ELECTRIC VEHICLES

AND

POWER PLANTS

Interactive Qualifying Project

Submission Date: **05/16/2014**

From:

Khoa Nguyen ______________________________

Submitted to:

Professor Robert Thompson

____

Advisor Signature

ABSTRACT

This study analyzed financial changes, emission reduction and social impacts in California 2040 if all automobiles on the roads are electric vehicles (EVs), which consist of pure electric vehicles (PEVs) and plug-in hybrid vehicles (PHEVs). At the beginning, the current picture of California was researched, including population, number of automobiles and their tailpipe emission, as well as electricity generation and consumption. Data collected was analyzed and used to project the transformation of above aspects in California from now until 2040. EVs are overall cheaper, require less maintenance effort and provide flexibility in fueling. In general, they are much more environment-friendly, and they also help the state depend less on petroleum usage.

Besides, results showed that electricity consumption of electric vehicles will only be 0.13% of the predicted total consumption statewide. To accommodate the need of all electric vehicles, approximately 673,543 of dual charging stations should be built until 2040. Also, California should build several power plants to ensure enough electricity for statewide usage, but specific numbers and types of power plants will be determined by various complex factors.

ACKNOWLEDGEMENTS

I would like to present my appreciation and respect to my advisor, Professor Robert Thompson, who has spent a lot of time to help me reach the goals of this Interactive Qualifying Project. His knowledge and experience helped me touch into the real impacts in the society. Without his support, I am not able to finish this project completely.

Moreover, I do not forget assistance from Ms. Deborah Scott, who shared useful information and experience about EVs, the market of EVs and her own PHEV. Next, I would like to thank Ms. Liz Tomaszewski because I received many useful resources about charging station and electricity consumption. Although that information was not mentioned in the report, it gave me a large view of charging stations network and their electricity consumption in California. In addition, I would like to thank Professor John Orr, who explained and gave me the knowledge of power plants, electricity distribution and the emission rate from power plants. Besides, Prof. John Orr gave me many hints and suggested me finding more important documents in the library. Finally, I'd like to acknowledge Mr. John Swanton, a representative of California Air resources Board. He explained many questions concerned about electricity consumption in California, zero emission plans and charging station.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Hybrid and electric vehicles have gained significant popularity in recent years. Consumers are paying more attention to benefits of using a low-emission vehicle. Car manufacturers are putting huge effort on developing new technology for hybrid and electric vehicles, including investing in both battery and car engines. In the U.S, the government expresses its interest and support by giving tax credits to owners of these vehicles. Specifically in California, a plan has been signed to promote ownership and usage of hybrid and pure electric vehicles [1], which will be generally called electric vehicles (EVs) in this report. EVs are also projected to earn more market share in the upcoming years. According to Michael Lew, an analyst at Needham & Co, "The market for electric cars is sputtering, but the price of the technology is falling, and sales will ramp up at some point" [2]. Statistics of EVs annual sales also support the prediction.

Figure 1: Can electrics rev up? [1]

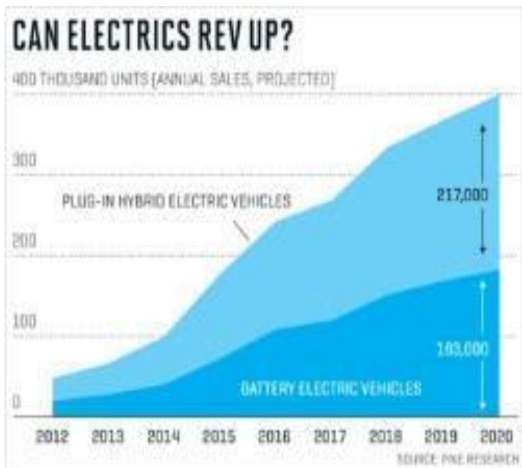
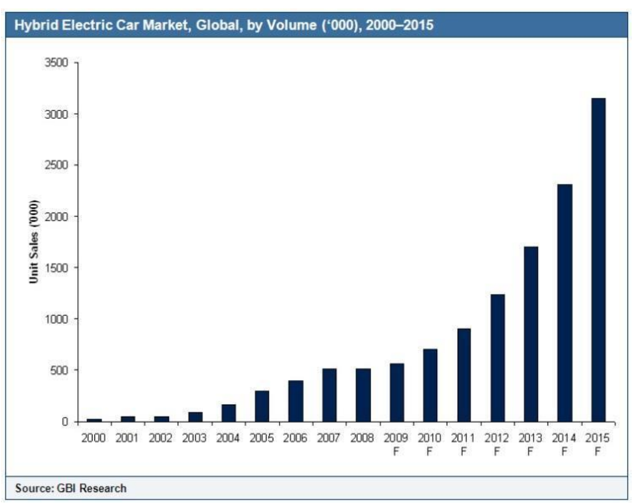


Figure 2: Hybrid Electric Car Market 2000-2015 [2]



Meanwhile, a big question is still left unanswered, "when and how can low-emissions vehicles replace traditional petroleum ones?" Current EV technology does not give the vehicles functionalities comparable to their peers. A Nissan Leaf can run only 100 miles, but take 6-8 hours to be fully charged. A Chevrolet Volt has shorter time, up to 4 hours, to charge full battery, but it only can run approximately 50 miles in spring and up to 26 miles during winter [3]. Moreover, petroleum vehicles have been so popular that at least one gas station is located in every town across the U.S. To provide electricity to EVs, a considerable amount of charging stations might need to be built, let alone power plants to support them. The current situation does not prevent CA governor Edmund G. Brown Jr. from believing in the fate of EVs. He has ordered that 1.5 million zero-emission vehicles “be on California roads” by 2025 [4]. This order may come true because Governor’s interagency working group has prepared the zero-emission vehicle plan with a lot of details. And this document is signed by Governor Edmund G. Brown Jr.

In this project, the current status of EV development was investigated, including technologies being used, market data, potentially additional power plants to maintain electric capacities and transportation statistics, to predict the future of EVs. Basic background of EVs and its development history was provided. Actual data collected was presented and analyzed before giving results and conclusions.

II. BACKGROUND

2.1 Relevant statistics for California

2.1.1 Transportation statistics

Table 1: Automobiles and driver licenses in California 2011 – 2013

	2009 [5]	2011 [6]	2012 [7]	2013 [6]
CA Population [8]	36,961,664	37,668,000	37,966,000	38,332,521*
Automobiles	21,898,286	22,083,049	22,473,717	23,237,523
Total vehicles	31,779,398	31,802,483	31,946,422	32,903,847
Auto/Person	59.25%	58.63%	59.19%	60.62%

**Population in 2013 is estimated by US Census Bureau*

California population and the number of vehicles give us an approximation of the current transportation situation: a couple is likely to own at least one car, and around seven out of ten vehicles on California roads are automobiles. Based on the average 2-year population change of 1.84% in 2009 – 2013, population may reach 49 million people and at least 29 million automobiles are needed provide transportation to the entire state.

