEV.

5 BACKGROUND INFORMATION ON LOS ANGELES

The County of Los Angeles incorporates 88 cities and covers an area of 4,079 square miles. In 2005, the population of Los Angeles County was 9.8 million according to the U.S. Census Bureau[90]. In 2008, the median earnings were $31,303[91]. At the beginning of 2007, there were 5,484, 606 automobiles in the L.A. County according to the California Department of Motor Vehicles. The average commute time for workers over the age of 16 who work outside the home was 29.6 minutes in 2005. Traffic congestion is significant problem in L.A. County, and, in 2003, travelers were delayed by 93 hours in 2003[92]. The household income statistics for L.A. are shown in the following figure[93].

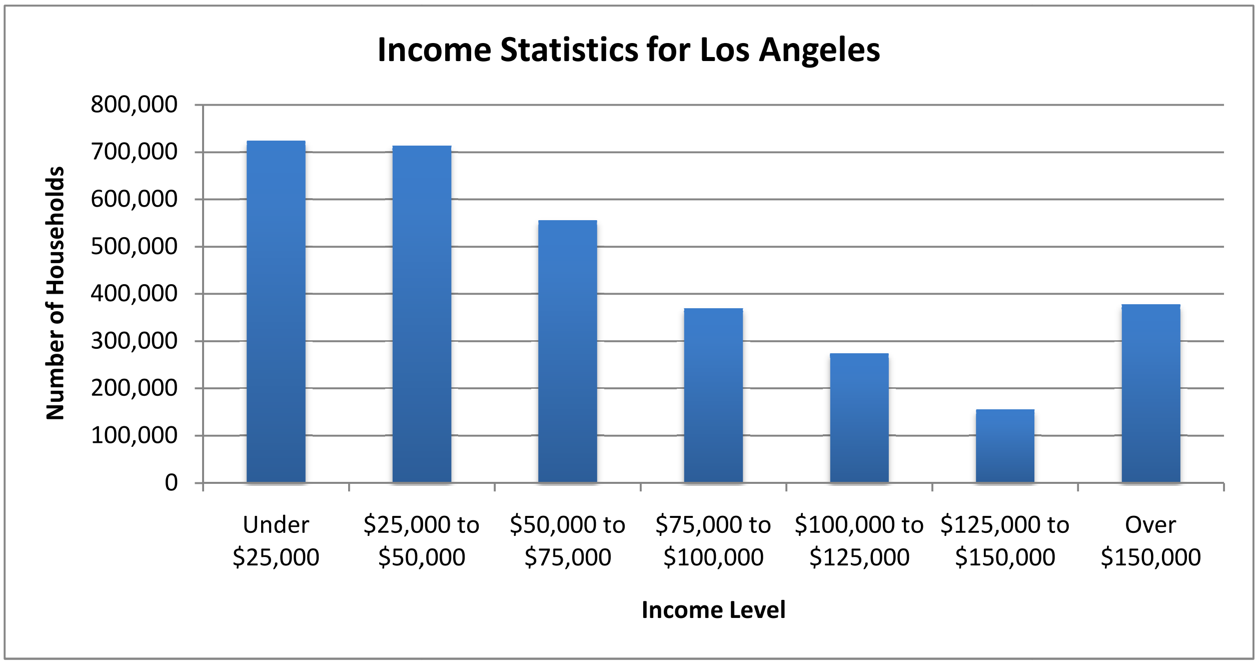

Figure 5 - Los Angeles Household Income Statistics(Los Angeles Alliance for a New Economy, 2009)

[90] (Los Angeles Department of Transportation, 2009)
[91] (U.S. Census Bureau, 2008)
[92] (Los Angeles Department of Transportation, 2009)
[93] (Los Angeles Alliance for a New Economy, 2009)

The daily vehicle miles travelled per capita was approximately 21 miles/capita in 2007. The population per square mile in Los Angeles is considerably higher than other metropolitan areas and this is a primary contributor to traffic congestion. Although it is commonly thought that NYC is the most densely populated city in the USA, this impression is based on the situation in Manhattan only. When all 5 NYC boroughs are included, it is in fact less densely populated than LA. The following graph shows daily vehicle miles travelled per capita versus population per square mile in 2007[94].

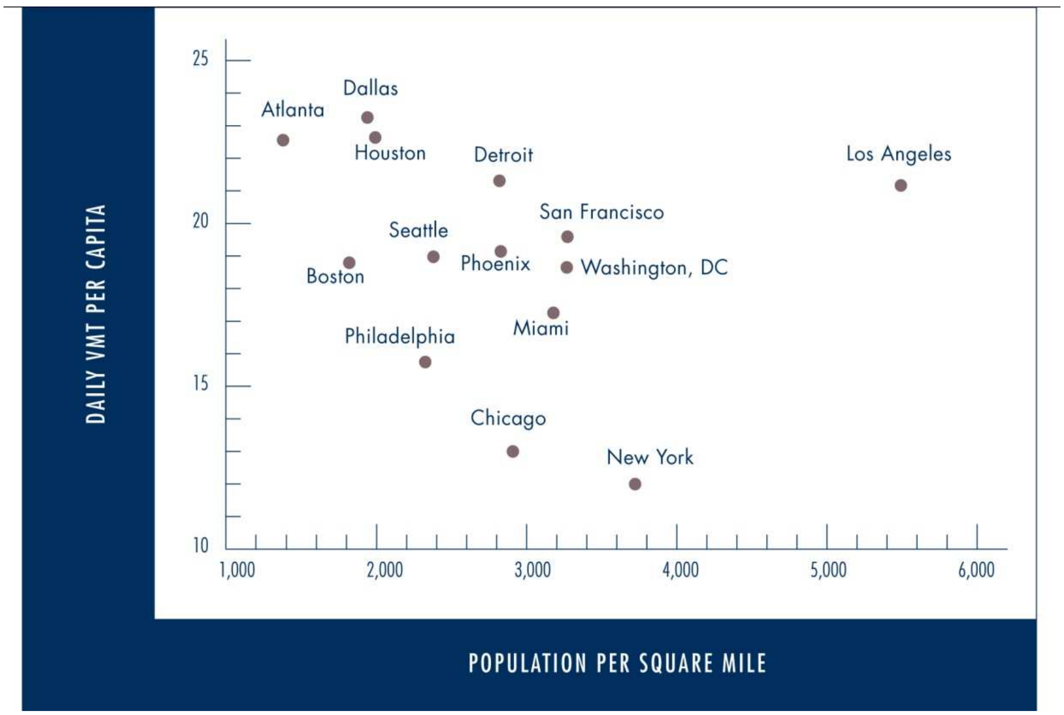

Figure 6 - Population Density vs. Daily per-capital VMT in Major Metropolitan Areas in 2007(Sorenson, October)

[94] (Sorenson, October)

In 2009, Los Angeles was the metropolitan area with the highest hybrid sales during the year, which were 26,667[95].

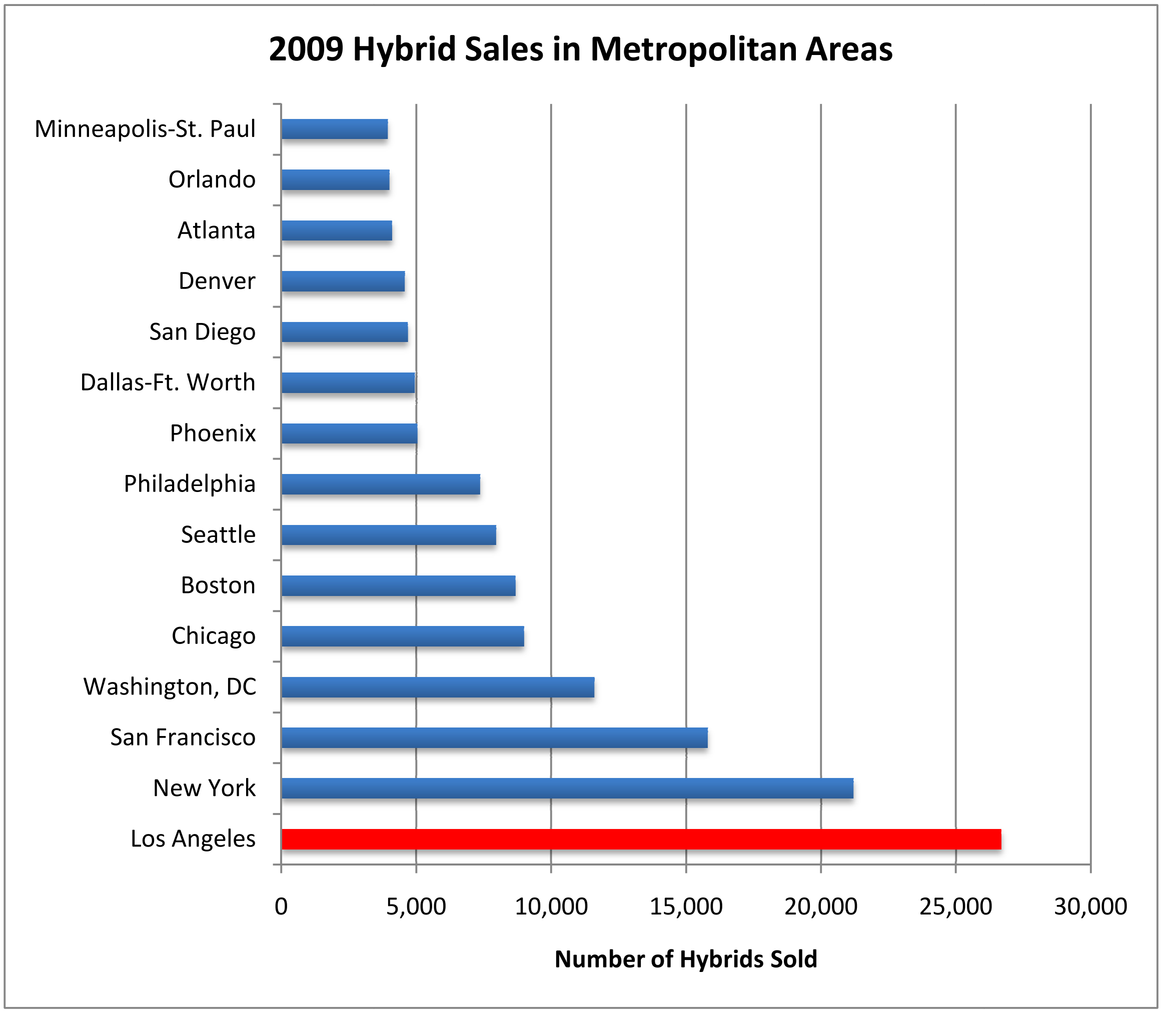

Figure 7 - 2009 Hybrid Sales in Metropolitan Areas(Hybrid Cars, 2010)

[95] (Hybrid Cars, 2010)

Relative to other metropolitan areas, Los Angeles has the 5th highest number of hybrids per 1000 households in 2006, which were 4.80[96].

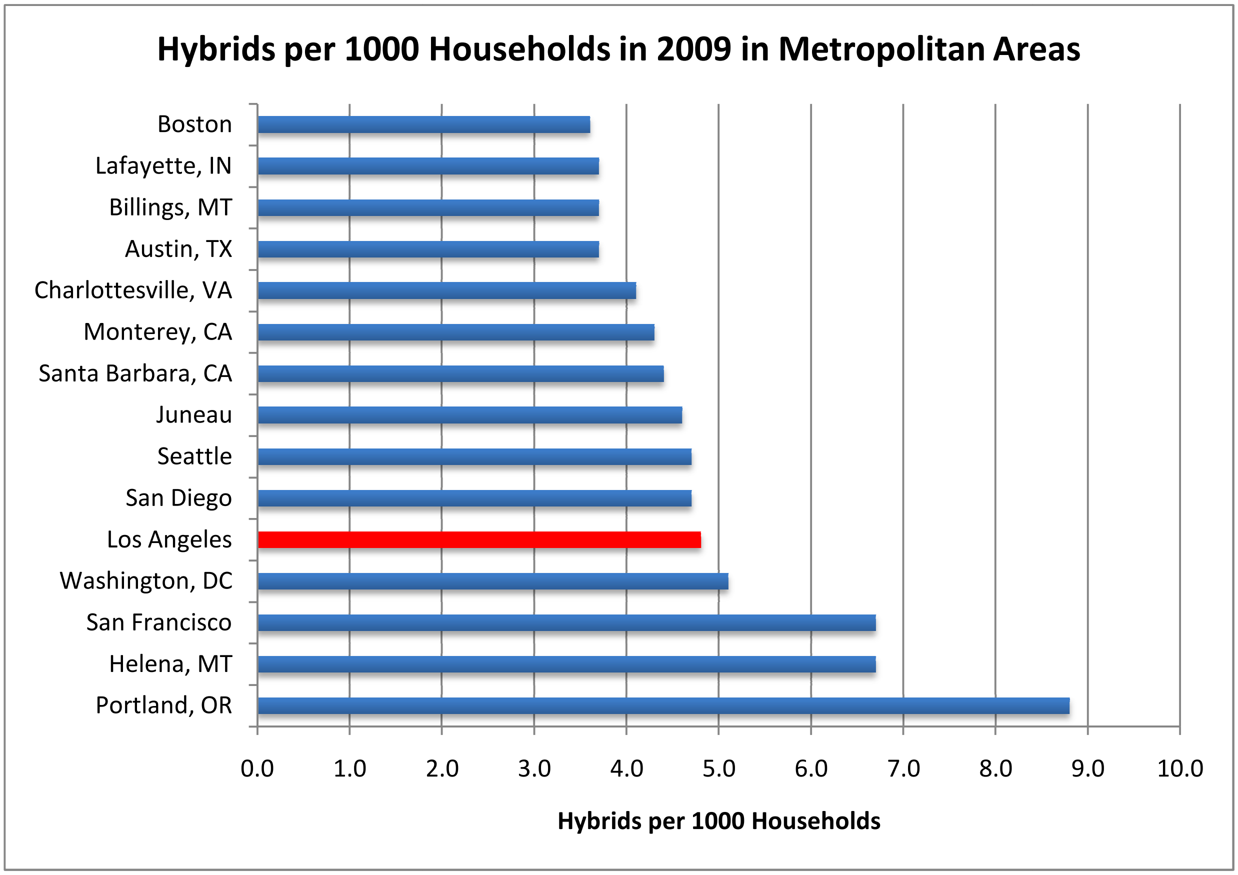

Figure 8 - Hybrids per 1000 Households in 2009 Metropolitan Areas(Hybrid Cars, 2010)

Currently, hybrid vehicles are relatively popular in L.A. and it is likely the new hybrid sales will continue to grow in the future. Given the relatively low daily vehicle miles traveled and the available income, L.A. is an ideal setting for PHEVs.

[96] (Hybrid Cars, 2010)

6 LOS ANGELES ELECTRICAL INFRASTRUCTURE

In addition to assessing PHEV technology, the project also examined its impact on electrical infrastructure. Because of the regional feasibility aspect of our project scope, we wished to assess the available generation capacity in order to determine whether the local LA infrastructure could support a mass transition away from ICEVs toward PHEVs without a net increase in generation capacity.

Our study region was defined to be the area serviced by the Los Angeles Department of Water and Power (LADWP), a utility company that operates independently of the California Independent System Operator (CAISO). Our analysis helps provide insight on what capacity upgrades are necessary, if any, and how the LADWP infrastructure can best adapt to the challenges and opportunities associated with the changing demand landscape.

In order to model hypothetical future scenarios, we constructed a modeling framework consisting of two components:

1) Supply-side model: this model illustrates how the available generation capacity could change with the implementation of various upgrades, such as added capacity, increased renewable generation, and vehicle-to-grid electrical storage systems.

2) Demand-side model: this model illustrates how the total hourly demand curve could change with the addition of PHEVs, allowing us to adjust parameters such as total PHEV fleet penetration, charging profile, and vehicle-miles traveled.

By combining these two components, we can illustrate any number of hypothetical future scenarios. For the purposes of our analysis, we selected a small sample of illustrative examples for discussion.

6.1 Supply-side Model for Generation Capacity

In order to construct the supply-side model, it was necessary to research the LADWP's current electricity supply composition and determine its maximum potential power supply. We did this by applying the allocable capacity factors to each resource as indicated by LADWP sources and then distributed the wind and solar generation according to regionally observed daily patterns. (Please refer to Section 2.3.3.1 on page 27 for technical clarifications on terms used in this section)

We also examined the impacts of carbon emission targets and how those targets could be met while simultaneously supporting increased energy demand due to a hypothetical influx of PHEVs. With this as our target case we then analyzed the potential benefits that the increased penetration of the PHEVs can have when coupled with a Smart Grid/ Vehicle-to-Grid (V2G) System.

6.1.1 LADWP Carbon Emission Reduction Targets and Increase in PHEV Electricity Demand

Figure 9 compares the current power generation mix in LA (dependable power produced per resource) to the targeted generation mix for 2020. The 2020 target generation pie chart is an estimation of the necessary generation mix for achieving the current 2020 carbon emission reduction targets. Current policies seek to increase the penetration of wind in the region to at least 20% and solar to at least 4% of total used electricity. The aim is then to significantly reduce the region's use of coal as power source.