Table 2: Vehicles and driver licenses increase in California 2011 – 2013

	2009-2011	2011-2013	2009-2013	Avg. 2-year change
Population	706,336 (1.91%)	664,521 (1.76%)	1,370,857 (3.71%)	685,429 (1.84%)
Automobiles	184,763 (0.84%)	1,154,474 (5.23%)	1,339,237 (6.12%)	669,619(3.04%)

Table 3: Projected increase in California in 2040

	2040	Change from 2013-2040
Population	49,016,693	10,684,172 (27.87%)
Automobiles	29,126,536	5,889,013 (25.34%)

2.1.2 Electricity Generation & Consumption

Table 4: Electricity Consumption in California 2006- 2012 [9] and 2040

Year	Population	Electricity Consumption (GWh)	Consumption per Capita
2006	35,947,461	281,199.55	0.007823
2007	36,185,908	287,288.57	0.007939
2008	36,538,008	287,782.12	0.007876
2009	36,887,615	278,496.74	0.007550
2010	37,253,959	274,984.47	0.007381
2011	37,668,000	276,615.66	0.007344
2012	37,966,000	282,140.84	0.007431
2040*	49,016,693*	373,536.20*	0.007621

*: Projected data

The average ratio of electricity consumption per capita from 2006-2012 is 0.0076. With the population in 2040 being 49,016,693, assume that the change of average ratio in 2040 is very small, the electricity consumption in 2040 is 373,536.20 GWh, not including charges for EVs.

Table 5: California Generation plus Net Imports (Gigawatt Hours) [10]

Year	Electricity Generation plus Net Imports	Ratio of Change
2006	298,454	
2007	304,823	0.02134
2008	307,428	0.00855
2009	298,996	-0.02742
2010	291,130	-0.02631
2011	293,652	0.00866
2012	301,966	0.02831
2040*	320,462*	

*: Projected data

The average change of electricity generation plus net imports from 2006 to 2012 is 0.002188. Assume the ratio of change will not have significantly difference in 2040. The approximate electricity generation plus net imports in 2040 is (0.002188 * 28 * 301,966 GWH) + 301,966 GWh = 320,462 GWh.

2.1.3 Power Plants

Ability of a power plant to produce electricity is measured by its capacity and capacity factor. In general, capacity is the maximum electric output a generator can produce under specific conditions. It is calculated by the generator's manufacturer and indicates the maximum output a generator can produce without exceeding design thermal limits [11]. Capacity factor is a measure of how often an electric generator runs for a specific period of time. Capacity factor compares how much electric generator actually produces with the maximum it could produce at continuous full power operation during the same period [12]. Electric generation is the amount of gross generation less the electrical energy consumed at the generating stations for station service or auxiliaries [13]. From those definitions, I calculated capacity factor using a formula that will be used in Table 7.

$$\boldsymbol{Capacity\ factor} = \left(\frac{\boldsymbol{Electric\ Generation\ (GWh)*1000}}{\boldsymbol{Electric\ Generation\ Capacity\ (MW)*24*365}}\right) * \mathbf{100\%}$$

The below figures show that California uses natural gas as its main energy sources, following by hydro, nuclear and renewable energy (wind and solar) [14].

Figure 3: Electric Generation Capacity (MW) from 2001 – 2013 [14]

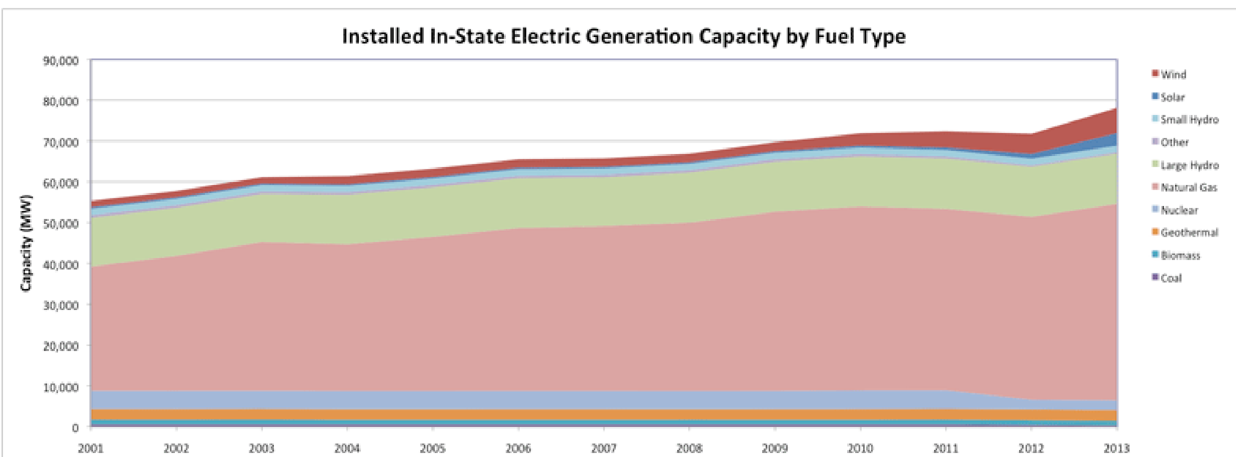
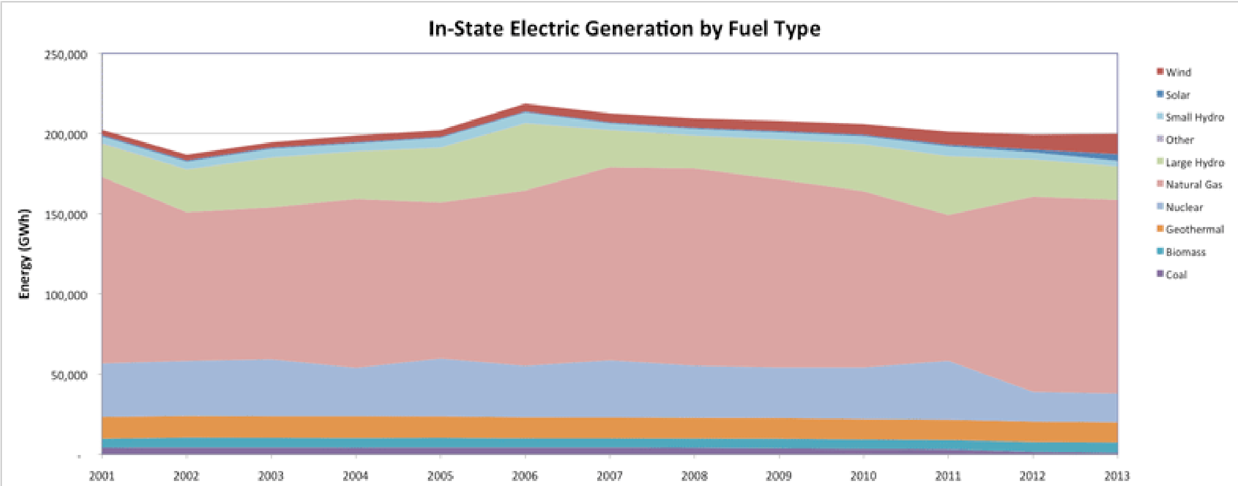


Figure 4: Electric Generation in California (GWh) from 2001 - 2013



From the electricity generation capacity and electric generation data in [14], capacity factors of each energy source each year from 2001 – 2013 and average capacity factors of each energy type were calculated. This data was used in later sections to calculate the numbers of power plants needed to be built