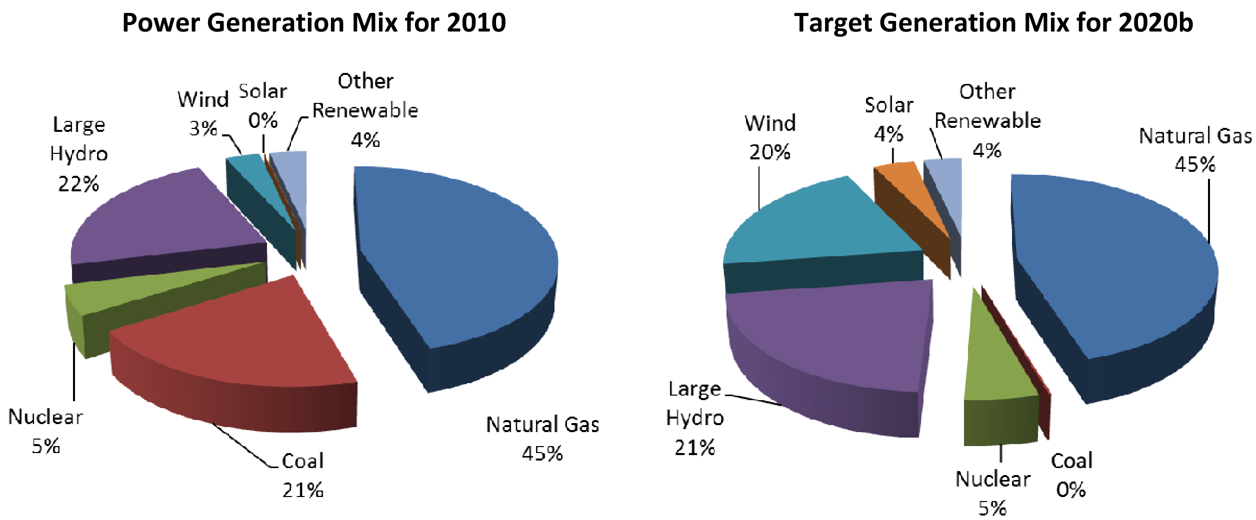

Figure 9 - Generation Capacity for 2010 and 2020 (Data from: (Los Angeles Department of Water & Power, 2009))

Both the graphs are for a Maximum Dependable Capacity of 7,362 MW. Table 11 gives the actual installed capacities per resource that are required to achieve the above penetrations in terms of energy used per source.

Resource	2010			2020			% Increase from 2010 - 2020	
	Installed Capacity (MW)	Produced Electricity (MW)	Capacity Credit	Installed Capacity (MW)	Produced Electricity (MW)	Capacity Credit	Installed Capacity	Produced Power
Natural Gas	3 414.6	3 337.0	98%	3 414.6	3 337.0	98%	0%	0%
Coal	1 679.0	1 524.0	91%	14.1	12.8	91%	-99%	-99%
Nuclear	387.2	380.8	98%	387.2	380.8	98%	0%	0%
Large Hydro	1 763.0	1 621.0	92%	1 763.0	1 621.0	92%	0%	0%
Wind	855.1	239.4	**28%**	6 811.2	1 498.5	**22%**	**700%(#)**	**525%(#)**
Solar	18.5	4.6	25%	1 027.2	256.8	25%	5 435%	5 435%
Other Renewable	361.6	254.8	70%	361.6	254.8	70%	0%	0%
TOTAL	**8 479.0**	**7 361.7**		**13 778.9**	**7 361.7**		**63%**	**0%**

Table 11 - Power Generation Breakdown per resource for 2010 and 2020 (Data from: (Los Angeles Department of Water & Power, 2009))

It will be noted that the installed wind capacity in 2010 produces only 3% of the total dependable electricity and has an associated capacity credit of 28%. The capacity credit at this low level of penetration was determined by using the general principles to determine the capacity credit for wind energy in California as described in the Section 2.3.3 of the literature review.

Figure 10 shows how the capacity credit of wind is expected to decrease as its penetration increases to 20% by 2020. The thick red line represents information for the LADWP region. This trend was plotted on top of information gathered in other studies of capacity credit over increased penetration levels to ensure that our information was consistent. It should be noted that the 2010 capacity credit calculation was calculated on a 10% penetration level, to be conservative, even though the current wind penetration is only about 3%.

In Figure 10, the amount of storage is kept constant and the effects of increased wind penetration on its capacity credit is observed.

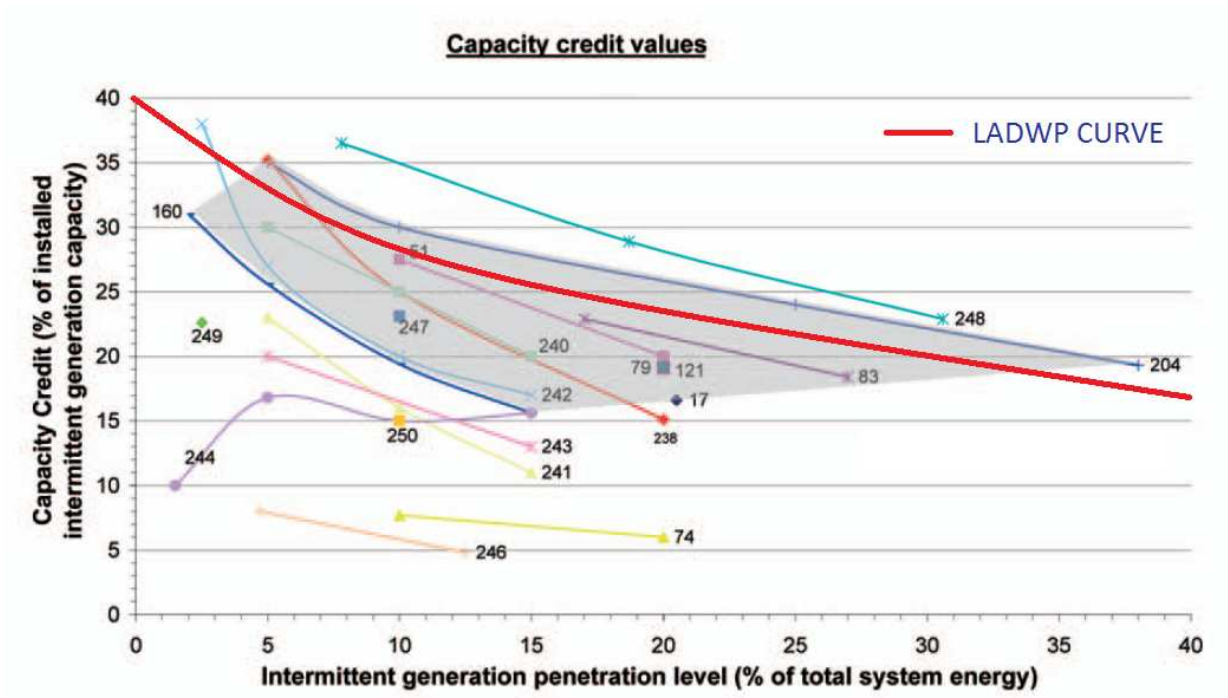

Figure 10 - Capacity Credit Reduction with Increased Wind Energy Penetration (Source: (UK Energy Research Centre, 2006))

Due to these effects, the capacity credit associated with the 20% wind penetration goal for 2020 is reduced to only 22%, down from 28%. This reduction in capacity credit is why a seven-fold increase in installed wind is necessary in order to produce 5.25 times more dependable power from wind in the LADWP region (Note (#) in Table 11). Putting this in context, one will notice that there is a 63% increase in the required total installed capacity due to the higher penetration of wind. This is due to the fact that low-dependability energy (wind, capacity credit = 22%) is used to replace relatively high-dependability energy (coal, capacity credit = 91%).

6.1.2 Smart Grid/Vehicle-to-Grid (V2G) Potential

Since it is beyond the scope of this project to simulate the working of the Smart Grid, it was decided to assume that the Smart Grid is functioning as intended for the last analysis of the model. This involves real-time net metering, including the ability to communicate two ways between the consumer and the utilities. For our analysis, this would mean that the utilities can have information on the projected charging demand from each PHEV (i.e. when a PHEV is expected to be fully charged and what the current state of its battery is). With this information the utility can determine to what extent it can make use of energy stored in the PHEV's battery at a given time and still meet the charge requirement as set by the owner.

We thus decided to further analyze the potential benefits that a V2G system could provide as a form of grid storage. As noted in Section 2.3.3.1 of the literature review, added grid storage can mitigate the intermittency of wind energy and thus increase the capacity credit of these resources. This benefit would allow more coal resources to be removed for a given level of installed wind capacity, without compromising system reliability. This would make the generation mix "greener" and could potentially reduce the cost of wind energy, due to the reduced need for backup capacity.

In order to pursue this V2G analysis, we needed to quantify the relationship between the capacity credit of wind resources and increased backup grid storage. First, it is known that capacity credit of wind in the LADWP region is expected to be 22% when wind penetration is 20%. This figure establishes the associated capacity credit at 0% additional storage. Meanwhile, the maximum capacity credit (with 100% backup storage) cannot be more than the capacity factor of the resource in the region. The maximum capacity credit with 100% storage was thus calculated to be 42% (the capacity credit of wind in LA). Adjusting this figure for the time allowed for maintenance brings the maximum capacity credit to about 41% for the region. From various other studies, it was concluded that capacity credit does not increase linearly as storage increases from 0% to 100%. A more accurate relationship is depicted for the LA region in Figure 11 below. [97]

In Figure 11 the wind penetration is kept constant and the percentage storage is changed.

[97] Please refer to the following paper for additional information if required: Wangdee, W & Li, W. 2009. *Coordinating Wind and Hydro Generation to Increase the Effective Load Carrying Capability.* Canada.

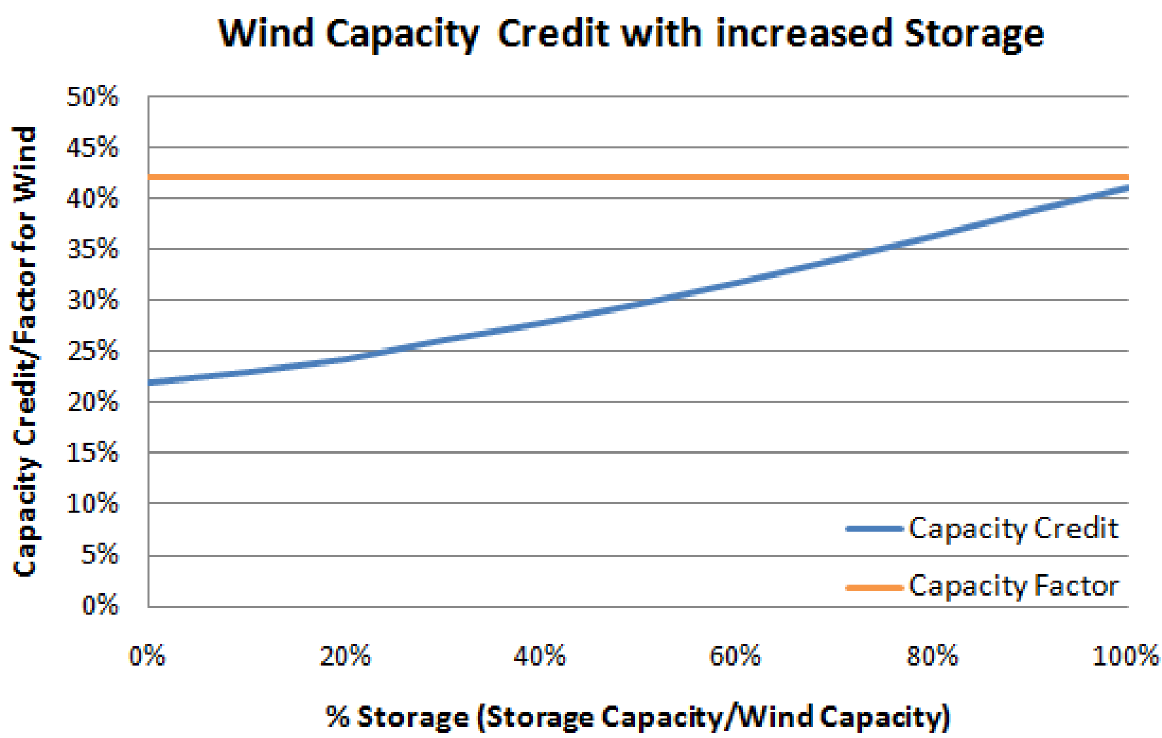

Figure 11 - Effects of Increased Storage on Wind Capacity Credit (Data from: (UK Energy Research Centre, 2006))

Now that we know how the capacity credit of wind energy would be affected with the increase in grid storage, we can assess the benefits of the V2G potential of the PHEVs. For this, we have assumed that the inverse of the average vehicle driving hours will give us a fairly accurate representation of when the PHEVs could be plugged in for charging (or V2G ancillary benefits). We have, however, scaled down the percentage of cars plugged in since not all drivers will necessarily participate in the V2G System and thus their cars may not be plugged in at all possible times. We have thus assumed that only 70% of PHEV owners would participate in the V2G System as noted in Figure 12.

We were thus able to approximate the number of vehicles available as grid storage, further assuming that the system would be allowed to draw and replenish 4 kWh per day of flexible capacity from each PHEV, on average.

The Volt has a 16 kWh usable battery capacity, which may make the 4 kWh available storage sound like a relatively high percentage. To put this in context, the average PHEV takes a maximum of 8 hours to charge at the slowest household rate, which means that each car participating in the V2G should be plugged in for 2 to 3 additional hours to supply the storage capacity that we have assumed in our calculations. It is also expected that this situation would improve with expected development in the charging infrastructure and increased battery capacities over coming years.

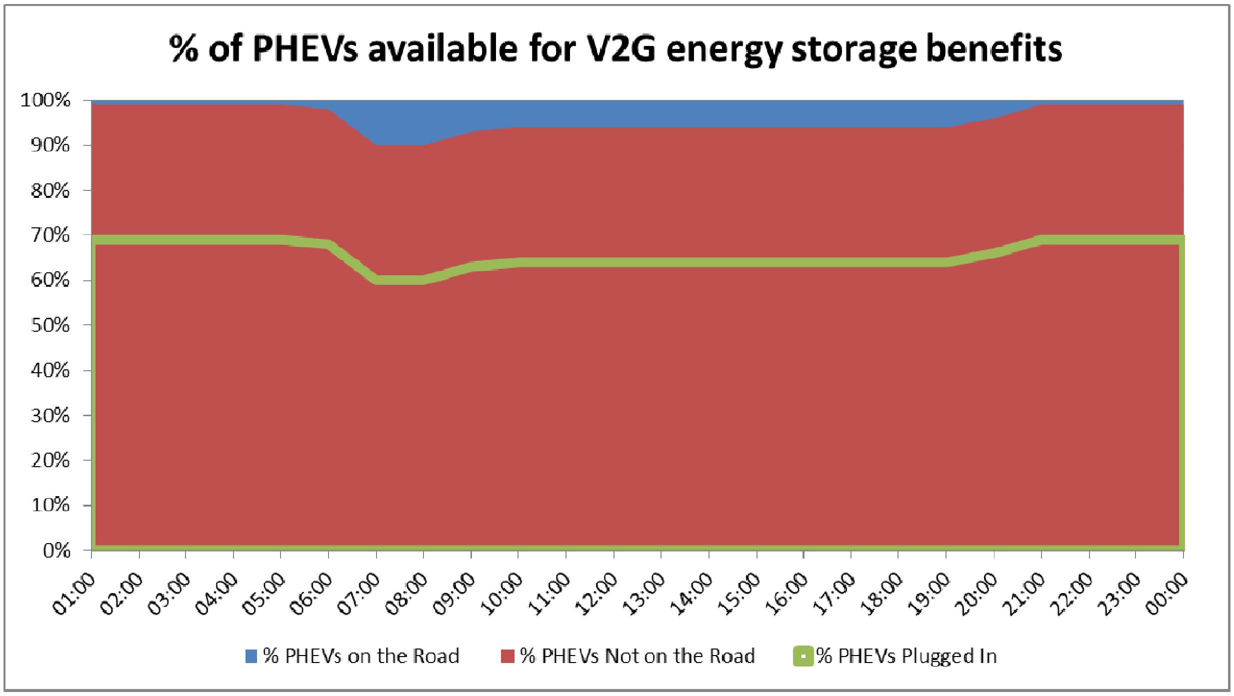

Figure 12 - Percentage of PHEVs available for V2G energy storage benefits (Data from: (Nicole Davis))

6.2 Demand-side Model for PHEV Penetration

In order to construct the demand-side model for total electricity demand including PHEVs, it was necessary to characterize the current electricity demand in the LADWP service region. By understanding the region's patterns and requirements, it would then be possible to determine the potential penetration of a successful PHEV fleet under various supply scenarios. It was decided that this data would be needed in the form of hourly power demand, and hourly possible supply. This was seen as the most relevant time frame, since PHEV charging patterns vary greatly over a 24-hour period.

6.2.1 Charging Profile

In order to characterize the potential PHEV electricity demand per hour, it was important to determine the portion of the PHEV fleet that is idle and potentially connected to the grid throughout the day. This helps define the potential charging weight per hour. Initially, we sought to research the hourly driving patterns of the LA population. Although no LA-specific data was found, national statistics were available, and it was assumed that LA trends would be similar to nationwide trends due to common patterns associated with work, leisure, and travel. Figure 13 depicts these patterns, in terms of the percentage contribution per hour over the course of a 24-hour day [98].

[98] (Green Car Congress)

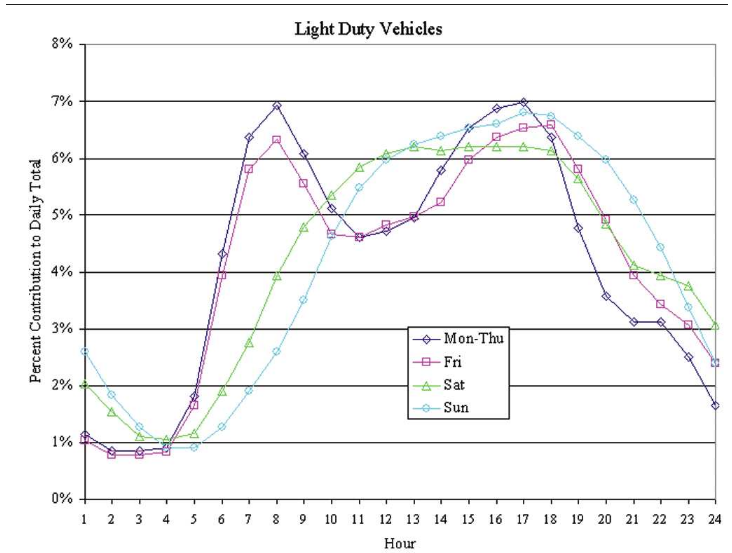

Figure 13 - Hourly driving trends for the USA – Source (Green Car Congress)

This information was useful for an initial visualization of a potential charging profile; i.e. when people were not driving, they could potentially be recharging their vehicles. However, this information alone does not allow for reliable conclusions concerning the PHEV charging profile. For example, when people are not driving, they may simply be parked or they may be in an area where no grid connection is available

Further research uncovered a PHEV charging profile based on the LADWP's own estimates (Figure 14). This charging profile matched our assumptions about the reciprocal relationship between driving patterns and charging patterns. [99] Using this charging profile, we were able to convert the PHEVs' daily electricity needs into hourly demands.

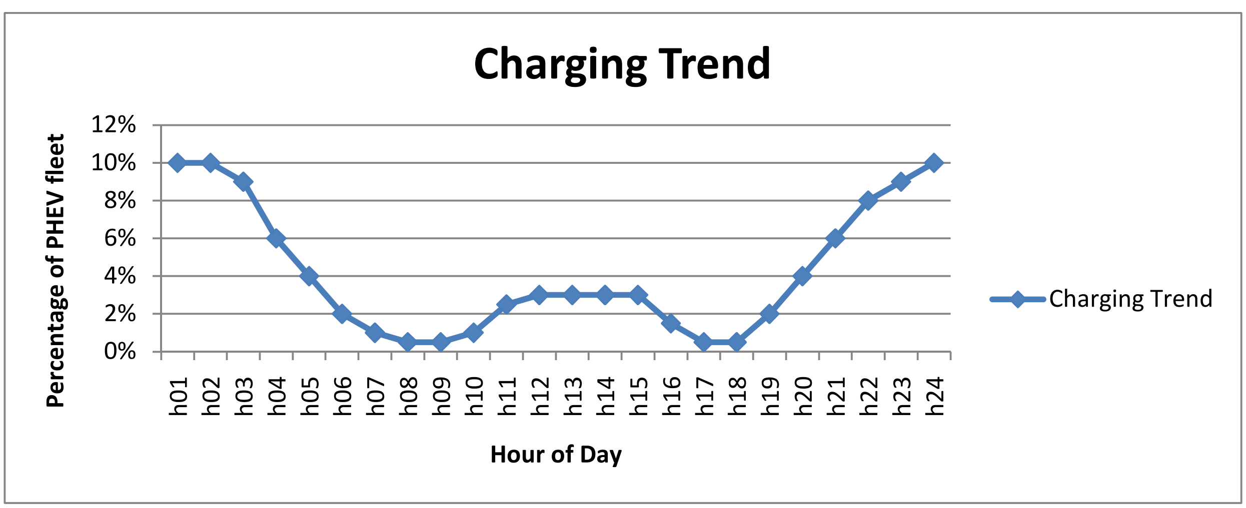

Figure 14 - PHEV charging Profile - Source:(City of LA department of Water and Power, 2010)

[99] (City of LA department of Water and Power, 2010)

6.2.2 Los Angeles Current Demand/Supply

In addition to researching the hourly variation in PHEV electricity demands, it was also necessary to research the current hourly demand in LA without the inclusion of a PHEV fleet of any size. However, this hourly pattern varies day-to-day and season-to-season.

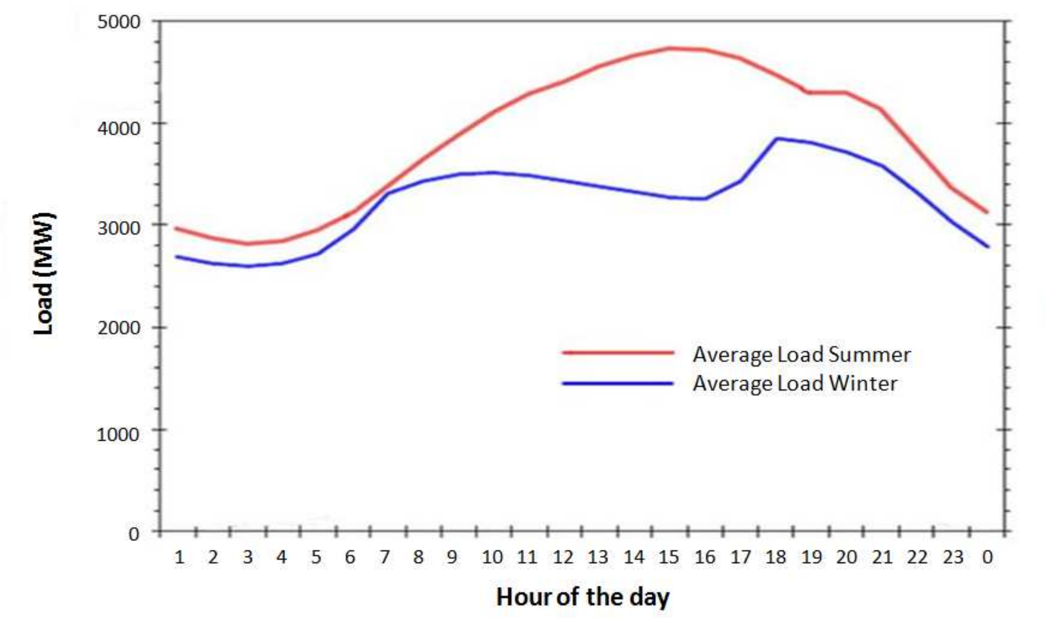

Figure 15 - Seasonal demand patterns- Source: (GE Energy Consulting, 2007)

Figure 15 illustrates the data which was found.[100] The graph details both the average summer and winter loads. The discrepancy here is largely due to air conditioning use in the summer.

At this stage, it was decided that it would be most relevant to use the highest demand in order to truly understand the maximum penetration for a PHEV fleet, since this added demand must be met at all points during a year. Therefore, it was seen as irrelevant to use an average. The team concluded that the day of highest demand (i.e. the hottest day) would be the most inclusive figure to use for the final analysis of LA's capability to cope with the introduction of PHEVs on a large scale. This data is shown in Figure 16.

[100] (GE Energy Consulting, 2007)

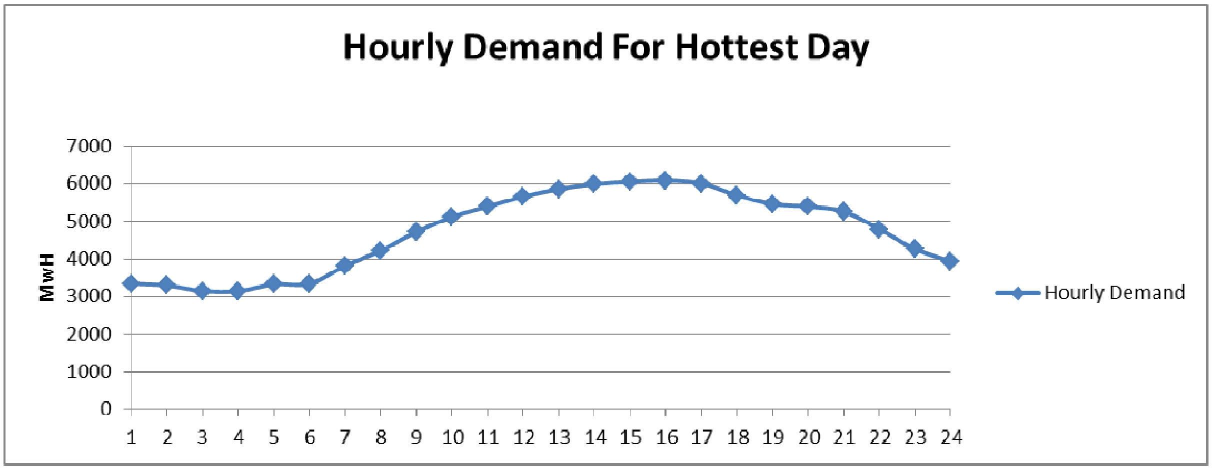

Figure 16 - Hourly demand for LA; hottest day

Now that the charging demand and the unique electricity demand for the LA region had both been characterized on an hourly basis, the combination of both demand curves could be analyzed. However, in order to make use of the hourly PHEV charging profile, the total daily electricity requirement had to be calculated.

6.2.3 PHEV energy demands

As a basis for determining the charging requirements of a PHEV, it was decided to use the most current model on the market – the Chevy Volt. Based on the figures released for this model, the battery capacity is 16 kWh, which allows for an average of 40 miles of all-electric travel.

Average Miles per day	21.00
% average use of electric motor	0.80
Average use on electric motor	16.80
kWh/mile	0.4
kWh per day	6.72

Table 12 - PHEV driving trends (data generated based on research and assumptions covered in the text)

Table 12 illustrates the model inputs used in our LA-specific feasibility study. It was found that, on average, an LA driver will travel only 21 miles per day. Based on the statistic that 80% of travel is inner-city, it was possible to conclude that around 17 miles per day would be driven on the electric battery supply alone – i.e. not using the ICE. Using the Chevy Volt's technical specifications to determine kWh/mile, it was then possible to determine the total daily energy requirements per vehicle in kWh. (Genral Motors 2009). This figure could then be multiplied by the total number of light-duty passenger cars in LA and the percent PHEV fleet penetration in order to calculate the total kWh electricity requirement for all cars.

Now that the PHEV demand curve and the current electricity demand curve had both been identified, a combination of the two could begin. By inputting data for the potential maximum hourly energy supply, a comparison could be carried out for the demand/supply relationship and the implications a varying number of PHEVs may have on this. In using the solver tool in Excel, an analysis could be carried out in order to realize the potential maximum number of PHEVs possible to add to the grid under various supply scenarios.

6.2.4 Simulation model

The model created is adaptable for a number chosen situations. In this case, it is desired to simply find the theoretical maximum penetration of PHEVs in the current market. The input variables for the model are given below.

- Vehicles on the road in LA
- kWh per mile per vehicle
- Hourly charging profile
- Hourly daily demand (non PHEV)
- Hourly maximum supply

To consider how many PHEVs could potentially be included in the grid at this time, the current number of cars on the road was decided to be considered, as a basis of understanding. It could then be concluded what maximum penetration of the existing fleet could be reached. By considering the maximum supply of electricity currently available to the region, the solver analysis could maximize the penetration of the PHEV fleet, whilst never exceeding the maximum hourly supply potential. In other words, our results illustrate how much penetration could take place in terms of hourly charging needs without exceeding the LADWP's hourly generation capacity.

6.3 Results and Discussion

6.3.1 Wind and Solar Effects on Supply Curves

As previously stated, the two main factors influencing PHEV penetration are the power supply and subsequent demand. In order for PHEVs to be a feasible technology, there must be adequate supply to match the increase in demand caused by the recharging of the vehicle's batteries.

The curves shown in Figure 17 were calculated by modifying the initial constant baseline supply. The blue line is simply the maximum daily power supply divided evenly throughout the day. However, this baseline must be modified to account for the changes in daily wind speed. Generally, wind speeds are higher at night than the middle of the day and thus provide more power between the hours of 7:00pm to 6:00am. As it turns out, maximum solar generation is on an opposite schedule to wind; solar provides more power during the middle of the day when the sun is directly overhead. This simple fact will prove to be vital as more of these renewable resources are brought online. Instead of having large peaks and valleys during certain parts of the day, an electrical generation plan that utilizes both wind and solar energies will help to maintain a more constant supply. In this way, wind and solar generation were correctly modified from the original baseline supply to account for these characteristics.

6.3.2 Scenario I Results –Penetration Based on Current Supply

This modification to the baseline generation was calculated using California wind averages to create an "hourly capacity factor." This intermediate factor is a per-hour percentage of the total installed capacity and was used as a way to determine the power production throughout the day. Using these individual hourly factors plus a wind capacity credit of 28% (based upon a conservative 10% wind penetration assumption) the hourly distributed wind generation was calculated. For this initial modification to the baseline supply, the true solar distribution was ignored. Calculating this distribution would follow the same procedure as wind generation but may be disregarded as solar power currently comprises such a small fraction of the total generation. With the above modifications, the true current power supply is described by the red curve in Figure 17.

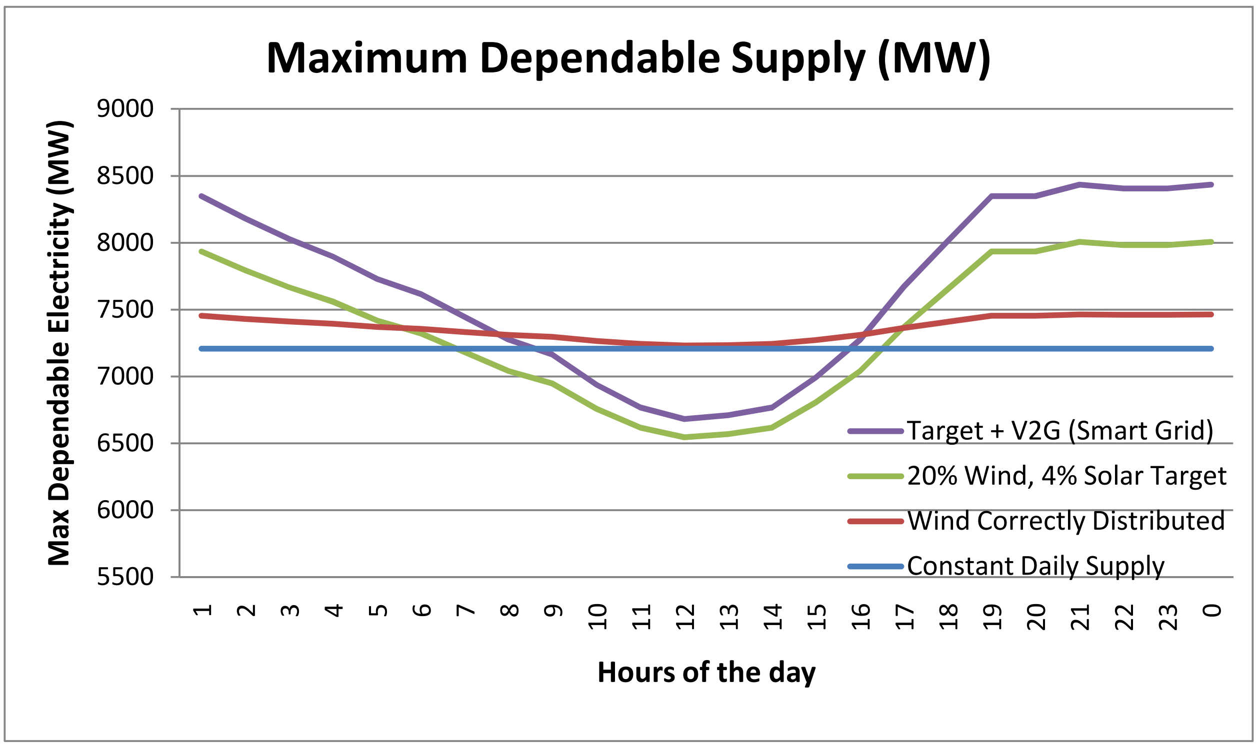

Figure 17 - Maximum Dependable Supply under various supply scenarios

The wind modified maximum dependable supply curve was then used to calculate the theoretical maximum PHEV penetration. The first step in this process was to determine the PHEV charging profile as displayed previously in Figure 14. This profile was used to assess the additional demand created by the influx of PHEVs. As can be seen, without any type of price or other incentives by the utility, the majority of PHEVs will be charged at night with a slight peak during the middle of the day. This profile corresponds well to the standard business day of high vehicle use during the rush hours of 7:00am through 9:00am and 5:00pm to 7:00pm. Consequently, there will be minimal charging during these times. The shape of this charging profile is one of the primary constraints to PHEV penetration. The ability to modify it may be considered one of the two best ways to increase potential penetration; the other being to simply increase power generation. There is tremendous potential to modify this charging profile through different types of incentives to get more people to charge during the middle of the day. Currently, the majority of charging takes places at the home mostly out of physical infrastructure necessity; there are very few public charging stations. However, additional charging stations at public areas such as shopping malls and office complexes where vehicles are parked for long periods of time will do much to alter the charging profile.

The LADPW's current maximum hourly demand curve is plotted in Figure 18 below. The charging profile from Figure 14 was added to the standard demand to produce the true hourly power demand including PHEVs. Using Excel Solver to equate the peak of the hourly demand profile to the minimum of the supply curve, the maximum PHEV penetration was calculated to be 113% of the total vehicle fleet in Los Angeles. In this way, Los Angeles can already support a vehicle fleet comprised of solely PHEVs without adding any generation capacity or charging incentives. Since 113% is only a theoretical number, the analysis determined that there would be a daily excess of 29,557 kWh based upon a PHEV only vehicle fleet. The minimum energy excess would occur at 2:00pm with a surplus of 132 kWh. An important factor to remember is the fact that the original demand profile was taken from the hottest day when air conditioners and other large energy consumers were running constantly. Therefore, the normal day would see an even larger excess supply and LADPW would still be able to sell off their surplus power to other utilities.

Finally, as a basis for comparison, the total kWh used per day per vehicle was modified to assume that the driver completely drained the battery. In this way, it was assumed that the battery would need to be fully recharged, demanding 16 kWh per vehicle. With this large increase in demand, the model calculated a new maximum PHEV penetration of 43%.