Table 6: Capacity Factor of Electricity Generation from 2001-2013 (Unit: Percentage)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Coal	80.09	84.72	84.61	80.98	84.88	83.04	83.58	78.82	76.41	69.06	63.26	42.34	42.26
Biomass	56.64	62.39	59.28	62.79	62.45	59.76	59.14	59.51	61.43	59.13	56.87	61.39	65.44
Geothermal	58.82	58.23	57.94	58.66	57.78	56.53	56.25	56.65	55.58	54.86	54.62	53.78	52.73
Nuclear	85.29	88.01	91.19	77.47	92.62	82.07	91.45	83.21	80.72	80.35	91.45	90.87	87.77
Natural Gas	43.65	32.01	29.67	33.46	29.38	31.27	34.06	34.08	30.49	27.83	23.36	31.01	28.64
Large Hydro	19.83	25.82	29.98	27.83	32.22	39.11	22.00	19.02	23.14	27.25	33.89	21.53	19.30
Small Hydro	30.68	33.99	39.22	35.42	43.60	48.43	29.16	29.41	31.67	36.53	44.80	30.67	24.38
Solar	23.16	25.56	22.80	22.26	19.83	17.45	18.92	20.61	23.19	20.18	20.13	18.21	15.32
Wind	24.13	26.22	24.10	23.55	22.59	27.11	30.81	31.66	32.87	24.85	23.21	21.24	23.35
Other	7.03	1.97	3.82	3.21	3.09	3.57	3.05	3.21	2.50	2.01	1.89	3.24	1.63
Grand Total	41.74	36.92	36.32	36.95	36.48	38.09	36.90	35.74	34.04	32.68	31.72	31.70	29.19

Table 7: Average Capacity Factor of Electricity Generation 2001 – 2013

Coal	73.39%
Biomass	60.48%
Geothermal	56.34%
Nuclear	86.34%
Natural Gas	31.45%
Large Hydro	26.23%
Small Hydro	35.23%
Solar	20.59%
Wind	25.82%
Other	3.09%
Grand Total	35.27%

Note: Table 7 was computed by the author of this report

2.1.4 Zero-emission goals and plans

Zero emission vehicles (ZEVs) action plan was an executive order by Governor Brown directing to state government to help accelerate the market for ZEVs in California. This order, issued in March 2012, sets a long term goal of reaching 1.5 million ZEVs will be on roadways by 2025 [15]. This order also sets a long term target of reducing green emission rate by 80 percent below 1990 levels by 2050 [15]. This plan separated the long term goals into three time period by 2015, 2020 and 2025. By 2015, California will finish major metropolitan areas to accommodate ZEVs, promote private investment and manufacturing in the ZE market and contribute to ZE market expansion [15]. By 2020, this state may support up to 1 million ZEVs. Also, the cost of ZEVs will be competitive and the ZEV market will attract more customers. California is going to ZEVs for public transportation and freight transport [15]. And by 2025, California will have 1.5 million ZEVs on the road. Besides, customers will have easy access to ZEV infrastructure. ZE industry will be a strong part of California's economy, and petroleum consumption will be reduced. To make this plan happen, California needs to pass several challenges, such as new infrastructure for ZEVs, limited consumers, up-front costs for ZEVs, operational limitations and limited categories of vehicles [15].

2.2 Electric & Plug-in Hybrid Vehicles

2.2.1 Pure Electric Vehicle

A Pure Electric Vehicle (PEV) uses large rechargeable battery packs to store electricity in order to power the electric motor [16]. To recharge the battery, drivers can plug the vehicle into an electric power source, such as a charging station or an outlet at home. Because different models of PEV have different battery capacities, the charging time is also different. The range of charging times is 4 – 6 hours. [17]

A PEV's most significant maintenance concern is its battery pack, which currently costs nearly half of the car's value, but is projected to drop dramatically in the upcoming years. "The average price for an electric vehicle lithium-ion battery pack was $689/kWh in Q1 2012, down 14% from approximately $800/kWh a year earlier and down around 30% from $1000-plus levels in 2009", and "Bloomberg New Energy Finance expects the cost of lithium-ion batteries to drop as far as $150/kWh in

2030" [18].

Table 8: Specifications of common light duty PEVs in US [19]

Make/Model	Approximate Range (miles)	Battery capacity (kWH Li-ion)	MSRP	Estimated cost - 2012 ($689/kWh)	Estimated cost - 2030 ($150/kWh) [18]
Chevrolet Spark	82	20	$27,000	13780	3,000
Fiat 500e	87	24	$32,500	16,536	3,600
Ford Focus	76	23	$40,000	15,847	3,450
Mitsubishi i	62	16	$29,200	11,024	2,400
Nissan LEAF	73	24	$28,800	16,536	3,600
Smart ED	68	16.5	$25,000	11,369	2,475
Average*	**74.6**	**20.6**	**30,420**	**$14,182**	**$3,088**