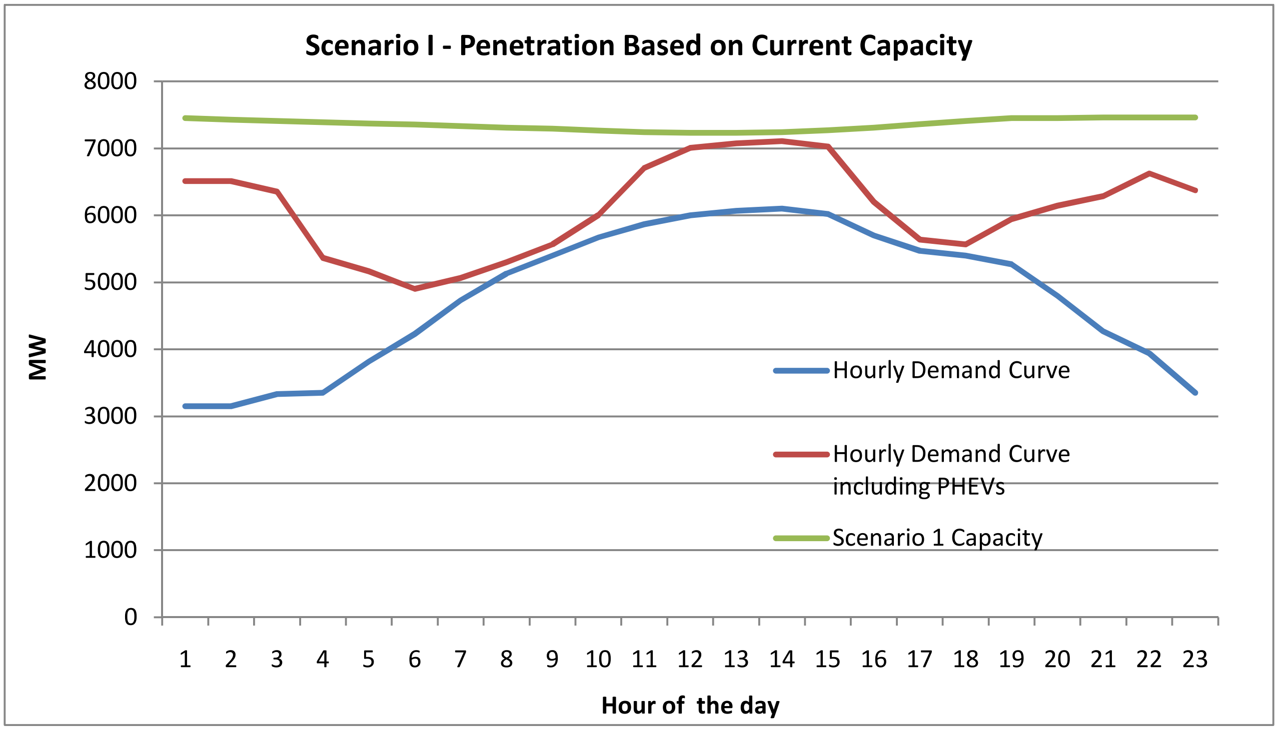

Figure 18 - Supply and demand curves for Scenario I

6.3.3 Scenario II Results –Penetration Based on 2020 Targets

After the analyzing the penetration based upon the current generation capacity, the next step was to determine the maximum theoretical penetration based on the 2020 power generation targets. In an effort to reduce carbon emissions, California has a goal to increase wind generation to 20% and solar generation to 4% of the total installed capacity and to eliminate the use of coal power.

A similar strategy was used to determine the "20% wind, 4% solar target" supply line in Figure 19 as was used to calculate the current generation profile. However, the capacity credit decreases from 28% to 22% for a 20% wind penetration model. In addition to the wind profile change, this new model cannot ignore the true solar distribution profile any longer. The solar distribution was calculated in much the same way as the wind; however a 25% capacity credit was used constantly though our calculations (25% is the currently used capacity credit used by the LADWP). As mentioned previously, solar energy makes up somewhat for the decrease in daytime wind speed as indicated in Table 13. However, there will still be a mid-day decline in supply as installed wind generation is still over 1,000 MW larger than solar power. There is simply not enough solar capacity to make up for the mid-day decline in wind speeds. In this way, the total daily power generated using 20% wind and 4% solar will equal the current supply. However, the generation will not be as constant throughout the day and will experience peaks and valleys. Figure 19 indicates that there will be a 345 MW decrease in power at 12:00pm compared to the current generation profile. As will be discussed, these valleys will affect the potential maximum penetration of PHEVs.

Time of Day	Distributed Solar MW	Time of Day	Distributed Solar MW	Time of Day	Distributed Solar MW	Time of Day	Distributed Solar MW
1:00	0	7:00	177184	13:00	654812	19:00	177184
2:00	0	8:00	415998	14:00	647108	20:00	0
3:00	0	9:00	523849	15:00	631701	21:00	0
4:00	0	10:00	616293	16:00	616293	22:00	0
5:00	0	11:00	631701	17:00	523849	23:00	0
6:00	0	12:00	647108	18:00	415998	0:00	0

Table 13 - Hourly available solar generation (Data from: (Hoste, Dvorak, & Jacobson, 2009))

After the above modifications to the original baseline supply curve, the maximum PHEV penetration was again calculated using a similar procedure as describe earlier. With the targets of 20% wind and 4% solar penetration, the maximum PHEV penetration was determined to be 84%. Due to the aforementioned nature of wind generation and subsequent mid-day decline in supply, maximum PHEV penetration is less than current generation allows. The model was then again run assuming each battery needed to be fully recharged to determine a modified maximum penetration of 32%. However, the introduction of a vehicle-to-grid smart system would be able to help increase these penetration levels, as discussed next in Scenario III.

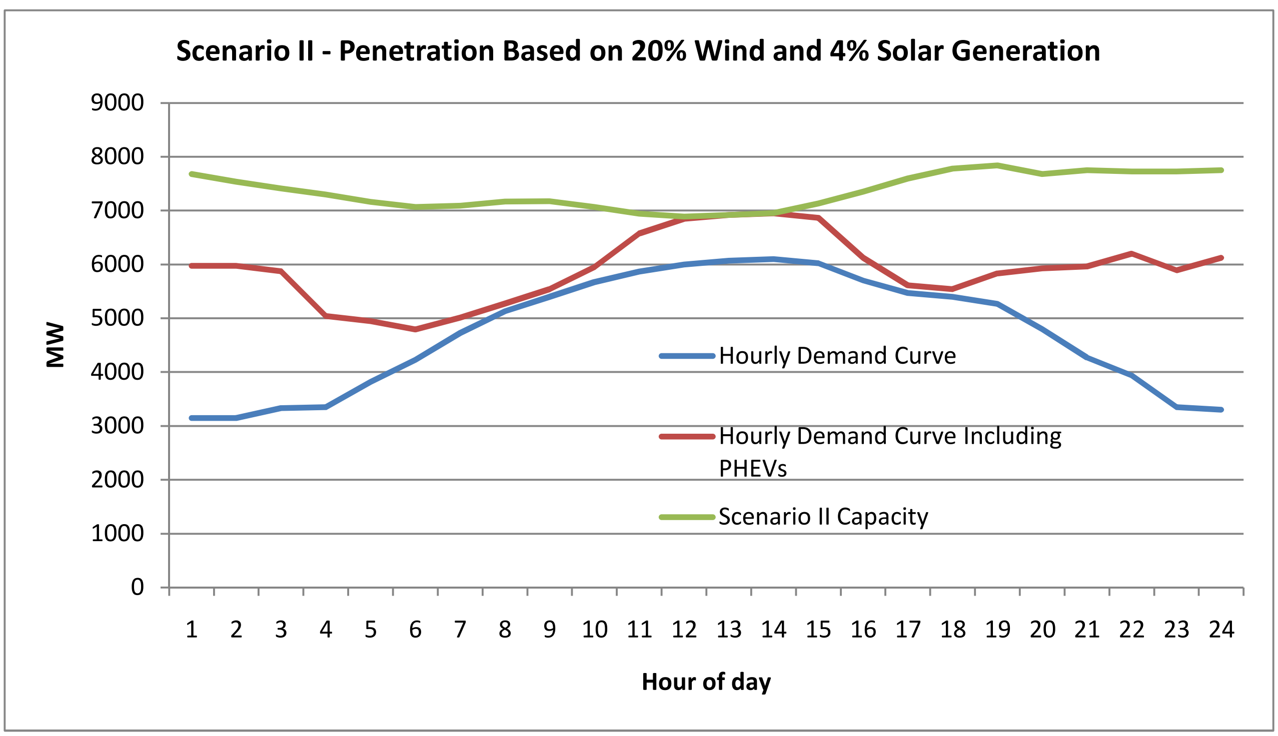

Figure 19 - Supply and demand curves for Scenario II

6.3.4 Scenario III Results –Penetration Based on 2020 Targets and V2G

The final scenario studied was the 2020 target generation supply with the addition of a vehicle to grid system. Using an assumed penetration of PHEVs in the total 5.5M Los Angeles light vehicle market, we were able to determine exactly how much added storage potential to use. As indicated in TTable 14 - Vehicle to Grid Constraints, we assumed a 15% penetration in the Los Angeles market which resulted in a 32% storage capacity as a percentage of the total installed wind energy. This would increase our wind capacity credit from 22% to 26.4%. The curve for this scenario is indicated by the purple line in Figure 17.

V2G Inputs		V2G Outputs	
PHEV fleet penetration	**15 %**	Percent storage	**32.0%**
Percent of PHEVs participating in V2G	**70 %**	Capacity credit	**26.4 %**
Avaiblable storage per PHEV (kWh / day)	**4**		

TTable 14 - Vehicle to Grid Constraints

The 4.6% increase in the wind capacity credit translates into an added reliable supply of about 300 MW which increases the total dependable supply about 4%. With the modifications as a result of a smart grid system, the new theoretical maximum PHEV penetration is 98%. Again, this theoretical percentage translates into a fleet that is comprised almost entirely of PHEVs. As a final comparison, the model was again run assuming every battery needed to be fully recharged, yielding a modified penetration of 37%.

If we assume that we have met the 2020 targets for installed wind energy, and that we are still allowed to make use of 4 kWh of each PHEV's battery capacity per day and that 70% of all PHEV owners would participate in a V2G system, then we will reach a level of 100% backup storage for the installed wind capacity when a PHEV penetration level of 47% is reached. Even if the PHEV itself does not reach a penetration level of 47% In the future, this level could still be reached if 100% of Electric Vehicles participate in such a V2G system. This will allow for a potential total reduction in required backup capacity of 1300 MW, which will result in significant cost savings and an even greener power generation mix than mentioned before. This is mainly due to the fact that we will then be able to increase the wind capacity credit not only to 26.4% but to the maximum 41%

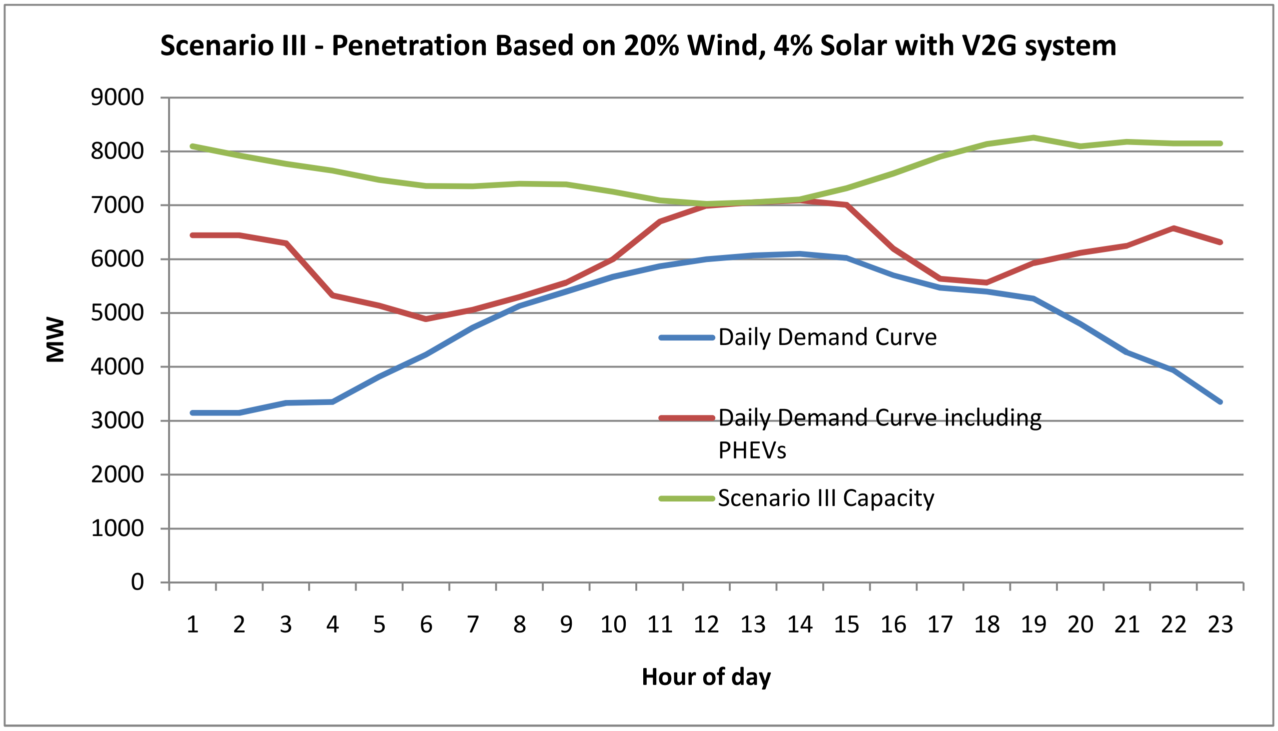

Figure 20 - Supply and demand curves for Scenario III

If we assume that we have met the 2020 targets for installed wind energy, and that we are still allowed to make use of 4 kWh of each PHEV's battery capacity per day and that 70% of all PHEV owners would participate in a V2G system, then we will reach a level of 100% backup storage for the installed wind capacity when a PHEV penetration level of 47% is reached. Even if the PHEV itself does not reach a penetration level of 47% one day, this level could still be reached if all Electric Vehicles participate in such a V2G system.

This will allow for a potential total reduction in required backup capacity of 1300 MW, which will result in significant cost savings and an even greener power generation mix than mentioned before. This is mainly due to the fact that we will then be able to increase the wind capacity credit not only to 26.4% but to the maximum 41%.

6.3.5 Summary of Results

Table 15 is a summary of the results of the three different scenarios analyzed in this study. The 'Maximum Penetration' column lists the percentage of the total fleet that Los Angeles would be able to support based on the assumptions presented in Table 12, specifically the 6.72 kwh consumed per day. The remaining column displays the maximum theoretical PHEV penetration based on a full battery recharge.

Scenario	Maximum Penetration	Maximum Penetration with Full Battery Recharge
Current Supply	100%	43%
2020 Targets	84%	32%
2020 Targets Plus Vehicle-to-Grid System	98%	37%

Table 15 - Summary of maximum penetration results

6.3.6 Potential changes

The above penetration percentages were based upon a number of assumptions, particularly in the areas of LADWP's supply capabilities and personal driving habits. Therefore, the penetrations are a function of the current knowledge of the power grid without any awareness of upcoming changes that may impact their accuracy. For example, any increase in the LADWP's baseline supply or a new record of the largest daily energy consumption by its users would certainly alter the percentages. In addition, there is the possibility of an increase in travel as the cost per mile decreases while operating a PHEV. These are just a few examples of the numerous ways in which any of the penetrations may be altered.

7 PHEV PENETRATION RATES

Now that it is established that the PHEV is an environmentally feasible alternative to the ICEV and that the LA electricity generation infrastructure is able to accommodate a PHEV market, the team will analyze the possible penetration rates of the PHEV. This will be done by studying the current hybrid electric vehicles (HEV) penetration and contrasting it with the PHEV penetration predictions done by other parties.

The table below shows the total vehicle (cars and trucks) sales, only car sales and HEV sales between 1999 and 2008 in the USA.

Year	Total LDV Sales	Cars Sales	HEVs Sales	% of LDV Sales	% of Car Sales
1999	15,218,000	8,120,000	17	0.00	0.00
2000	16,574,000	8,826,000	9,350	0.06	0.11
2001	15,610,000	7,961,000	20,282	0.13	0.25
2002	16,119,000	7,860,000	36,035	0.22	0.46
2003	15,775,000	7,442,000	47,600	0.30	0.64
2004	15,711,000	6,982,000	84,199	0.54	1.21
2005	15,893,000	7,305,000	209,711	1.32	2.87
2006	15,105,000	7,179,000	252,636	1.67	3.52
2007	15,277,000	7,473,000	352,274	2.31	4.71
2008	13,900,000	6,750,000	312,386	2.25	4.63

Table 16 - HEV Sales 1999-2008(Data, Analysis and Trends)

The sales have increased every year except for 2008 where it is assumed to be due to the start of the recession. The percentage shows the percent sales penetration and not the percent market penetration. To compute the market penetration, it is possible to assume that all HEVs that were bought since 1999 are still in use. The total number of HEV in the LDV fleet can be computed as the sum of all the sales between 1999 and 2008. This adds up to 1,324,490 HEVs. It is estimated that in 2008 there were 250 million LDVs in the US automobile market fleet[101]. From these numbers, it can be computed that as of 2008, the HEVs made up 0.53% of the LDV fleet. In other words, it took 9 years to achieve a market penetration of about half a percent.