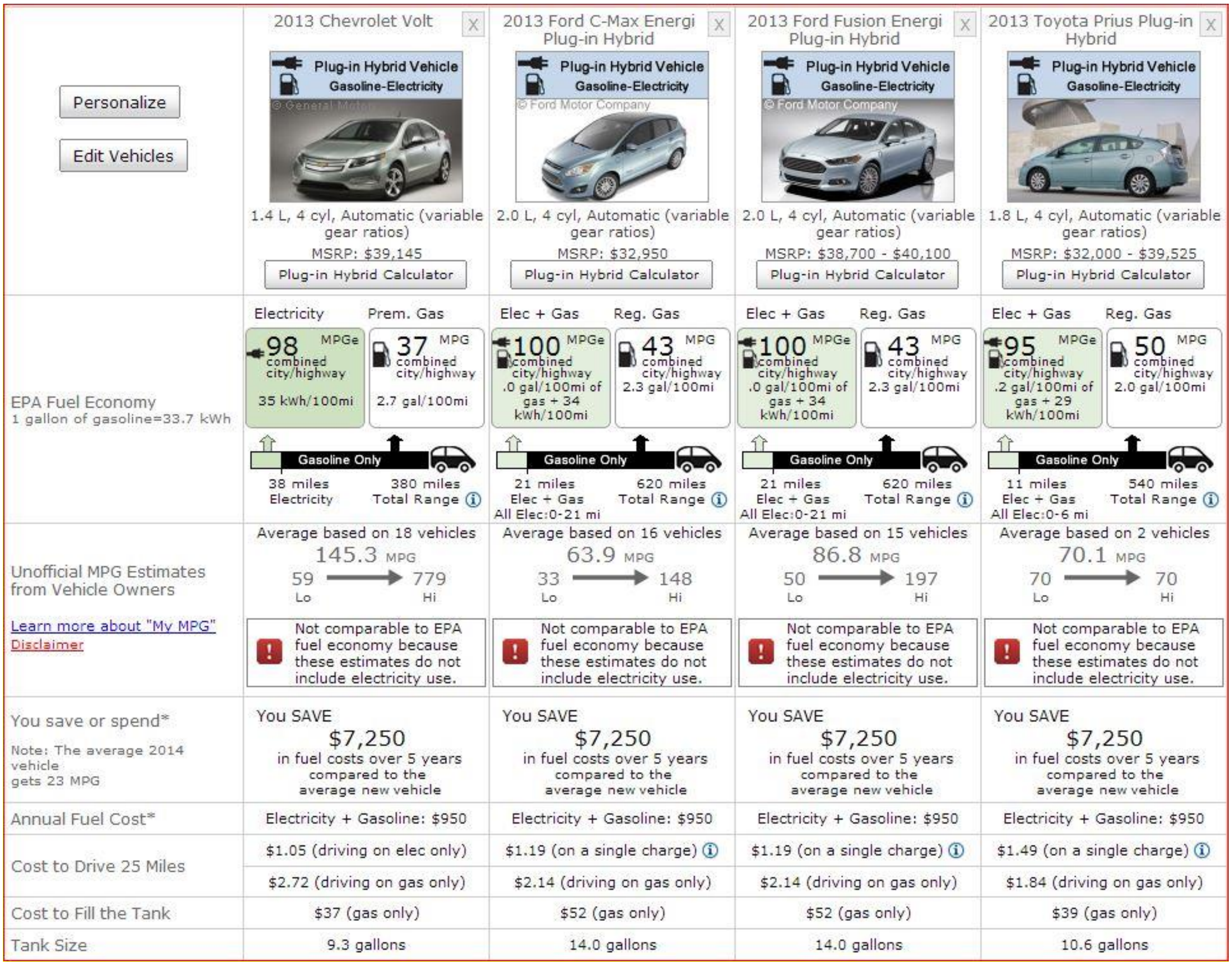
*: calculated data

Based on Table 8, a typical battery replacement cost in 2012 is $14000, around 50% of the total automobile cost. In California weather, a battery should last 10-15 years [20]. However, customers buying electric cars at the mean time will not need to replace batteries until around 2028-2030, when the cost is projected to drop to approximately $3100.

2.2.2 Plug-in Hybrid Electric Vehicle

Different from PEVs, a Plug-in Hybrid Electric Vehicle (PHEV) has a gasoline engine and an electric motor. There are two basic plug-in hybrids on the market. Series plug-in hybrids only use motor to turn the wheels and the gasoline engine generates electricity to power the electric motor [21]. On the other hands, parallel or blended plug-in hybrids use both gasoline engine and electric motor to turn the wheels [21]. Both kinds of hybrids can be recharged as drivers plug them into an electric power source. The battery capacity of PHEV is often smaller than a PEV, so the charging time of PHEVs is shorter than PEVs, around 1-4 hours [21].

Figure 5: Four models of PHEVs in 2013 [22]



	2013 Chevrolet Volt	2013 Ford C-Max Energi Plug-in Hybrid	2013 Ford Fusion Energi Plug-in Hybrid	2013 Toyota Prius Plug-in Hybrid
Personalize Edit Vehicles	Plug-in Hybrid Vehicle Gasoline-Electricity © General Motors 1.4 L, 4 cyl, Automatic (variable gear ratios) MSRP: $39,145 Plug-in Hybrid Calculator	Plug-in Hybrid Vehicle Gasoline-Electricity © Ford Motor Company 2.0 L, 4 cyl, Automatic (variable gear ratios) MSRP: $32,950 Plug-in Hybrid Calculator	Plug-in Hybrid Vehicle Gasoline-Electricity © Ford Motor Company 2.0 L, 4 cyl, Automatic (variable gear ratios) MSRP: $38,700 - $40,100 Plug-in Hybrid Calculator	Plug-in Hybrid Vehicle Gasoline-Electricity 1.8 L, 4 cyl, Automatic (variable gear ratios) MSRP: $32,000 - $39,525 Plug-in Hybrid Calculator
EPA Fuel Economy 1 gallon of gasoline=33.7 kWh	Electricity: 98 MPGe combined city/highway, 35 kWh/100mi Prem. Gas: 37 MPG combined city/highway, 2.7 gal/100mi Gasoline Only 38 miles Electricity 380 miles Total Range	Elec + Gas: 100 MPGe combined city/highway, .0 gal/100mi of gas + 34 kWh/100mi Reg. Gas: 43 MPG combined city/highway, 2.3 gal/100mi Gasoline Only 21 miles Elec + Gas 620 miles Total Range All Elec:0-21 mi	Elec + Gas: 100 MPGe combined city/highway, .0 gal/100mi of gas + 34 kWh/100mi Reg. Gas: 43 MPG combined city/highway, 2.3 gal/100mi Gasoline Only 21 miles Elec + Gas 620 miles Total Range All Elec:0-21 mi	Elec + Gas: 95 MPGe combined city/highway, .2 gal/100mi of gas + 29 kWh/100mi Reg. Gas: 50 MPG combined city/highway, 2.0 gal/100mi Gasoline Only 11 miles Elec + Gas 540 miles Total Range All Elec:0-6 mi
Unofficial MPG Estimates from Vehicle Owners Learn more about "My MPG" Disclaimer	Average based on 18 vehicles 145.3 MPG 59 Lo → 779 Hi Not comparable to EPA fuel economy because these estimates do not include electricity use.	Average based on 16 vehicles 63.9 MPG 33 Lo → 148 Hi Not comparable to EPA fuel economy because these estimates do not include electricity use.	Average based on 15 vehicles 86.8 MPG 50 Lo → 197 Hi Not comparable to EPA fuel economy because these estimates do not include electricity use.	Average based on 2 vehicles 70.1 MPG 70 Lo → 70 Hi Not comparable to EPA fuel economy because these estimates do not include electricity use.
You save or spend* Note: The average 2014 vehicle gets 23 MPG	You SAVE $7,250 in fuel costs over 5 years compared to the average new vehicle	You SAVE $7,250 in fuel costs over 5 years compared to the average new vehicle	You SAVE $7,250 in fuel costs over 5 years compared to the average new vehicle	You SAVE $7,250 in fuel costs over 5 years compared to the average new vehicle
Annual Fuel Cost*	Electricity + Gasoline: $950	Electricity + Gasoline: $950	Electricity + Gasoline: $950	Electricity + Gasoline: $950
Cost to Drive 25 Miles	$1.05 (driving on elec only)	$1.19 (on a single charge)	$1.19 (on a single charge)	$1.49 (on a single charge)
	$2.72 (driving on gas only)	$2.14 (driving on gas only)	$2.14 (driving on gas only)	$1.84 (driving on gas only)
Cost to Fill the Tank	$37 (gas only)	$52 (gas only)	$52 (gas only)	$39 (gas only)
Tank Size	9.3 gallons	14.0 gallons	14.0 gallons	10.6 gallons

Table 9: Specifications of PHEVs in US [23]

Make/Model	Approximate Range (miles) electric/total range	Battery capacity (kWH Li-ion)	Gasoline Tank Capacity (Gallons)	Average MPG (equivalent)	MSRP
Chevrolet Volt	38/380	16.5	9.3	39.5	$39,145
Ford C-Max Energi	21/620	7.6	14	43.84	$32,950
Ford Fusion Energi	21/620	7.6	14	43.84	$38,700
Toyota Plug-in Prius	11/540	4.4	10.6	50.48	$32,000
Average*	22.75/534.75	9.03	11.98	44.42	

*: Calculated data

From Figure 5, average mile per gallon equivalent was calculated in case the vehicles run at their full capacity, including both electricity and gasoline. For an example, a 2013 Chevrolet Volt can run 380 miles if fully fueled. When operating with electricity, it has 98MPGe, which results in an equivalent of 0.33 gallons for 38 miles. In total, the model's fuel economy is around 39.5MPGe. The same method is applied for other models.