[101] (US Department of Energy, 2010)

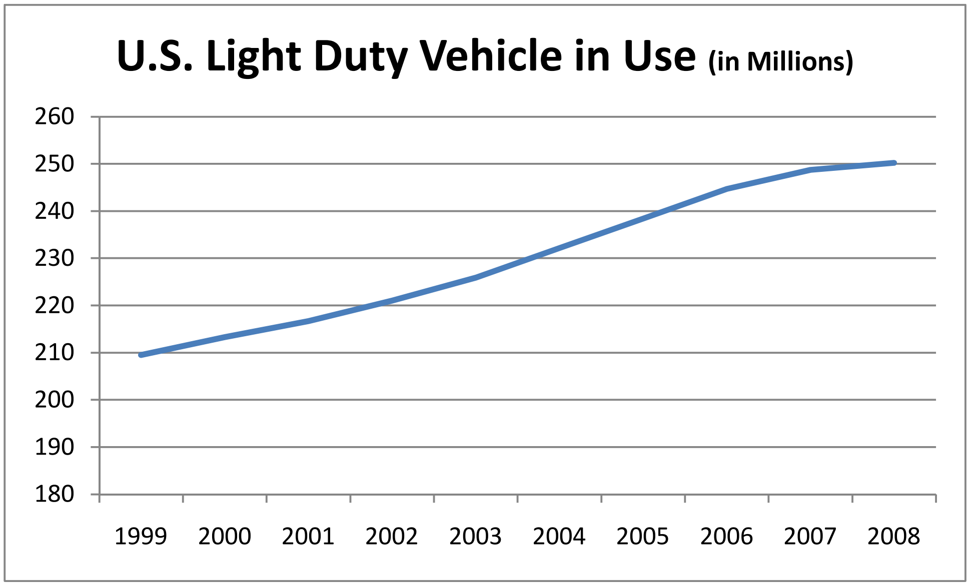

Figure 21 - U.S. Light Duty Vehicle in Use(US Department of Energy, 2010)

The HEV data above shows that the penetration was market driven. The PHEV penetration can occur in two possible ways. It will either be a market driven penetration or an accelerated one. A market driven penetration grows slowly. The technology hasn't proven itself and presents a high risk to the early adopters. Also the high initial costs discourage people from taking the risk of trying the new technology. An accelerated penetration occurs when stakeholders outside the auto industry get involved and help the PHEV reach higher penetrations faster. Stakeholders such as the utilities and the government can provide special electricity rates, purchase incentives, tax credits as well as have an important role in educating the customers. Incentives that could lead to an accelerated market penetration of the PHEV are discussed in the later sections of this report. Figure 22 shows how each of these penetration scenarios would evolve with time[102].

[102] (Duvall, 2008)

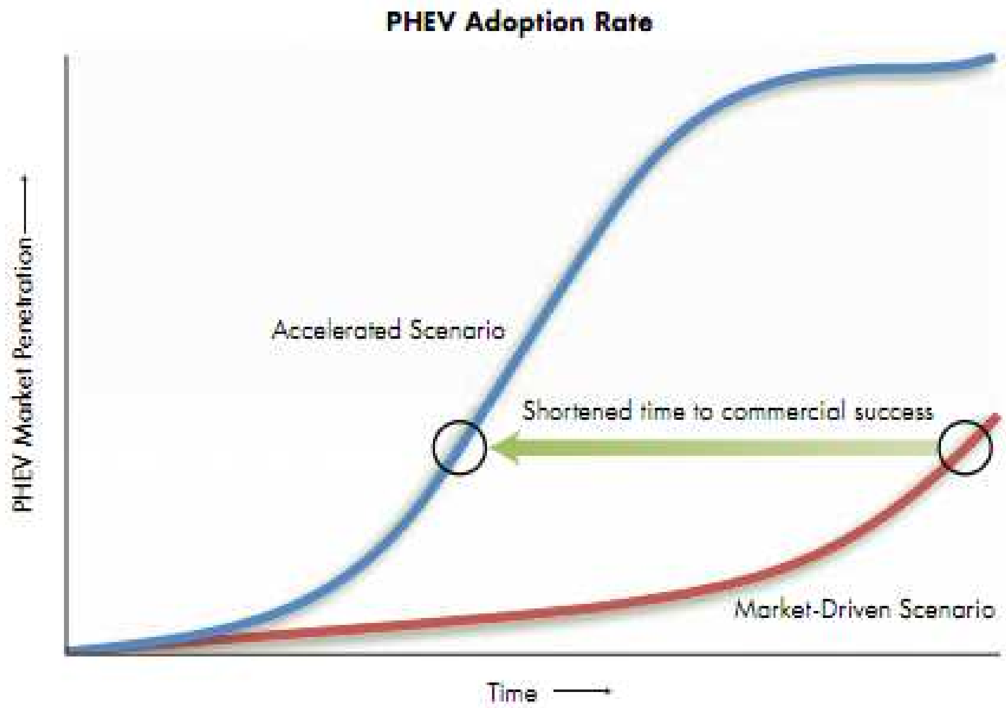

Figure 22 - PHEV Adoption Rate(Duvall, 2008)

Several studies have been done for a proposed PHEV penetration curve. In the study done at the University of Michigan – Transportation Research Institute, the Virtual AutoMotive MarketPlace (VAMMP) model was created to simulate an actual marketplace comprised of actual decision makers[103]. It was designed to test the success of a new vehicle technology such as the PHEV. The decision makers included:

- The consumers,
- The government,
- The energy providers and,
- The auto manufacturers.

When the simulation was run, all of the above agents took decisions that achieve their individual or organizational benefits and objectives. Figure 23 shows the results of 20 simulations.

According to the VAMMP simulation, it would take up to year 2040 to reach a market penetration of about 15%, as shown by the band of 17 out of 20 runs that are in the range of 0.13 to 0.18.

[103] (Sullivan, Salmeen, & Simon, 2009)

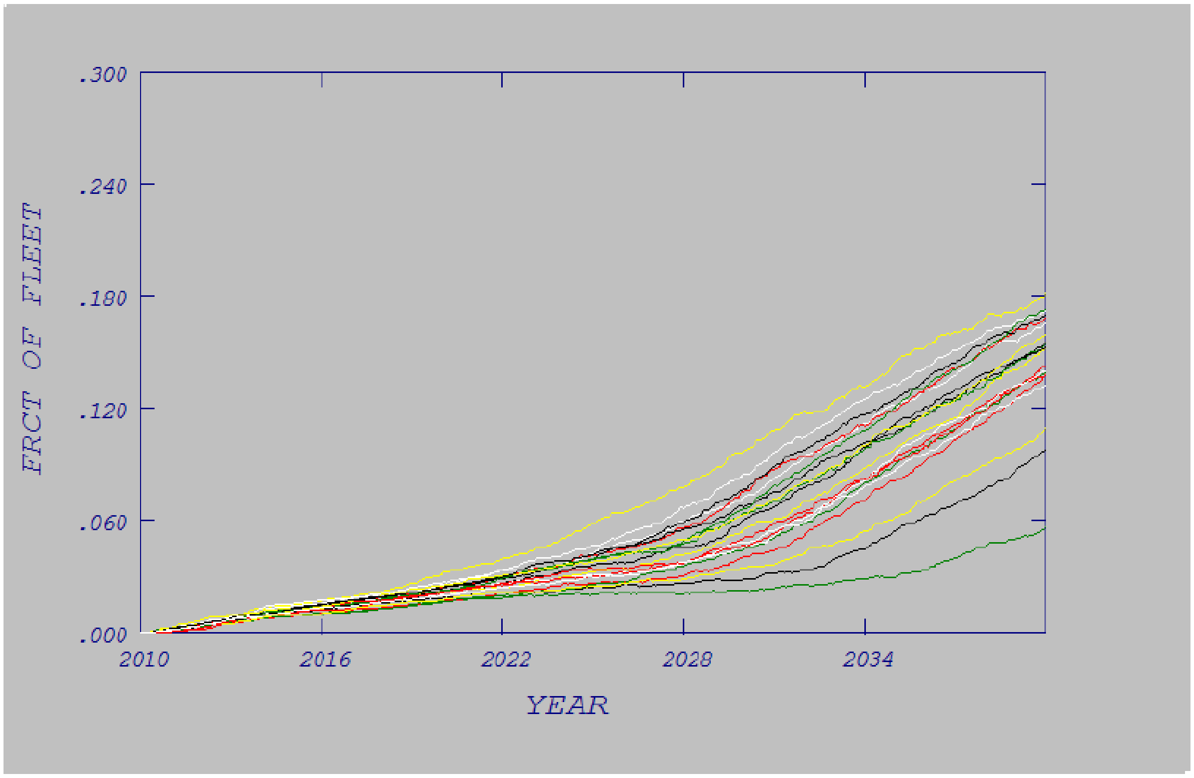

Figure 23 - PHEV Penetration[104]

It would be unreasonable to assume a penetration rate faster than the one portrayed above. This is because the assumed life of the car is 15 years. A 15% penetration in 30 years is achievable if and only if the accelerated scenario is followed and the political decision to implement a transition is taken. Without such a decision it is unlikely to reach such penetrations, in the same that it took the HEV 9 years to achieve just half a percent penetration.

[104] (Sullivan, Salmeen, & Simon, 2009)

8 COST ANALYSIS

The following analysis highlights the differences in costs between PHEVs and ICEVs to the consumer over the life of the vehicle. Both direct and indirect costs are presented; direct costs include the initial capital cost of the vehicle, the operating costs as well as the disposal cost. Indirect costs measure the effect of health hazards and emissions caused by the vehicles.

8.1 Direct Costs

8.1.1 Capital Cost

This analysis assumes that the ICEV is a mid-size passenger vehicle and the capital cost is based on the Honda Accord. The base model of the Honda Accord is priced at $21,180[105].

The capital cost of the PHEV is based on the GM Chevy Volt, which is $41,000[106]. Owners of new PHEVs can qualify for the "New Qualified Plug-in Electric Drive Motor Vehicle Credit". This credit is composed of $2,500 plus $417 for a vehicle which draws propulsion energy from a battery with at least 5 kilowatt hours of capacity plus an additional $417 for each kilowatt hour of battery capacity in excess of 5 kilowatt hours. The portion of the credit that results from batter capacity, cannot excess $5,000. As a result, the total credit allowable for each new PHEV is $7,500[107]. After taking into account the federal tax credit, the capital cost of the PHEV is $33,500.

The price of PHEVs will eventually decrease as the market becomes more competitive and PHEVs become more popular. The entry of PHEVs into the market provides an opportunity for U.S. manufacturers to invest research into the production of batteries, the generation of more efficient electricity, and other industries associated with PHEVs. This increased demand will create new jobs, increase research in new technology areas as well as strengthen the U.S. economy.

8.1.2 Operating Costs

Operating costs include daily gasoline and electricity costs as well as maintenance and tire costs. The lifetime of both the PHEV and ICEV is assumed to be 15 years, and annual vehicle miles traveled is 12,000 miles. While the ICEV uses gasoline for all types of driving, it is assumed that the PHEV uses electricity for urban driving and gasoline for intercity driving. Assuming 80% of miles traveled are urban in nature and the remaining 20% are intercity, a total of 9,600 miles are traveled in urban settings each year and 2,400 miles are traveled in intercity conditions.

ICEVs, such as the Honda Accord, travel 22 mpg in urban conditions and 31 mpg in intercity travel[108]. For a projected average gasoline price of $4.00/gallon, the total urban fuel cost is $1,745/year and the intercity cost is $310/year. The maintenance and tire costs are estimated at $0.056/mile and therefore

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[105] (Honda, 2010)
[106] (GM-Volt, 2010)
[107] (IRS, 2009)
[108] (www.fueleconomy.gov, 2010)

the total maintenance cost for the ICEV is $672/year[109]. The annual operating costs for the ICEV are $2,727. Using a discount rate of 7%, the rate typically used by the U.S. government when evaluating investments, the net present value of the operating costs of the ICEV over the life of the vehicle is $24, 838.

Assuming PHEVs use electricity in urban areas, the cost of electricity to the consumer is estimated at $0.02415/kWh[110]. The PHEV achieves 3 miles/kWh in urban driving and 38 mpg in intercity travel. The total urban electricity cost is $77/year and the intercity gasoline cost is $253/year. The maintenance and tire costs are again estimated at $0.056/mile and therefore the total maintenance cost for the ICEV is $672/year[111]. The annual operating costs for the PHEV are $1,002. In year ten, the battery of the PHEV will have to be replaced which will cost approximately $10,000. Using a discount rate of 7%, the net present value of the operating costs of the ICEV over the life of the vehicle is $14,209.

8.1.3 Disposal Cost

When analyzing disposal costs, several parts of ICEVs and PHEVs, for which lifecycle and costs are different, must be considered. The primary driver of the disposal cost for the ICEV is the body itself, which is made of steel. There is also a small battery, which is made of lead-acid. In PHEVs, an important component of the disposal cost results from the lithium-Ion battery. In Los Angeles, the disposal of ICEVs and PHEVs is free to the owner of the vehicle[112].

8.1.4 Total Direct Cost

Over the life of the vehicle, PHEVs are approximately $1,700 more expensive than ICEVs. Given the 15-year life of the vehicles, the additional expense is deemed to be minimal. The issue arises from the high up-front capital cost of the PHEV. Ways to resolve this will be discussed in the business section of this report. The following graph summarizes the capital costs and operating costs for the ICEV and the PHEV.

[109] (Commute Solutions, 2010)
[110] (Los Angeles Department of Water & Power, 2009)
[111] (Commute Solutions, 2010)
[112] (Donate a Car 2 Charity, 2010)

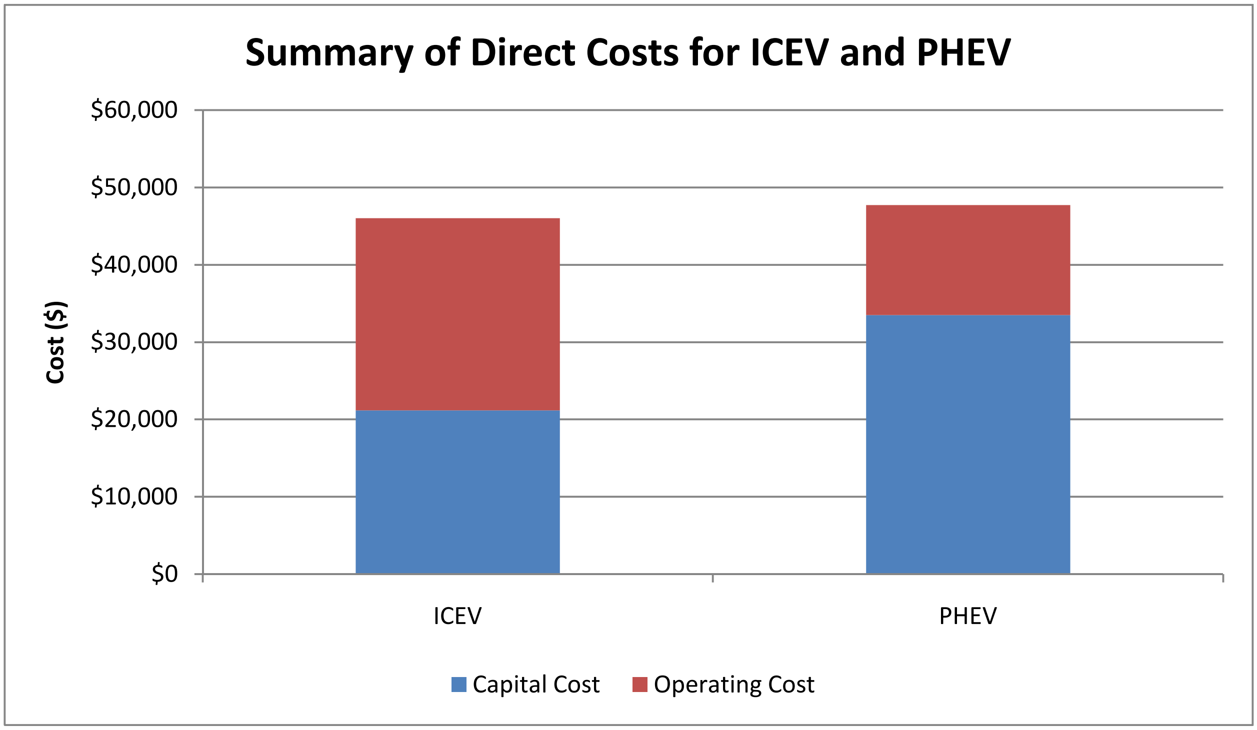

Figure 24 - Summary of Direct Costs

8.2 Indirect Costs

8.2.1 Health Costs

Dependence on vehicles in the U.S has many negative effects on society including decreased opportunities for physical activity, increased vulnerability to traffic crashes as well as increased exposure to air pollution. It is estimated that the social costs of air pollution associated with vehicles are between $30 billion and $349 billion per year[113].

The following table summarizes the estimated economic costs of motor vehicle-related air pollution in 2000. The majority of costs are attributed to mortality, chronic bronchitis and other respiratory and heat diseases caused by inhalation of particulate matter[114].

Pollutant	Impact	Costs of Rural Motor Vehicle Travel	Costs of Urban Motor Vehicle Travel	Costs of All Motor Vehicle Travel
		$1990 (millions)	$1990 (millions)	$1990 (millions)
Particulate Matter	Mortality	12,695	21,558	31,162
Particulate Matter	Non-fatal Illness	3,683	6,232	9,183
Sulfur dioxide, nitrogen dioxide, carbon monoxide	Non-fatal Illness	0	51	51

113 (U.S. Department of Transporation, Federal Highway Administration, 2000)
114 (U.S. Department of Transporation, Federal Highway Administration, 2000)

Ozone	Non-fatal Illness	28	16	47
Total		16,406	27,857	40,443

Table 17 - Estimated Economic Costs of Motor Vehicle-Related Air Pollution in 2000(U.S. Department of Transporation, Federal Highway Administration, 2000)

Given the substantially decreased air pollutions from PHEVs as compared to ICEVs, the health costs due to air pollutions will also be greatly diminished as PHEVs become more popular.

8.2.2 Emission Costs

In 2008, 1,945.8 million metric tons carbon dioxide equivalent were emitted by the transportation sector in the U.S, which represents approximately 28% of all greenhouse gas emissions[115]. Currently, the U.S. has not committed to the Kyoto Protocol, which calls for a reduction of greenhouse gases by 7% from 1990 levels in 2012. Should the U.S. agree to sign the Kyoto Protocol, the cost would be extraordinary. Transportation is an ideal sector to begin decreasing greenhouse gas emissions. There has been a trend to increase efficiency of internal combustion engines, however, a significant decrease in emissions is not likely. New technologies such as PHEVs provide an alternative to traditional ICEVs and greatly decrease U.S.' carbon footprint.

[115] (U.S. Energy Information Administration, 2009)

9 BUSINESS ASPECTS OF THE TRANSITION

The next section discusses the business aspects of a transition from ICEVs to PHEVs in the Californian market. At first, the major stakeholders of a PHEV introduction are identified and their key interests explained. Next, the current legal incentives to promote low emission vehicles in California are described before potential new incentives to increase and expedite PHEV market penetration are presented. Later, the manufacturers' strategies to overcome the challenge of governmental regulations are described and a potential marketing strategy to promote PHEVs is developed.

9.1 Stakeholder Analysis

At first, the various groups that are likely to affect or to be affected by a PHEV introduction in the greater LA area are identified. Manufacturers, consumers, the utilities, banks and car dealers in LA as well as the Californian government will influence how fast and to which extent PHEVs will penetrate the market. The following figure illustrates the different stakeholders and lists some of their major concerns related to PHEVs.

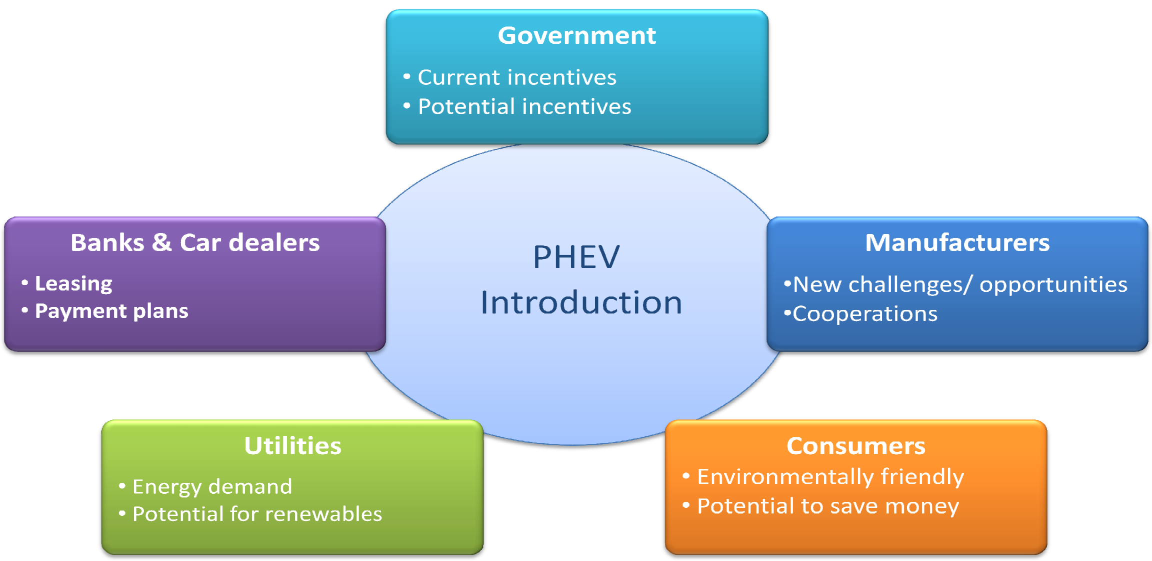

Figure 25 - Stakeholders of the PHEV Implementation

Domestic and international **car manufacturers** face new challenges in the Californian market. The introduction of Assembly Bill 32, the Global Warming Solutions Act of 2006, sets reduction targets for greenhouse gas emission until 2020. This will be further discussed in the next sections. Each car manufacturer cannot exceed defined average GHG emissions of all cars sold in a specific year. The emission limits decrease every year from 2010 to 2020. Therefore manufactures will have to introduce new technologies to lower the average emissions of their sales fleet or introduce smaller cars with smaller engines to fulfill the requirements. In this context and due to the fact that California has the highest Hybrid penetration of all US states, PHEVs are a business opportunity for the Californian market. However to make PHEVs more attractive for consumers and competitive to the ICEVs, car manufacturers might need to cooperate in research and development of production processes and for the battery technology to reduce the initial cost difference of PHEVs and ICEVs.

A PHEV introduction would give **consumers** the choice to pay extra for an environmentally friendly solution of private transportation. Smog and noise pollution can be reduced by PHEVs which would positively affect health issues in the region. In addition, the lower operating costs of the PHEVs make them attractive for consumers who exceed a certain amount of miles driven over the lifetime of the car. Furthermore, it can be assumed that the battery technology is not mature and that batteries will become cheaper, lighter and or have more capacity after further years of research. Therefore the PHEVs might become attractive from a cost perspective in a few years.

As discussed earlier, a PHEV penetration in the Californian market would affect the **utility companies** in the region as the energy demand as well as the potential for renewable energy would increase. Oil companies might try to oppose a PHEV introduction and influence other stakeholders such as the government and the consumers.

Payment plans and leasing options can give PHEVs an advantage in their competition with ICEVs, as PHEVs require a higher initial payment with the advantage of lower operation costs throughout the lifetime of the car. For that reason financial service packages around the PHEV can become an interesting market for **banks and car dealers**.

The **Californian government** is a key stakeholder of a potential PHEV introduction as they have a high power of influence and a high interest in the technology as opportunity to reduce green house gas emissions. The next two chapters will discuss in detail which current incentives are in place in California and which potential initiatives can be undertaken by the government to increase and expedite PHEV penetration in the market.

9.2 Current Initiatives to Promote PHEVs

The Californian government promotes PHEVs through passing legal regulations for the car manufacturers as well as offering various benefits for PHEV users. In order to meet California's air quality standards and greenhouse gas emission reduction goals as well as to reduce the dependence on foreign oil, a transformation away from petroleum is required.[116] The following incentives are either fully implemented or in the process of implementation in the greater LA area: Climate change program (AB32), zero emission vehicle (ZEV) program, carpool lane/HOV lane access for PHEVs, environmental performance label as well as tax credit given to the consumers when they purchase PHEVs.

9.2.1 Climate Change Program - AB32

In 2006, the Legislature passed the Global Warming Solution Act of 2006 to set greenhouse gas emission reduction goals through 2020. This act helped the California Air Resources Board (CARB) begin developing actions to reduce greenhouse gases while also prepared a roadmap to illustrate the series of implementation steps in order to accomplish the ambitious 2020 limit, as indicated in the act.[117] The first reduction target is set for 2011. The overall goal of AB32 is to reduce GHGs to 1990 levels by 2020. After

[116] (California Government, Nov. 2010)
[117] (Schwarzenegger, Dec. 2008)

that, California's goal is a reduction of 80 percent from 1990 levels by 2050.[118] In addition, the board approved the 2020 emission limit of 427 million metric tons of carbon dioxide equivalent of greenhouse gases.

9.2.2 Zero Emission Vehicle

CARB has been a frontrunner in developing programs to reduce emissions from vehicles. They have adopted a new approach to passenger vehicles by combining the control of smog-causing pollutants and greenhouse gas emissions into a single coordinated package of standards. The new approach also includes efforts to support and accelerate the numbers of - zero-emission vehicles in California (PHEVs is one kind of such vehicles). The zero emissions vehicle regulation requires large volume and intermediate volume manufacturers to introduce and operate a certain percentage of zero emissions vehicles in California, including PHEVs with almost zero emissions

9.2.3 Carpool lane/HOV Lane Access and Free Parking

California Governor Arnold Schwarzenegger signed a bill (SB 535) that extends HOV-lane access to 40,000 miles and allows plug-in hybrid vehicles to use these lanes starting in 2012.[119] In addition, PHEV owners have the privilege to park for free in some areas of LA.

9.2.4 Environmental Performance Label

Since 1998, all new cars sold in California need to have a Smog Index Label. The label is intended to help consumers compare the smog forming emissions from different vehicles. Assembly Bill 1229[120] signed into law in 2005 required the ARB to redesign the Smog Index Label to include information about emissions of global warming emissions. The Environmental Performance (EP) Label was approved by the Board in 2007 and has to be shown in the window of every new car sold in California that was manufactured after January 1, 2009. The new EP Label includes both a Smog Score and a Global Warming Score, both range from 1 to 10, with 10 being the score of the cleanest vehicles in both smog and greenhouse emissions and 1 being the score of the dirtiest vehicles.[121] The environmental performance label helps to raise awareness of the customer and allows vehicle comparison by their emissions and effect on global warming.

9.2.5 Tax credit

The Clean Vehicle Rebate Project (CVRP), funded with a total of $4.1 million by CARB, was established in order to promote the production and use of zero-emission vehicles such as plug-in electric and fuel cell vehicles. The program was created from Assembly Bill 118 that was signed in October 2007. The funding will be provided on a first-come, first-served basis, and the project is expected to go through 2015. Eligible vehicles include only new CARB-certified or approved zero-emission or plug-in hybrid electric

[118] (California Air Resource Board, Sep. 2010)
[119] (Jay Friedland, Jan. 2010)
[120] (California Government, Oct. 2005)
[121] (Mary D. Nichols, Sep. 2010)

vehicles. Vehicles must be purchased or leased on or after March 15, 2010. Rebates of up to $5,000[122] per light-duty vehicle are available for individuals and business owners who purchase or lease new eligible vehicles. Certain zero-emission commercial vehicles are also eligible for rebates of up to $20,000. The base credit is $2,500, plus $417 for a base 5 kilowatt pack, plus an extra $417 for each kilowatt of capacity over that (up to 16). The government offers up to $7500 tax credit for PHEV depending on the size of the battery package.

9.3 Potential Initiatives of the California Government to Promote PHEVs

Current incentives in the United States and California are mostly in form of financial advantages. While this is effective, and raises awareness, there are several drawbacks of the financial incentives as they cause revenue losses for the government and trigger opposition from individuals and organizations. They argue that especially during the economic crisis, the cost of financial incentives to promote low emission vehicles do not outweigh the benefits. Therefore service based incentives can complement the current financial incentives which should be used only to initially increase the PHEV market share.

Service based incentives draw attention from the general public. By watching PHEV owners getting benefits from PHEVs, it increases people's desire in wanting to own a product like it, thus increase the likelihood of them purchasing one.

The government could pass laws or regulations to enforce service-based incentives from private organizations, such as entertainment facilities like Broadways, Six Flags, Disney World, etc. Public entertainment facilities would have to dedicate specific ticket booths to PHEV owners. The government could require similar prioritizations to car wash companies, auto shops, dealers, etc.

These incentives are non-monetary-based and could be applied more ubiquitously throughout the public. Service-based incentive implementations do only incur negligible financial losses to both the government and private organizations.

Another potential initiative to enhance PHEV awareness and market penetration is to gradually replace government ICEV fleets with PHEVs. For instance, police PEHVs would draw attention from the public. By transitioning the police fleets to PHEVs, it shows the trust of the government in the new technology which could help to convince the general public of PHEVs. This transition does not only apply to police fleets but also to ambulances and fire truck fleets. Furthermore, vehicles of politicians and other officials could also be replaced by PHEVs.

9.4 Manufacturers Strategies

9.4.1 Current Strategies and Upcoming Challenges

With reference to Table 18 the emission limits will be challenging to satisfy in the second half of this decade. The main strategy of the manufacturers is to impose US customers the European way of thinking

[122] (Center for Sustainable Energy California, 2010)

about cars, which is "smaller vehicles with smaller engines".[123] However it is questionable whether the US customers will adopt this idea. Another shortcoming of this strategy is the customers' tendency to drive more miles per year if their vehicles become more efficient. Figure 26 shows that while the fuel use per capita has stayed constant, the miles traveled per capita continuously increased.

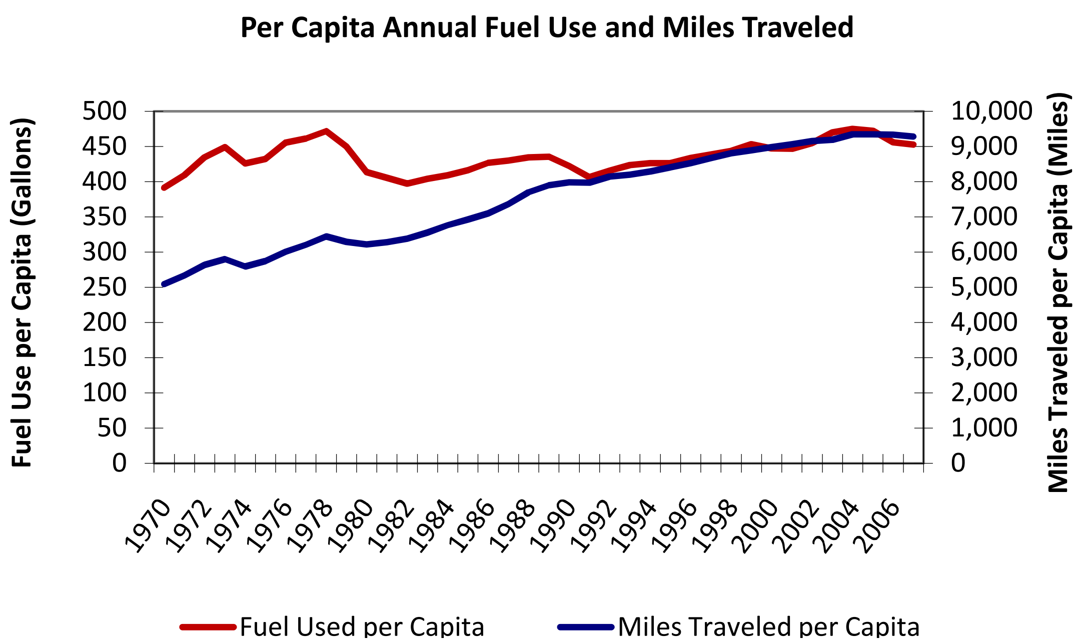

Figure 26 - Per Capita Annual Fuel Use and Miles Traveled(Davis, 2009)

This shows that as the IC engine became more efficient in terms of gas consumption, the people started to travel more. It can be seen that increasing the efficiency of IC engines did not actually decrease the overall emissions. Although the situation doesn't affect the manufacturers directly, it makes it harder for the government to accomplish the overall emission targets. Consequently, especially for the California region which aims to reach the AB 32 target, increasing efficiency of the IC engine doesn't contribute to the emission reductions significantly. Therefore it would be better to focus on other strategies, such as the introduction of PHEVs to the fleets.

The companies which are planning to introduce PHEVs' to their fleets will be able to offer larger and heavier cars while satisfying the regulations because the PHEVs will lower the average fleet GHG emission levels. Moreover the introduction of PHEVs such as the Ford Escape to the California market proved that the PHEV technology is capable of offering larger and heavier vehicles. Consequently, besides promoting smaller cars, different type of PHEVs can be included in the fleets and the customers can continue to enjoy the advantages of larger cars while not polluting the environment.

[123] (White, 2010)

9.4.2 Potential Strategies in the 4 P Marketing Framework

A recent survey has shown that the majority of new vehicle buyers have little to no familiarity with the idea of a PHEV.[124] To ensure a successful PHEV transition, it is imperative for the manufacturers, dealers, and commercial companies to apply various marketing strategies to appeal to consumers. While the government can only offer external incentives for driving a PHEV and penalties/additional liabilities for not driving them, the manufacturers' marketing campaign can alter the consumers' perception of PHEVs and hence create the internal drive to purchase them.

The following paragraphs describe possible strategies for the manufacturer to promote PHEVs based on the Marketing Mix, or more commonly known as 4 P's. The term was popularized by Neil Borden and later simplified by E. Jerome McCarthy.[125] The concept consists of 4 variables that are used for marketing management: Product, Price, Promotion, and Place. These variables are internal elements that can be controlled by marketing managers in order to satisfy a targeted market.[126] "Product" relates to function, quality, appearance, packaging, service, and other aspects related to the product (or service) sold to the targeted customers. "Price" covers list price to customers, pricing policies and segmentation (e.g. for revenue management purposes), customer payment options (e.g. full payment, finance, lease, etc) and payment methods (e.g. cash, credit cards, etc). "Place" is associated with channel of distribution and the supply chain decisions. "Promotion" involves decisions related to advertisement and its media, public relations, promotions and budget to perform those activities.[127] Due to their nature, price and promotion decisions can be implemented quickly, while place and product decisions require more time to implement.

Figure 27 shows an overview of a 4 P marketing framework for manufacturers to promote PHEVs in California.

[124] (Axsen & Kurani, 2008)
[125] (NetMBA Business Knowledge Center, 2010)
[126] (QuickMBA, 2010)
[127] (Borden, 1984)

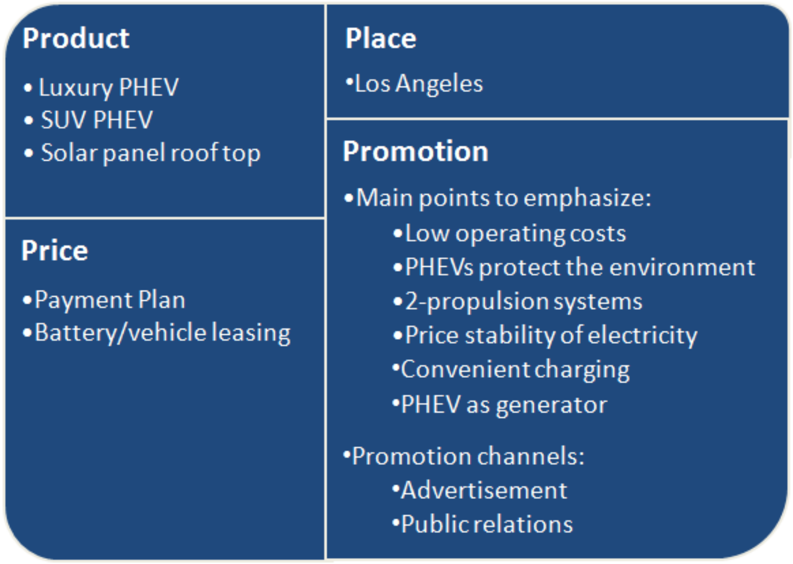

Figure 27 - Four P Marketing Framework

9.4.2.1 Product

9.4.2.1.1 Luxury PHEV

While Chevrolet has been launched this year, along with the existing Chinese model BYD Auto F3DM, most PHEVs in progress are targeted to mass market segments. Toyota, Volvo, Volkswagen, Ford, Hyundai, Kia, and specialty manufacturers are launching at least one PHEV model in the next 5 years[128]. In addition to the mass market there is an opportunity to target luxury segments with PHEVs. Upper class consumers are less price-sensitive and they are more likely to purchase premium luxury PHEVs. Using hybrid as a model, Hybrid Car Sales statistics[129] showed that luxury hybrids, such as the Lexus RX450h, count for 10% of total hybrid vehicle sales.