2.3 Charging Station Technology

Based on updated daily station data of Energy Department of The United State, there are totally 8,091 electric charging stations, excluding private charging stations, which have approximately 19,634 charging outlets [24] in May 11th, 2014.

Types of Charging Stations

To re-charge a Plugin Electric Vehicle (PEV), equipment used to communicate to PEV from charging stations is the electric vehicle supply equipment (EVSE). Its purpose is to ensure that an appropriate and safe flow of electricity is supplied to the vehicle. Currently, there are three types of charging stations. Two of them use alternating-current (AC) to charge the battery and the other uses direct current (DC).

Table 10: Charging Equipments [25]

	Input Voltage	Charging rate
AC Level 1	120V AC	2 – 5 miles per hour of charging
AC Level 2	240V AC	10 – 20 miles per hour of charging
DC fast charging (DC Level 2)	480V AC	60 – 80 miles in 20 minutes of charging

AC Level 1 provides standard charging through 120 volts (V) AC to PEV via power cord. With 120V AC, customers can charge their vehicles easily from the household outlets. This type charges 2 – 5 miles of range per hour. The advantage of AC Level 1 is very convenient to use from home. However, its disadvantage is the long charging time required. Users need to charge PEVs overnight to get a full battery (in average more than 12 hours).

AC Level 2 charges PEV through a 240 volts (V) AC plug. Customers can reduce charging time from 12 hours to 4 – 6 hours for a full charge (depended on various PEV models and battery capacity). With AC Level 2, the charging station may generate 10 – 20 miles per hour. Almost all public charging stations are using AC level 2 to help users charge their vehicles faster. Besides, users can build an AC Level 2 charger at home. However, AC Level 2 EVSE requires installation of home charging or public charging equipment and a dedicated circuit of 20 – 100 amps, depending on the EVSE requirements [25]. Advantages of AC Level 2 are user can setup one EVSE at home to charge overnight from the outlet 240V AC and can use same connector with AC Level 1. Both AC Level 1 and 2 use a standard connector J1772 for PEVS.

DC fast charging or DC Level 2 is a superfast charger currently. This charger has input voltage is 480V AC. The alternative current is converted to direct current (DC) at the charging station before the current flows to the vehicle. This type may charge full battery within 20 minutes (depend on PEVs' models). But, only limited PEVs can use DC fast charger because this type has a different connector.

III. METHODOLOGY

The purpose of this project was to forecast the future of California in 2040 where all automobiles driven are pure and plug-in hybrid electric. The project analyzed changes in transportation cost, electricity supply and consumption, emission level as well as impacts on the society and economy. The project also discussed consequences and proposed solutions to negative side effects resulted from such changes.

3.1 Background Research

To gain basic knowledge about EVs, charging stations and electric distribution, the author had interviews with Professor John Orr of Electrical and Computer Engineering Department, Ms. Deborah Scott and Ms. Liz Tomaszewski, faculties at Worcester Polytechnic Institute (WPI) to collect information about charging stations, knowledge about power plant and its distribution to charging station and experience from a real user.

Data about transportation, emissions, power plants and resources for power plants were researched to support ideas and arguments in results and discussion section. In addition, EV's performance of different brands in terms of cost, travel distance, charging time and battery capacity were also collected to examine the costs and benefits of constructing additional power plants and charging stations. The data was also used to discuss advantages and drawbacks of using an electric vehicle.

3.2 Data analysis, results and discussion

The following methods were used to predict and analyze aspects of the transformation:

- Collect and analyze data about California population and registered vehicles in recent years. Future data is inferred from present data, particularly the number of automobiles in 2040 and the number of traditional vehicles need to be replaced.
- Collect and analyze current emission rates in California, including emission from vehicles. Future data of the following two scenarios was calculated and compared against each other: California 2040 where all automobiles are electric, and California 2040 where all automobiles are petroleum engine-powered.
- Collect and analyze current electricity generation and consumption, from which predict electricity demand in 2040. The forecast also includes the number of power plants and the number of charging stations to be built potentially. Power plants types such as coal, nuclear and renewable kinds are also discussed and compared to estimate efficiency and pollution level.
- From current and future data reported, discuss and conclude positive impacts as well as unexpected side effects of the transformation.

IV. RESULTS

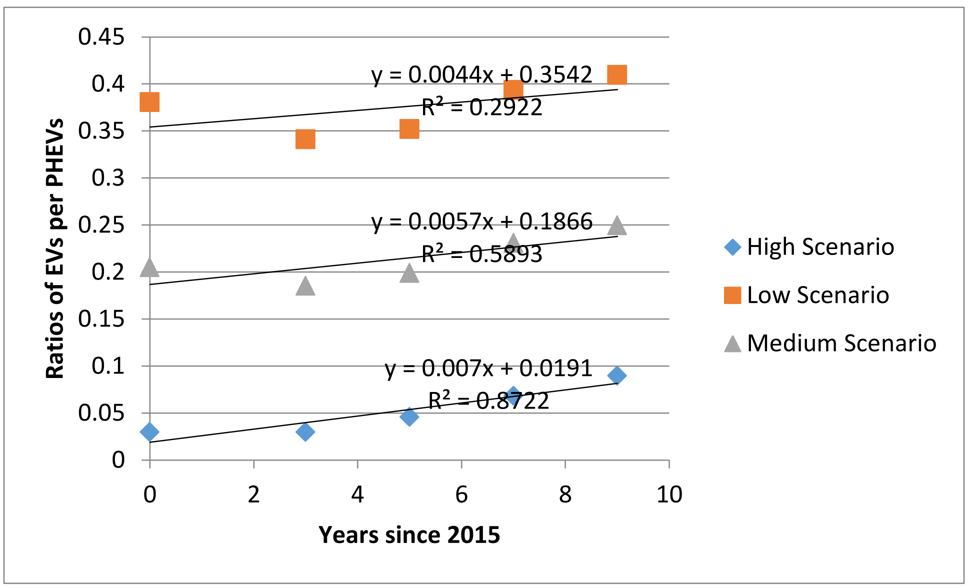
4.1 Changes in number of vehicles and vehicle types

Table 11: Ratios of PEVs over PHEVs from 2015-2040 [26]

	High Scenario	Low Scenario	Medium Scenario
2015	0.029568	0.380614	0.205091
2018	0.029512	0.340962	0.185237
2020	0.04568	0.352003	0.198842
2022	0.068042	0.393672	0.230857
2024	0.089424	0.409411	0.249418
2040*	**0.1941**	**0.4642**	**0.3291**

*: Projected data

Figure 6: Ratios of PEVs per PHEVs since 2015 in different scenario



From Table 11, the medium scenario was calculated by taking average of the other two scenarios. After that, a linear regression was used to draw three linear lines representing high, medium and low scenarios, to estimate the ratio in 2040. The medium scenario was chosen to calculate in later sections. In addition, amount of PHEVs and PEVs in 2040 were calculated by using system of linear equations with the ratio 0.3291 in 2040 and the total vehicles in 2040 (29,126,536 vehicles)

$$\begin{cases} EVs = 0.3291 * PHEVs \\ EVs + PHEVs = 29{,}126{,}536 \end{cases}$$

The unknown variables in this system of linear equation were amount of PHEVs and PEVs. Solving the linear in systems yielded 21,914,480 PHEVs and 7,212,056 PEVs.