Indeed, Audi, BMW, Lexus and Mercedes already have some models in development, but there are other brands who haven't considered PHEVs: Acura, Infiniti, Maserati, and Jaguar among others. Increasing model variety for upper class segment may trigger more sales as customers who are brand loyal can purchase a PHEV from their favorite manufacturer.

9.4.2.1.2 SUV PHEV

Using similar argument, there is an opportunity to target SUV aficionados. With the increasing popularity of the SUVs' (Sport Utility Vehicle) the vehicle profile in the US roads has changed dramatically. Figure 28 shows the increase in the light truck sales during the last three decades.

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[128] (Plug In America, 2010)
[129] (Hybrid Cars, 2010)

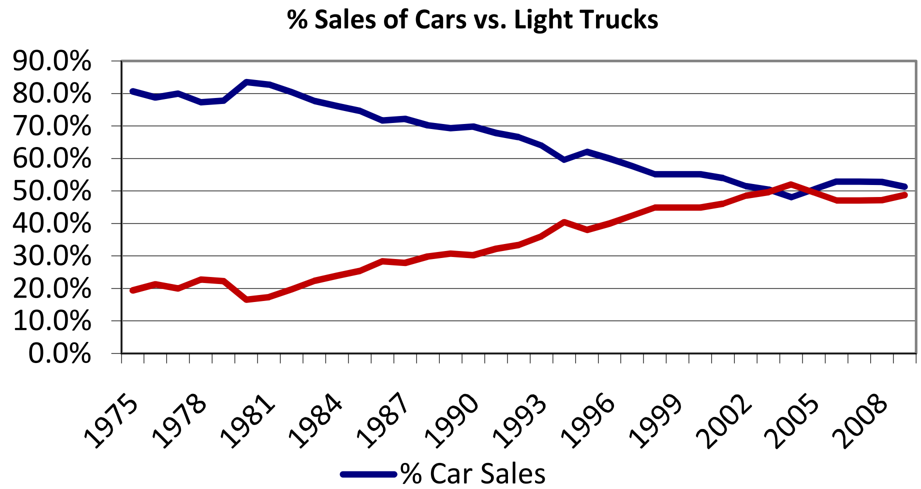

Figure 28 - Sales Trucks vs. Passenger Cars(Davis, 2009)

Many heavy vehicles having off-road capabilities are only driven in urban areas. A significant amount of four by fours is only used in daily routine activities that can also be done by regular passenger cars. SUVs create an extra amount of carbon dioxide emission, as they are relatively heavier and less efficient compared to regular passenger cars. This extra portion of emission can be referred to as “luxury carbon emissions”. Although the California government has introduced strict emission caps for the vehicles, SUVs are included in the light truck category and the emission constraints for these vehicles are less strict than those for other passenger cars which are illustrated in Table 18.

4,000 mile Durability Vehicle Basis		
Model Year	Fleet Average Greenhouse Gas Emissions (grams per mile CO2-equivalent)	
	All Passenger Cars and Light Duty Trucks from 0-3750 lbs.	Light Duty Trucks from 3751 lbs. and Medium-Duty Passenger Vehicles
2009	323	439
2010	301	420
2011	267	390
2012	233	361
2013	227	355
2014	222	350
2015	205	332
2016+	205	332

Table 18 - Fleet Average Greenhouse Gas Exhaust Mass Emission Requirements (California Air Resource Board, 2010)

According to the trend shown in Figure 28 SUVs will continue to play an important role in private transportation. The luxury carbon emission problem can be tackled with the introduction of SUV PHEVs to the market. Currently, there are 4 SUV PHEV models in development/pilot phase: Saturn Vue, Ford Escape, Mitsubishi PX-MiEV, and Velozzi SOLO[130]. The news is promising for the concept of SUV PHEV; Ford has introduced to the California market 20 plug-in hybrid Escapes, offering 30 electric only miles. The later versions will be developed according to the feedbacks from these current models[131].

To support the "Luxury carbon emission" argument, further research should be done on estimating the amount of GHG emitted by using SUVs in daily activities instead of a standard passenger car. With a consumer survey, the number of SUV drivers who never go off-road can be determined. Considering the difference in the average exhaust emissions between the SUVs and passenger cars the amount or ratio of "luxury carbon emission" can be calculated for a specific region.

9.4.2.1.3 Solar Panel Rooftop

There is also a proposed idea to study the feasibility of installing solar panel rooftops on PHEVs. This will make the operational costs less expensive since consumers would have to purchase less electricity from

[130] (Plug In America, 2010)
[131] (Bianco, 2007)

the grid. Currently, Solatec LLC produces rooftop-mounted solar panels for hybrid vehicles. The panels are .6mm thick and cause no change in aerodynamic drag.

9.4.2.2 Place

This element will not be discussed further since the vehicle distribution system/channel will remain the same: through dealers in Los Angeles.

9.4.2.3 Price

There has been the misconception that a PHEV has a higher overall cost compared to an ICEV. The cost analysis (Section 8) has shown that the total cost of each type, discounted to present value, is similar. However the computed value for PHEVs does not include highway taxes. Currently those taxes are charged on gasoline sales. If highway taxes were charged on electricity sales the overall operating costs of PHEVs would increase. However, the operational cost a PHEV is still much lower than that of an ICEV. The challenge is to educate the consumers about this fact, as not everyone is familiar with finance concepts such as the value of time. Two approaches to respond to this challenge:

9.4.2.3.1 Payment Plan

It is given that financing is always possible for any kind of purchase. However, general financing doesn't really tell the consumers anything about the cost effectiveness of PHEVs: They can simply finance and still think that a PHEV is overall more expensive than an ICEV.

A more specific payment plan will provide an intuition that owning a PHEV is not as expensive as consumers thought. They will pay the capital cost of a comparable ICEV (e.g. Volt to Civic), the remaining will be a loan from the dealer or a bank. In the subsequent years, any operational cost savings will be used to pay the remaining loan. With this approach, it can be shown that using the same yearly payment as that of an ICEV, consumers can enjoy the benefit of a PHEV.

The following is an example of a payment plan:

	GM Volt	**Honda Civic**
Total Cost	$64,925	$78158
Discounted Total Cost	$52,536	$53,766
Capital Cost	$16,000	$16,000
Annual Cost (year 1-13)	$4,150	$4,150
Annual Cost year 14	$3,706	$4,150
Annual Cost year 15	$1,129	$4,050

Table 19 - Payment Plan

Volt potential buyers will be presented this payment plan where they only have to pay the price of the Honda Civic ($16,000), and take a loan for the difference. Each year, they will have to pay the usual operating cost (electricity, gas, service). The lender will calculate that year's operating cost if it were a Honda civic ($4,150), and have the owner pay the savings as the loan payment ($4,150 – Volt operating cost). This is more intuitive for consumers who lack financial literacy because they can immediately see that owning a Volt is not so much different than owning a Civic.

9.4.2.3.2 Battery/vehicle leasing

Dealers and independent auto shops can also lease PHEVs or the battery, and offer options to purchase them at the end of the lease term. This option is also especially useful for consumers who are interested in driving PHEV but are not ready for a total commitment to the transition.

9.4.2.4 Promotion

9.4.2.4.1 PHEV Promotional Values

Branding, or brand equity, is a logo that identifies a product or service. A well-known brand attached to a product/service can add a significant value to the customers, even if other aspects of the product/service are similar to the non-branded ones. Brand equity is an intangible asset and it may require significant financial resource to create.[132] It is important for the manufacturers (and possibly the government) to have a join PHEV-branding campaign to promote PHEV as a preferable lifestyle. Driving SUVs, for example, is highly regarded because it is associated with toughness or strength. It is imperative to promote PHEV's forte and embed these to consumers' mind. The following paragraphs discuss PHEV values to be promoted to consumers.

One example is to emphasize the value of environmental protection and anti-pollution and make it as the value people remember when they hear the word "PHEV". Car manufacturers have to launch a strong marketing campaign that shows how owning an ICEV destroys the world and causes various human health problems. Until today, none of the manufacturers is doing so due to the following reasons:

i. They don't sell PHEVs and it does not make sense and might hurt their car sales to discourage consumers to buy ICEVs.
ii. They sell PHEVs but the campaign might cause the consumers to turn to other brands who are not conveying the same message. This is due to the perception that these manufacturers are focusing on its PHEVs and therefore compromising their ICEV qualities.

Based on these problems, it is clear that to have a strong national PHEV brand, the majority of manufacturers (that constitute 80% of market share or more) have to have PHEV models. They also have to agree on launching the campaign together, which is something that might not occur without a government's push.

Another value is the minimum noise pollution of the PHEVs. A marketing campaign can emphasize how loud engine noise causes discomfort to drivers, passengers and other people. This value can be sold to

[132] (NetMBA, 2010)

consumers with family and consumers who drive luxury cars. Since PHEVs do not produce any noticeable sound during operation, it is also predicted that companies and users will create software that allows PHEV owners to change the sound of their cars.

There is also a value of safety due to the fact that PHEVs have two parallel propulsion systems. Combustion engine breakdown on the interstate highway is not an issue for PHEVs, neither is an electric motor malfunction. This value is especially important for long-range drivers, travelers, and consumers who drive to locations where the infrastructure level is below average. One of the consumers' concerns after the launch of GM Volt is the scarcity of non-residential charging stations. This is an opportunity for commercial locations (e.g. restaurants, malls, beauty salon, supermarkets, dealers, etc) to provide charging stations to their customers. This service also means special parking spots, which is an additional incentive to the consumers especially during busy hours where parking spots are hard to find. On the downside, ICEV drivers might resent this.

Although the electricity supply in the United States is relatively reliable compared to the other countries, power shortages do occur occasionally. According to the historical data, there have been 92 outages in US, between the years 2001-2005 affecting 50,000 or more customers in US. This number doesn't include small scale shortages that affect less than 50,000 customers[133] . Additionally, over-relying on the electricity supply may cause vulnerability in case of an extraordinary power shortage. With a large battery having a 16kWh storage capacity, PHEVs' can protect their owners from these kinds of situations. The average power requirement of a house is 1kW, however this is not constant and changes during the day and varies according to season. Assuming a power demand of 2kW a PHEV battery could supply a house for around 8 hours. According to statistics of the Center for Risk and Economic Analysis of Terrorism Events[134], three fourths of the power outages in the US are caused by either equipment failure or extreme weather conditions. The average expected duration of a shortage is around 5 and 27 hours for equipment failures and extreme weather conditions respectively. Accordingly the PHEV battery has enough storage to protect the customer from a power outage caused by an equipment failure in most cases. For longer outages the inhabitants can reduce their electricity consumption during the shortage to make sure that they will have electricity until the system is recovered.

9.4.2.4.2 Promotion Channels

Advertising

Related to some concepts discussed previously, the following are some ideas that can be incorporated to television commercials and print advertisement:

a. Due to its battery, PHEV can be used as a portable power generator so that it can power outdoor activities such as barbequing, lighting up outdoor activities such as playing basketball outdoor at night, etc. This opportunities brought by PHEVs can be displayed in the commercials.
b. A simple advertisement that shows the quietness of the car, for instance sleeping children on the back seat and whispering parents in the front.

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[133] (Amin, 2010)
[134] (Center for Risk and Economic Analysis of Terrorism Events, 2005)

c. A split screen that shows two gas stations. The first screen shows how often an ICEV have to fill out their gas tank, while the other screen shows how rarely a PHEV does so.
d. A TV commercial could show a group of friends driving to the beach in a PHEV. They decide to share fuel costs and each give a penny to the driver.
e. Another idea of a potential commercial to attract young drivers and brand the name PHEV to be “cool” would be the following: A group of people having a house party. A “nerdy” looking guy stands in the corner and is ignored by all the girls. Suddenly, the power shuts down, lights go off and the music is out. Everyone is annoyed as the party seems to be over when the guy from the corner says:”Hey! I have a PHEV! Let me connect my car to the house grid!” The car is quickly connected to the grid and the party continues. The “nerdy guy” becomes the attraction of the party being surrounded by a group of girls.
f. Similarly, one screen can show how cars behave according to gas price on a gas station. The other screen shows the stability of electricity price on a day-to-day basis and how PHEV drivers don’t have to worry about price fluctuation.
g. In particular in the LA region celebrities driving a PHEV could be shown on billboards and in commercials to raise public awareness and support the idea of emission-free private transportation.

Public relations

Since PHEV is a new technology, of which consumers might not be familiar, it is crucial for car manufacturers to have a bi-directional promotion strategy where consumers can easily inquire for more information. There is detailed information, such as total ownership cost of PHEV, energy efficiency and environmental benefits of PHEV among others that are difficult to convey through a simple television advertisement. An effective way to educate the consumers is to have mini-seminars in shopping centers and other public places. Car manufacturers can also show their PHEV models in public institutions and locations and let consumers to test-drive the unit while representatives can fill them in with relevant information.

10 CONCLUSION

The following key conclusions can be determined from the analysis of this project:

- The semi-quantitative life-cycle analysis, presented in section 4, showed that when compared with ICEVs, the PHEVs have less impact on both the environment and on society.
- The research presented in section 6 showed that;
  - The current LA infrastructure is already capable of handling a transition to a PHEV market.
  - PHEVs are highly compatible with wind generation due to similarities in hourly demand and supply patterns, with both having peaks during the night.
  - The high storage capacity of PHEV batteries allow for the possibility of a vehicle-to-grid system that can help mitigate supply intermittency; is one of the key challenges associated with wind power.
- The cost analysis showed that the initial cost of a PHEV is significantly higher than the ICEV but over a perspective lifetime, this cost is compensated for via lower running costs.
- As PHEV is a relatively new concept, it allows diverse innovative ideas to be raised, in terms of marketing. Aside from the primary benefits of PHEV technology, the large battery capacity in particular may provide concurrent advantages such as vehicle to house electric supply.

The cost analysis shows that although PHEV is a new and developing technology, it is still comparable with the ICEV technology, which has been developing for more than a hundred years. This shows that it is likely that PHEV technology will be remarkably more competitive than ICEVs in the following century and will dominate the market if no other more feasible technology arises.

The penetration model was successfully able to demonstrate how PHEVs may be able to fit into the current demand/supply relationships in LA. Where some assumptions have been made and the final outcome can only be considered theoretical at this time due to implications in charging access points, transmission limitations etc, it is important to take note that the overall findings strongly concur with the ability for a wide scale PHEV market penetration. The model was constructed in such a way that it can easily be adapted to other regions for analysis of their potential penetration by varying the inputs to as per their own situation.

For a successful evolution into a PHEV market, it is vital for all stakeholders to become involved in the transition process. Consumer awareness of the PHEV must be developed in order for the sales to increase. Even though the technology is feasible and the infrastructure is able to support a substantial penetration, it will not succeed unless the customer is made aware of the benefits and is given enough incentives in order to justify the potential risks associated with such a new technology.

11 RECOMMENDED TOPICS FOR FURTHER STUDY

The analysis resulting from this project can be used as a foundation for further studies relating to PHEVs, their implications for electricity infrastructure, and their business feasibility. Below are some example topics that future project teams may be interested in pursuing:

- Quantify the need for public and commercial charging stations. Assess potential deployment strategies, taking into consideration the number of stations needed, the types of charging provided (i.e. voltage), potential locations, and the speed at which they should be introduced.
- Assess the case for using large park-and-ride facilities in major cities as potential sites for vehicle-to-grid storage capability. PHEVs parked at such facilities would have very predictable V2G potential.
- Quantify the marginal financial value that a hypothetical V2G system could provide to a utility company, taking into consideration the increased capacity credits for renewables, the reduced need for installed capacity, and the reduced need for competing services such as spinning reserves, pumped storage, or demand response.
- Explore the various possible pricing models for sharing the value of V2G with the PHEV owner, thus incentivizing PHEV ownership and participation in V2G.
- Research the logistics of operating a smart grid, identify the key parameters of a successful system, and estimate the levels of consumer participation under various scenarios and assumptions.
- Simulate an average 24-hour household electricity usage cycle combined with a PHEV, across various seasons. Explore the role that a PHEV could play for a household that uses “off-the-grid” electricity from small-scale wind or solar power.
- Obtain hourly solar and wind data for a focus region and simulate the effects of added V2G storage capacity on an hourly basis, using techniques from the Engineering Management Methods class.
- Quantify the total potential revenue losses for the government due to tax credits and financial incentives to promote PHEVs
- Quantify the potential loss of tax revenue from gasoline taxes, due to PHEVs’ low gasoline consumption. Assess alternative models for collecting taxes for road maintenance from PHEV drivers.
- Analyze the case for introducing PHEVs into various government fleets as a way to stimulate manufacture of PHEVs and raise public awareness.
- Perform a comparative assessment of PHEVs versus other low-emission vehicle technologies in the context of vehicle manufacturers’ strategies for complying with AB32 targets.

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Midterm Management Report

Summary

The individual midterm management evaluations indicate that the team is working well together up to this point, that the leadership and organizational structure has been effective, and that each team member is acting in a professional, and responsible manner regarding assigned tasks. Most of the midterm goals have been accomplished and several comments were made. Potential improvements have been suggested in the evaluations that will be implemented in the coming weeks.

Initially the team was divided into two smaller teams – the PHEV team and the Infrastructure team. The PHEV team is responsible for researching the technology itself while the infrastructure team is responsible for researching a myriad of topics including the Grid, charging infrastructure, vehicle-to-grid charging, generation capacity, integration of renewables, etc. Up until this point, this organizational structure has been effective. Many team members commented that increased communication between the two groups is necessary in the second half the project. Currently, each sub-team meets weekly and develops a plan of action for the following week. Representatives from each sub-team meet with Professor Vanek on a weekly basis to discuss results from the previous week and goals for the remainder of the semester.

Several team members commented favorably on the use of Google Documents, Google Group, Doddle Poll and Dropbox. These technologies have been very useful for a variety of purposes including scheduling meetings and presentations and storing deliverables and documents from previous projects. Dropbox is a new technology for the team and it will be used more frequently to store research, and sources.