Besides, section 2.1.1 showed that in 2040, California's population would be 49 million, and there would be around 29 million automobiles to accommodate residents' needs for transportation. In 2013, there were around 187 thousand electric vehicles registered [26]. In order for all 29 million cars to be PEVs or PHEVs in 2040, on average every 2 years the number of electric vehicles should increase 2,143,607 units, including 532,863 PEVs and 1,610,744 PHEVs, in the mean time replacing 1,646,406 traditional vehicles. The graph and table below illustrate discussed changes:

Figure 7: Auto – PEVs - PHEVs 2013 – 2040

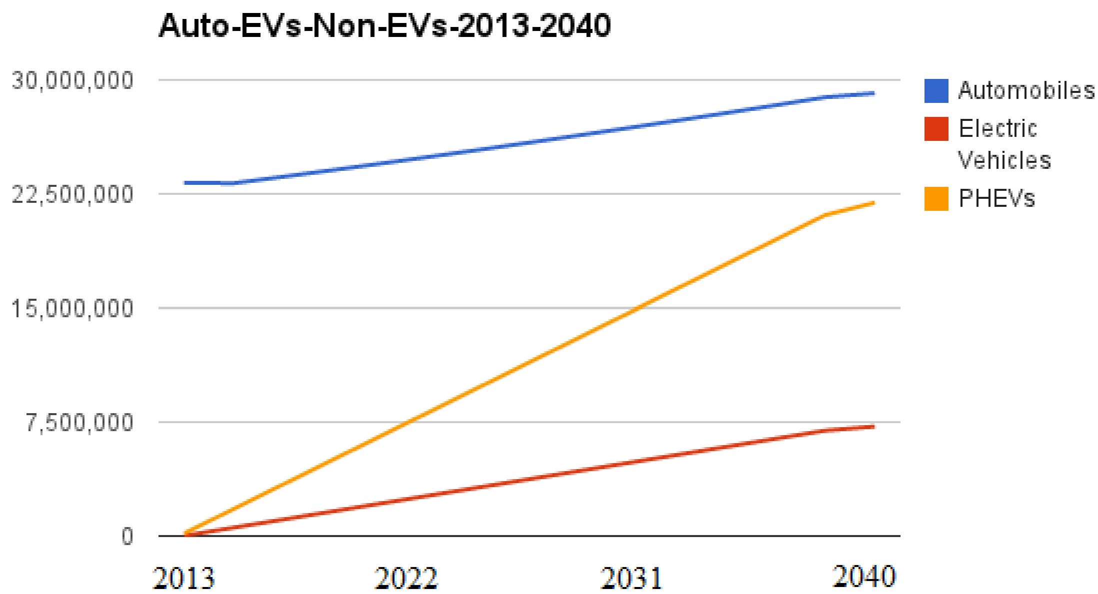


Table 12: Projected increase in California in 2040

	2013	2040	Change 2013-2040	Avg. change/2 years
Population	38,332,521	49,016,693	10,684,172	3,630,866
Automobiles	23,237,523	29,126,536	5,889,013	436,223.18
Electric vehicles	18,406 [26]	7,212,056*	7,193,650	532,863
Plug-in Hybrid vehicles	169,430 [26]	21,914,480*	21,745,050	1,610,744
Non-EVs	23,049,687	0	-23,049,687	-1,646,406

(*: expected change)

4.2 Changes in light duty vehicles tailpipe emission rates

United States Environmental Protection Agency used average carbon content values to estimate CO_2 emissions from a gallon of gasoline, which resulted in about 8,887 gram CO_2/gallon [27]. Besides, an average gasoline automobile on the road in 2012 had fuel economy of about 21 miles per gallon (MPG) [27], a gradual increase since 1985 from 15.9 MPG [28]. It was expected that the average MPG of a light-duty vehicle will be 24.5 in 2040, given that automobile technology continued to evolve. The following table shows average emission rates of an automobile, and of all registered cars, in 2012 and 2040, assuming a car runs about 12,290 miles/year [29].

Table 13: Light-duty gasoline vehicle emission in 2012 and 2040

	2012	2040
MPG	21	25
Emission/mile (grams)	423	355
Annual emission/car (metric tons)	5.2	4.4
Total emission from non-EVs (metric tons)	116,863,328	101,418,623*

**: projected, if all autos are gasoline.*

Table 14: Plug-in Hybrid Electric Vehicle emission in 2013 and 2040

	2013	2040
MPG	44.42	44.42
Emission/mile (grams)	200.1	200.1
Annual emission/car (metric tons)	2.46	2.46
Total emission from PHEVs (metric tons)	416,798	18,598,819

Using the same CO_2 emission rate and assumed travel range, the emission per mile of PHEVs in 2013 and 2040 was computed. Given that 34.5% automobiles drive more than 50 miles per day [30], it was reasonable to assume that only 34.5% of PHEVs used gasoline when they were out of battery after two full charges. Also, suppose that the fuel economy of PHEVs in 2040 stays the same, 44.42MPG, the total emission from PHEVs in 2040 is 18,598,819 metric tons. As a result, California may cut down more than 82 million metric tons if this state only uses PEVs and PHEVs. This number only reflected the tailpipe emission rate, not including the emission rate from power plants. The net emission rate would be calculated in later sections.

4.3 Changes in automobile costs of operation

This section describes calculations of operational costs of gasoline, PHEVs and electric vehicles in 2013 and 2040. The total cost per year per vehicle is presented, and then the overall estimates of all vehicles on California roads are projected. The calculations were based on the assumption that a typical automobile travels 12,290 miles/year [29].

Gasoline vehicles consume a lot of fuel and the petroleum cost is increasing every year. The U.S Energy Information Administration (USEIA) reported that the average motor gasoline costs $3.57/gallon in 2013, and will be $3.90/gallon in 2040, with the growth rate of 0.2%/year [31]. With this rate, a regular consumer expects to pay at least $2000 annually to drive a car. This number was computed before consideration of inflation.

Table 15: Annual Operational Cost of Gasoline Vehicles, PHEVs and EVs

		MPG	Cost per mile ($U.S)	Annual cost ($U.S)
2013	Gasoline Vehicles	21	0.170	2040
	PHEVs	44.42 (MPGe)	0.080	983.2
	PEVs	112.33 (MPGe)	0.032	393.28
2040	Gasoline Vehicles	25	0.160	1920
	PHEVs	44.42 (MPGe)	0.088	1170.4
	PEVs	112.33 (MPGe)	0.035	465.5

On the other hand, electric vehicles are very cost-efficient compared to their gasoline peers. According to the Department of Energy, "today's light-duty PEVs (or PHEVs in electric mode) can exceed 100 mpg and can achieve 30-40 kWh per 100 miles" [32]. Electricity price is significantly cheaper than gasoline's, with the California residential rate in 2013 being 11.6 cents/kwh, and is expected to increase to 13.3 cents/kwh in 2040 [33]. The unit kWh per 100 miles of PEVs and PHEVs was converted to MPGe (equivalent MPG) to compare with MPG of gasoline vehicles. It was assumed that PEVs consumed 30kWh per 100 miles in 2013 and 2040, equivalent to 3370 [34] /30kWh = 112.33 MPGe.

From above calculations, it was clear that the annual operational cost of electric or plugin-hybrid vehicles is significantly lower, around $500-$1,200 compared to $1,920 of gasoline cars in 2040. Currently typical PEVs and PHEVs batteries can last 10-15 years [20], and battery prices are expected to drop to $3,000-$4,000. Hence over a course of 12 years from 2014, the estimated cost of a PEV or PHEV is around $18,000 compared to $24,000 of a gasoline vehicle, a saving of approximately $6,000

.

V. DISCUSSION

5.1 Benefits

5.1.1 Consumers' personal benefits

Plug-in Hybrid Electric vehicles and Electric vehicles bring more benefits than a regular driver would actually think. According to Department of Transportation, 85% of vehicles travel less than 100 miles/day [30], hence the widespread misconception about EV's limited travel range may be outweighed by advantages described below.

Currently, one of the very attractive benefits for electric vehicle users is incentives offered by both federal and state governments. An electric vehicle buyer may receive up to $10,000 rebate, including $2,500 rebate from California [34] and up to $7,500 from federal [35]. With the credits, a Nissan Leaf costs around only $20,000. Besides, PHEV customers may receive up to $7,500 from federal and $1,500 rebate from California. [36] Moreover, until 2019, EV's owners in California are receiving stickers to allow single occupant access to California High Occupancy Vehicle (HOV) lanes [37].

From a financial perspective, consumers end up saving a considerable amount of cash in automobiles' operational costs. Ms. Deborah Scott, an employee at WPI, explained about features and performance of her Chevy Volt. Although her vehicle was a plug-in hybrid electric vehicle (PHEV), it still had features similar to a pure electric vehicle except smaller battery capacity. Ms. Scott confirmed that a significant benefit from using PHEV was much cheaper operational cost. Based on her monthly bills, she paid on average $20 monthly for electricity used to charge her car plus $20 to refill its gas tank, compared to a spending of $240/month if she had used conventional a gasoline vehicle. Ms. Scott estimated that since she switched to using a PHEV, she saved about $200/month for fueling, which translated to $2400 a year. The number was close to which was already calculated in section 4.3. The actual electricity cost of using EVs might be lower, as $417 is the amount billed for a whole year when a full charge is done every night. Ms. Scott's calculation also did not take into account subsidized charges that a driver might get from public charging station. In particular, Ms. Scott was benefiting from free public charging stations that WPI has been providing for all faculties and students. Ms. Liz, WPI employee at facilities department, said WPI was able to support free charging service to everyone at campus because electricity consumption from charging station was very small. But, if the electric consumption from both charging station was increased significantly, WPI would stop the free charging service. And then, customers must pay their own charging fee.

Moreover, PEVs and PHEVs do not require as much maintenance as conventional vehicles do. Ms. Scott shared that although her vehicle was PHEV, she only spent money for changing four tires and regular maintenance service. She did paid any additional fees related to the entire gasoline engine system. Her only significant concern was the car's battery pack, which typically lasted around 8 years [32] in the meantime. Although this was a significant expenditure now, with the calculations in Table 11, battery price is projected to drop dramatically by 2040.

Another important benefit of driving a PHEV or PEV is, users have the flexibility in fuelling as

PHEVs and EVs can be charged at home, and PHEVs can use gasoline as a backup plan to generate power to electric motor as necessary. With a short travel range, PHEVs may not need to use gasoline at all. For PEVs, there is no need to stop at a gas station to refill gasoline anymore. If a user uses a level 1 AC charger, he or she can plug PEVs or PHEVs into an electric power source in the evening, and the car will be ready by the following morning. The charging time will reduce to only 4-6 hours for PEVs or 1-4 hours for PHEVs if the user uses a level 2 AC charger. Current EV technology is sufficient for regular daily trips of most American, as around 80% of vehicles traveled less than 75 miles per day [30]. With California's population growing from year to year, the number of houses, schools, shopping places and workplaces are also expected to grow; it is unlikely that the number of daily traveled miles will increase. Assuming that the mentioned ratio does not grow in 2040, with the current capacity of battery pack of around 70 miles, one full charge per day is typically enough for most drivers. On the other hand, for long trips, PHEVs can achieve approximate 540 miles with battery and gasoline. And both PEVs and PHEVs can always use public charging stations at their convenience when the infrastructure is more widely available.

5.1.2 Benefits for society and economy

According to the Department of Energy, three quarters of total U.S. petroleum consumption was spent for transportation [35], with 32% of which being used by automobiles [38]. Overall, automobiles alone consumed nearly one quarter of all petroleum available in the U.S. From section 4.3's results, the estimated fuelling cost for 23 million autos in California 2014 was around US$55.77 billion annually. Likewise, the same cost for 29 million autos in California 2040 was expected to be US$55.92 billion annually. If California is going to replace 1,646,706 gasoline vehicles by at least the same amount of either PEVs or PHEVs, where a single vehicle saves at least $1,000 compared to its gasoline peer, the state may save US$1.65 billion of fuelling cost per year.

Using electric vehicles will dramatically reduce tailpipe emission level. Emission from gasoline vehicles in California is an extremely important issue that its government has to resolve because more than 95% of Californians live in areas that fail to meet federal or state air quality standards [39]. In 2010, carbon dioxide emission level in California was the second highest across U.S, around 370 million metric tons, with nearly 65% of which comes from petroleum [40]. Section 4.2's results showed that automobile's tailpipe emission in 2013 was around 116 million metric tons, 32% of total emission, and was expected to decrease to 101 million in 2040 if no electric vehicles are used. With new technologies, gasoline vehicles can reduce emission per mile, but not significantly. If PEVs and PHEVs are the only kind of automobiles on California roads in 2040, carbon dioxide emission level can reduce to only around 18 million metric tons, around 18% of the total emission, nearly half of the level in 2013.

5.2 Challenges

5.2.1 Limitations of EVs

Currently, the biggest limitation of electric vehicles is short travel distance compared to its gasoline peers. As calculated in Table 11, a typical PEV can travel only 75 miles, just enough for a day trip to places within 30 miles of a driver's home; a PHEV can travel only 20-30 miles in electricity, before it starts to use gasoline. Meanwhile, a conventional gasoline vehicle can travel around 300 miles with a full gas tank. Electric vehicles also need to be charged in several hours, or in the best case several minutes, while a conventional car can be fully fueled in 5 minutes at any gas station. Another disadvantage is that while gas stations are very common to find across California streets and along highways, charging stations are not, making it almost impossible for an electric vehicle to travel high miles in the meantime. The issue will be resolved if more charging stations are built, and the battery technology is improved to produce higher capacity battery packs.

Another drawback of electric vehicles is that their suggested retail prices are considerably higher than gasoline vehicles'. EV technologies are too new to the market, and its annual sales statistics are not high enough to motivate manufacturers' to lower their prices. With its limitation in travel range, it is understandable that a household owning an EV also owns gasoline vehicles. Current cash rebates and tax incentives are not attractive enough for an average person with medium income to choose a PEV or a PHEV over its gasoline peer, if he or she cannot afford to own both vehicles. In fact, EV buyers are looking to take advantage of the parking and driving privileges that the state is offering. But the privileges will expire 2019, suggesting that the California government needs to introduce other types of incentives to boost EV purchases statewide.