Generally, the team members appear to be aligned with regards to objectives, goals, deliverables and schedule. Each person is doing their allotted work and is contributing their knowledge and expertise to the greater team and project.

Potential Improvements

Potential improvements have been suggested regarding communication between the PHEV sub-team and the Infrastructure sub-team; particularly as the team begins work on the transition study from an ICEV market to a PHEV market in the Los Angeles region. Several team members have suggested creating a liaison from each sub-team to attend the other sub-team's weekly meetings. The liaison would be responsible for summarizing the information and then reporting back to their own sub-team. This liaison could either be an assigned position or a rotating position within each sub-team. The purpose of this role would be to keep every team member informed of the activities of the group, ensure research is not repeated and to be a point of contact for requests between the two sub-teams. This role will be particularly important

Final Management Report

Several team members have indicated that that many of the issues raised during the midterm management report have been appropriately addressed and the entire team has benefitted from the implemented changes. All the final goals and deliverables have been met and submitted on time due to a concerted team effort.

Initially the team was divided into two smaller teams – the PHEV team and the Infrastructure team. The PHEV team was responsible for researching the technology itself while the infrastructure team was responsible for researching a myriad of topics including the Grid, charging infrastructure, vehicle-to-grid charging, generation capacity, integration of renewables, etc. In the last few weeks, a third sub-team, the Business team, was created. This team was responsible for researching existing incentives for consumers to purchase PHEVs as well as to brainstorm potential future incentives that could be put in place in order to increase PHEV sales. The Business team was composed of members from the PHEV team as well as the Infrastructure team. The composition of the Business team seemed to greatly benefit them and the other two sub-teams had enough remaining members to be able to finish their respective research.

One of the issues raised in the midterm management report was in reference to communication between the sub-teams. Immediately following the submission of the midterm management report, liaisons from the sub-teams attended the other sub-teams' weekly meetings. This idea was only carried out for a few weeks due to the increasing number of weekly meetings. However, communication between all sub-teams was deemed to be adequate and the liaisons were no longer necessary.

Following the midterm management report, Google Documents and Dropbox were particularly important. While preparing the final presentation and final report, many edits were made and many versions of each document were created. Dropbox was especially useful in managing those processes to ensure that all of the necessary corrections were implemented and all team members had access to the documents at all times.

One of the main challenges that the team faced throughout the semester was dealing with the large number of team members. A massive organizational effort had to be put forth by the subteam leaders as well as each team member in order to accomplish all of the required tasks.

Generally, the team members appear to be aligned with regards to objectives, goals, deliverables and schedule. Each person is doing their allotted work and is contributing their knowledge and expertise to the greater team and project.

APPENDIX II – REFLECTIONS

Adam Stevens

I was initially interested in this project as it appealed to my interest in renewables, future technologies and also because it took the form of a feasibility study. I have career aims in such sectors and this project gave me valuable experience in the problems which may be faced in real world situations. I feel that we were initially hindered in some sense because of the generalness of the scope and there was some confusion with both how we would structure the project, and what our final outcome would aim towards. However, I think that as time and progress moved on, the team enjoyed this sense of 'openness' as it allowed use to move in the directions we wanted and we could put a higher level of passion into the work.

We structured the team in an efficient manner that I felt worked exceedingly well, with eventually three different subgroups. The teams at times had a slight lack in communication but this was of no real determent to the final outcome. Each sub team had a clear understand of their aims and deliverables and it portioned the work to be completed well I believe.

One major part of this project which I enjoyed was the coming together of many different backgrounds, cultures and personalities. We all had to adjust to the ways in which others operated and in the end, the differences are what made the team strong.

I feel that our final outcome was very pleasing and it allowed us to visualise how a PHEV penetration may impact the grid, and also the lifestyles of the consumer. I think we correctly waited to divide the teams into 3 for the business analysis as this firstly could only be completed once details were known, but also it allowed for every member of the group to first gain an understanding of the situation and information.

The project will be a very good basic teaching to any further research into the area, and I feel proud of this. There is much possibility to carry on with the business model or the infrastructure (transmission lines in particularly) impact which may be caused. I would especially be interested in seeing any future research into the V2G system and the smart grid applications.

Alice Yu

This project has definitely been one of the more positive group experiences of my Cornell career. The team has enjoyed a very strong and healthy social dynamic, which has fostered good communication, trust, and teamwork (not to mention making the project much more fun than it would've been otherwise). It is also one of the largest and most diverse project groups I have been a member of, and the challenge of managing such a group has been a great learning experience. The diversity of the group has been a valuable asset, as many different viewpoints, strengths, and experiences are brought to the table, and we have been able to depend on each other for support to cover any weaknesses we may have as individuals.

When I compare this project with previous experiences that involved large groups, I see several key factors by which this team distinguished itself, and which I consider to be central to success. These factors are: individual engagement, communication, and flexibility.

I have worked in a number of teams of similar size; a frequent pattern is that 1-3 people are very strong-willed and enthusiastic, and they end up providing most of the heavy lifting and research guidance while everybody else plays a passive role. This was definitely not the case in this team; although there was some variability in level of engagement, passive players were the exception rather than the rule. Most people were engaged and proactive about framing the research, doing the work, and creating the deliverables. I think this is well-illustrated in the way leadership and initiative has been spread out among many people. We have a team leader, several sub-team leaders, and many task-specific leadership roles such as final report manager.

Our good communication and flexibility has allowed the project to take maximum advantage of the strong engagement of its individuals. A good example of this is the way in which we managed our sub-team structure. There was a lot of discussion initially, and several possible structures were proposed. Through this process, we realized that everybody was interested in business and transition, so we decided to divide into two broader sub-teams that would both keep the business picture in mind during research, with a plan to collaborate on the transition study later in the semester. When we reached this point, our flexibility allowed a smooth transition from two sub-teams to three.

When I review my own personal goals for the project that I wrote at the beginning of the semester, I find that all of them have been addressed in some form. My goals were grouped into three categories – technical, professional, and interpersonal. In line with my technical goals, I have become much more knowledgeable about PHEVs and can speak more confidently about the critical issues and strategic challenges that are relevant. In line with my professional goals, I have improved my organizational and management skills, particularly with respect to managing information and delegating tasks. In line with my interpersonal goals, I have experienced good teamwork with this group and fostered personal relationships that will continue after the project is over.

Auret Basson

The PHEV was a new concept to me at first, but I soon realized it is a possible way of transitioning into the era of the electric car that people have been speculating about for many years now. I think the PHEV has a very important role to play in our movement to a more sustainable world and it was very good to get behind of the details of how it works and how we envisage it working for us. With the HEV's getting more and more popular it seems to be only a matter of time before all the main car manufactures will a PHEV model in their catalogues.

I think being a part of this project has broadened my perspective of the world of energy. The way toward a sustainable energy future seems to be more focused on smaller scale personal devises, of which the PHEV seems to be the next piece in the puzzle. The PHEV through V2G seems to be a way of making better use grid energy and household renewable energy installations. I thus think that there will be significant benefit in a vehicle market saturated with PHEV's (or EV's for that matter) not only on a utility scale, but also on a personal level.

With such a diverse team you are bound to learn some valuable lessons; be it from how communication methods differ between people to how different cultures/people perceive the same concept and why they deem them valuable to society. In such a diverse group of intelligent people there will always be a new opinion and most probably better ways of looking at something that you have thought about before. I have learnt so much not just from the project matter covered, but have also learnt a great deal from my team mates. The difference being that you cannot find the latter on the internet or in a book; I could only have learnt from the group by being part of it, and I must say, even from this perspective, I think this project was a great success!

Christina Lu

The biggest learning experience from this MEng Project is working with a wide-diversified group of people. The 11 of us represent 9 nationalities and 4 continents (if I counted correctly). Everyone comes from a different background and brings into the team a set of unique talents and useful skills.

Being a member of 11-people team, what surprises me the most is that it actually worked more effectively compared to the usual team of 3 or 4 members. The diversity of people created both challenges and opportunities for the team. It was easy to come to an agreement *what* needs to be done, however due to the fact that people come from different backgrounds, it was difficult in the beginning to come to an agreement on *how* to get it done. People have different perspectives mainly because they had different educations from their countries compare to the ones in the United States, therefore, what they consider as not professional might be acceptable here and vice versa. However, once people realize that disagreements were due to cultural differences, people tend to react to them more smoothly. Although, challenges were not the only thing diversity has brought into the team, the opportunities it brought were tremendous. The different experiences and backgrounds were essential to bring great ideas and implement them effectively with the skills each of us possesses into our project.

Mert Berberoglu

In the beginning of the project I was in the room with 11 individuals that I didn't have any idea about. Besides the initial ambiguity in the team forming stage it was quite obvious that it's going to be an extraordinary experience. When we first met, it was surprising that almost all the people have came from different parts of the world. There were so many different cultures and so many different personalities that it was surprising that this team became a jelled team and gained a strong identity. Individuals were supportive and had respect to each other. Different perspectives and different expertise were combined in harmony and created a high quality work. "Collaboration" was the key of our success.

We have also experienced a "halfway point" that almost all the teams experience. The first half of the project time has mostly passed by collecting information and creating ideas. When we were in the middle of our project time we were a bit nervous thinking that we haven't done much work. However the ideas and knowledge was there. In the second half we were extremely productive and working with enthusiasm and great commitment. We have formed a new sub-team in the second half to focus on the business aspects and I was also involved in that team. I can say that it was the best team experience of my life. The meetings were extremely productive and we have applied facilitation techniques that we learned in other managerial courses. It was great to see that these theoretical concepts really work in practice.

Finally, I am proud that I was a part of this team and I believe that our conclusions are helpful for the parties that make important decisions about renewable energy and PHEV technology.

Naji Zogaib

I originally chose this project for my interest in energy and the environment in general and PHEVs in particular. Looking back at the past four months, I can see that both, my knowledge and interest in PHEVs, the auto market, the electric grid and the environment have increased substantially. Considering this project is designed for the Engineering Management students, I really enjoyed learning how to interact and work with the team on a day to day basis, especially considering how multicultural the team was. Having to manage yourself and others throughout the meetings and work sessions was a very useful experience. Being able to apply the tools taught by Professor Frank Wayno in CEE5900-Project Management throughout the semester made them more concrete and more meaningful.

Looking back at how it all started, the team was very confused about what had to be accomplished. The fact that the team was allowed to set their own goals for this project made it that much more interesting. The general topic of the project was given to us but we had to discuss between each other and conclude what we wanted our deliverables to be, all with the approval of the advisor. These introductory meetings were very important. It could be determined from these early meetings who were the take charge team members, who was able/willing to lead and who just wanted to follow. In the first few meetings, it was agreed to divide the team into 3 sub teams; PHEV, infrastructure and business. When everyone wanted to be on the business sub team, it was decided to drop it and to stick to two sub teams. After performing the cost analysis, it was concluded that the PHEV is not economically feasible from a customer point of view. Towards the end of the semester, around a week before the final presentation, it was decided that a business sub team was essential to analyze ideas that would make the PHEV economically feasible. The business sub team was formed by a group of individuals extracted from each of the other two sub teams and together they came up with ideas that would help sell the phev to the customer.

The weekly meetings with professor Vanek and the sub team leaders were very useful in keeping everyone on the same page. The sub team leaders coordinated the work between their team's members and the remaining teams' members. This was the key so that no overlapping work was done twice.

Overall, I am very satisfied with the project choice I made. The topic was very interesting, but what made it a successful research was the people involved in it. Even though there were no two individuals from the same nationality/culture, the team was very well coordinated and we all jelled well with each other. Moreover, the way Professor Vanek dealt with the team made it come together even better. Having to define our own deliverables and having to choose our own team leaders made us all assume part of the responsibility of succeeding in this project.

Sara Lachapelle

The Plug-in Hybrid Electric Vehicle project within the Master's of Engineering, Engineering Management Program has been a great experience in terms of the material studied and working with my fellow team members. One of my primary goals at the beginning of the semester was to work effectively in a large team of people. I believe that this project has given me the opportunity to meet many people from across world with various backgrounds. One of the most challenging aspects of this project was the large number of people involved in the research. Learning to work with that many people is an important skill that I am sure will be useful to me in the future. Another of one of my goals for this project was to learn about the PHEV technology and determine whether or not it is feasible in the current economic and energy situation. I found that the scope of the project was very relevant and I had the opportunity to learn about many different aspects that are related to PHEVs. I was able to study both technical and non-technical subjects such as the PHEV technology itself, infrastructure and future business solutions for increasing PHEV sales. Overall, I enjoyed my experience working on the PHEV project with my colleagues. I believe that the skills learned during the semester will be very beneficial in the future and the subject of the project is also very relevant given the uncertainty surrounding energy sources.

Whitney Bi

My experiences with the PHEV project, improved my communication and teamwork skills. I also had a chance to put my theoretical background in to practice.

Perhaps the most beneficial part of this project was the opportunity to work with people coming from different cultures and backgrounds. Before enrolled in the project, I was very shy, and didn't want to talk with people that I am unfamiliar with. But currently, I'd love to continue exchanging ideas and thoughts with my 10 colleagues that I work with during the project. Moreover, I am currently more confident about talking to people.

This project experience has totally changed my idea about teamwork. In my education, in china the weight given to the team work was relatively less. I didn't have many group projects and presentations during my undergraduate studies. However, this PHEV project provided me to gain experience and new skills in both team work and presentations. It is not easy to operate a team by taking the advantage of every individual's background, knowledge and experience. Acknowledging that, I integrated my ideas together, and made sure that everyone has understood my ideas. During my participation in business sub team, I have applied the knowledge that I've got from my Marketing Management class to develop a marketing strategy for PHEV. This was actually very exciting experience form as I was able to use my academic knowledge in the project.

Torio Risianto

Working with a large group was a rare experience for me. At first I thought that the team would be chaotic in terms of splitting up a fair workload, but our team had shown otherwise. Even during the early phase (i.e. writing the literature review), we discussed, defined and created sub-teams to handle the project tasks. The time required for my sub-team's literature review was very efficiently spent, and I believe that the other sub-teams were as effective.

During the core phase, the team reconvened and was split into two sub-teams: PHEV and infrastructure. In this sub-team, I experienced the same positive atmosphere. More importantly, we covered each other's tasks when required, especially due to the fact that this semester is full with job interviews. For example, one person who had to work less on that week due to interviews would work more on the following week to cover another person's tight schedule. This work dynamics enabled us to accomplish our tasks efficiently.

In the middle of the semester, we all realized that sub-team communications had to be improved, and we conclude that a liaison for each sub-team had to be created. Although this was a good idea, the implementation didn't last long due to at least two reasons: the creation of the business sub-team (which requires each liaison to attend three sub-team meetings) and the improved communications between the three sub-teams. Since joining the business sub-team, I was more involved in the marketing strategies. While the PHEV sub-team requires a lot of research effort, the business sub-team requires basic background information and a lot of recommendation idea generations. These varieties of my role were very engaging to me.

Overall, the whole team was very supportive. Everyone consistently got feedback of their work and was offered assistance whenever needed. I am content that I was able to volunteer to help other members' issues at certain times and receive support in other times, particularly during both presentation preparations. I believe that working in this project has given me more teamwork experience, which will be a relevant skill-set in my future jobs.

Torsten Steinbach

I chose the PHEV project due to my strong interest in the automotive industry and the application of new technologies for a cleaner way of private transportation. I enjoyed that we could set our own goals and agree on our own deliverables. By that we could shape our own Master of Engineering project within the given framework. The project offered various opportunities for all team members to apply material learned in class and to deepen their knowledge in fields they were interested in. From forecasting models and optimization techniques to making good use of project management principles and applying basics of marketing and finance – a variety of opportunities were given to engage in the project.

The group size of eleven students made the project an interesting and challenging experience. It required more communication then projects I was involved in during my undergraduate and professional career. Good communication especially in the second half of the semester helped us to align our efforts and to work efficiently. It was satisfying to see the development of the team. At the end of the term the term a group of people from nine different nations was able to discuss various technical details around PHEVs in depth.

Overall, I enjoyed the PHEV project and I am satisfied with the final deliverables. Personally, I think I developed in three areas: My technical understanding of the electrical infrastructure and the interplay with renewable energies, my communication and team work skills, and my project management skills improved throughout the course of the semester.

Vincent DeRosa

Overall, I was very pleased with how the project turned out and how the group came together. I think one of the best aspects of the team was the fact that members were from all different parts of the world. People used ideas from their specific cultures that certainly helped to develop the final project. It was fascinating that while some of the ideas were from ordinary experiences at home that the person may have thought to be extremely trivial, they turned out to be quite novel to the other members of the group. A simple example of this was some of the vehicle type restrictions and commuting distances that apparently are in place in London. While this may have been commonplace for certain members of the group, I was unaware of this type of restriction. Therefore, I think that the makeup of the team, specifically the fact that the members hailed from all different parts of the world, helped to create many great ideas. We were able to take some of the best attributes from a wide range of sources to determine things that we thought would be useful in Los Angeles.

One of the main concerns I had at the mid-term report was how the team was going to attack the remainder of the semester. The team was split into two sub-groups at the onset of the project, one focusing on the PHEV technology itself and the other dealt with the subsequent infrastructure. This model worked well for the first half when the work separation was much more defined and clear cut. The technology team analyzed the PHEV while the infrastructure side researched the Los Angeles power grid. However, the second half of the semester saw the need for a much more interdependent approach. Assumptions made by one side needed to be communicated to the other and vice versa. I know specifically for the infrastructure side, we needed to use many of the technological values such as battery capacity and driving habits that the other sub-team developed. The creation of a sub-team liaison therefore helped tremendously in this task. There was certainly the possibility of difficulties maintaining this cross team communication and the high potential for slow feedback that would have really hurt the overall project. However, with a sub-team liaison attending the other group's meetings, the answers to various questions were much more readily available. In this way, many of the concerns that I had during the mid-term evaluation report did not actually happen as a result of great team chemistry and the foresight to mitigate any situations before they became true problems.