5.2.2 Challenges of building charging stations

If all vehicles on California roads in 2040 are either pure electric or plug-in hybrid, it is highly demanded that a large number of charging stations need to be built. From 2013 to 2040, California will have approximately 266,432 more PEVs and 805,372 more PHEVs on the road each year. Given that only 20% of the daily miles for all vehicles are more than 75 miles [30], only 20% of PEVs, 53,286 units might need public charging stations for the second full charge. Besides, there is only round 12.5% of all vehicles drive daily from 20 – 50 miles [30]. Therefore, it is rational to estimate the same percentage of PHEVs, resulting in 100,672, need use public charging stations for the second full charge. Although PHEVs may not need to be recharged during the day as these vehicles can use gasoline instead, it is likely that drivers like to have a second charge to get use of the vehicle's electricity.

It was assumed that working time started from 7am to 7pm, when workplaces' parking lots start to be filled. Within 12 hours, a charging outlet may charge 2 PEVs in maximum 6 hours each, and 4 PHEVs in maximum 3 hours each. As a result, California needs 26,643 charging ports for 53,286 PEVs and 25,168 charging outlets for 100,672 PHEVs each year. Totally, the state needs at least 51,811 charging outlets per year. Generally, until 2040, California needs at least 1,347,086 charging outlets, as a PEV travelling more than 75 miles a day and a PHEV travelling 20-50 miles a day will need two full charges, where one is assumed to be overnight at the driver's home.

Currently, single or dual level 2 AC charging station costs from $500 - $7000 before incentives [41]. To estimate the total cost of charging station construction, CT2020 ChargePoint Networked

Charging Stations [42] was chosen as a model of a dual charging station. Priced around $7,300, it supplies two 7.2 kW (240V at 30A) level 2 charging ports, and it has network connection to support electronic payment and location services to help users in locating available charging stations via smartphones or computers. If California is going to utilize this model, the total cost to build 673,543 charging stations from now until 2040 is $4,916,863,900, with approximately $189,110,150 needed to build 25906 stations each year. As a suggestion, the targeted number can be reached if the state is able to collect around $100 from each vehicle, given around additional one million PEVs and PHEVs are registered with California DMV annually. There are various ways to achieve this by either raising vehicle registration fees, sales tax, excise tax on gasoline or reducing the amount of tax incentives.

Another viable solution is to install stations that can accommodate up to four vehicles at the same time [43]. Although the cost of such charging stations could not be found and they seem not to be as popular as their dual plug-in peers, this type of stations are likely to be cheaper, since installation and equipment costs can be reduced considerably compared to the number of dual stations needed to supply electricity to the same amount of vehicles, let alone savings of physical spaces.

Table 16: Number of charging outlets and charging stations estimated in 2040

	2014 (currently)	To be added each year	2040
Charging outlets	5,137 [44]	51,811	1,347,086
Charging stations (2 connectors)	1,711 [44]	25,906	673,543
Charging stations (4 connectors)		12,953	336,772

The location and distance between charging stations depends on different geographic and demographic situations. A dual EV charging station only takes up a small space between two parking lots, unlike a gas station, where a lot more space is needed for temporary customers' parking. The model CT2020 is only 55.5 in x 11.8 in x 8.5 in dimension. Electric charging stations may be built along with parking signs on streets that allow public parking. At shopping centers or companies' campus, charging stations can be built in parking lots, first as specific spots and later expands to a larger area. Among available EV models, Mitsubishi i has the shortest range of 62 miles, hence it is suggested that the longest distance between two stations should be 55 miles, considering that the vehicle needs to save the last 10% of its battery for emergency. Moreover, on highways, charging stations can be built within areas of current gas and services stations, with the number of stations varying depending on the population density.

5.2.3 Challenges in building additional power plants

Using the same statistics as in the previous section where 80% of the vehicles drive less than 75 miles per day [30], it was assumed that 80% of PEVs only need one full charge per day, either completed overnight at the drivers' homes or at a charging station. The other 20% which travel more than 75 miles would need one additional charge completed during daytime, most likely at a charging station. Similarly, 53% of the vehicles drive less than 20 miles per day and 12.5% of the vehicles drive 25 – 50 miles per day [30]. Hence if 53% of PHEVs only need the one full charge, most likely at home, then 12.5% of PHEVs need the second charge during daytime and the rest of PHEVs (34.5%) use gasoline when they are out of battery for longer trips. From results in section 2.2.1 and 2.2.2, if in average a PEV needs 20.6 kWh for one full charge, it needs 41.2 kWh for two full charges. Likewise, a PHEV needs 9.03 kWh for one full charge and 18.06 kWh for two full charges.

Table 17: Electric consumption of all EVs in 2040 (GWh)

	2040
1 full charge (80%)	480.005313
2 full charges (20%)	240.002657
Total	720.00797

Table 18: Electric consumption of California State in 2040 (GWh)

	2040
without EVs	373,536
with EVs	374,256

In 2040, 29 million PEVs and PHEVs only consume approximate 493 GWh, equivalent to 0.13% of the entire electric consumption. In fact, electric consumption of all PEVs and PHEVs is negligible when considering the increasing total electric consumption of California from 2013 to 2040. Even if all vehicles in 2040 need to take two full charges per day, the total electric consumption of EVs is around 693 GWh, around 0.19% of the statewide electric consumption.

In 2012, California generated 199,324 GWh of electricity, imported 102,000 GWh and consumed 282,141 GWh, 93.5% of total available electricity. In 2040, assume that California will consume the same percentage and save 6.5% remaining for other purposes, the projected net generation is 399,094 GWh. Additionally, it is assumed that California 2040 also imports the same amount of electricity as in 2012, 102,000 GWh. The rest of electricity generation, 297,094 GWh needs to be produced in-state. After all, from 2012 to 2040, California needs to generate 97,770 GWh more.

The electric generation capacity of a California power plant database [45] was calculated to estimate how many power plants need to be built in 2040. Since for a type of energy source, capacities of different power plants varied greatly, the average capacity was computed and used along with the largest capacity to compute results. For instance, if California builds additional natural gas power plants that have maximum capacity as of right now, 2484 MW, it may need to build 15 more plants. Otherwise, if the state aims to build smaller plants with the calculated average capacity, the number of added plants raise to 313. In general, California needs to build a lot of power plants in the future if it chooses natural gas, renewable energy and hydropower energy sources, as these types have low capacity factors, as mentioned in section 2.1.2. However, if California is going to use only nuclear power to generate more 97,770 GWh in 2040, the state only needs to build 6 additional power plants because nuclear power plant has large electric capacity factor, 86.34%. The below table contains projected results in 2040, given that California continues to focus on its current top four energy sources [14].

Table 19: Selected Electricity Generation Capacity (MW) [46]

	Quantity	Min	Max	Average	Standard Deviation
Natural gas	410	0.1	2484	113.5	278.9
Nuclear Energy	1	2323			0
Renewable Energy	271	0.2	550	32.08	59.44
Hydro	365	0.1	1331	37.14	115.95

Table 20: Net Selected Electricity Generation and Power Plants to be built

	Net Electricity Generation (GWh)		Power Plants to be built		Emission from power plants (metric ton)
	Maximum	Average	Max	Average	
Natural Gas	6843.5	312.7	15	313	50,334,69
Nuclear Energy	17569.7		6		n/a
Renewable Energy	1118.02	65.21	88	1500	n/a
Hydro	3582.98	99.98	28	978	n/a

Considering emission levels, while emissions from renewable, nuclear and hydropower power plants are negligible, the average carbon dioxide emission rate of a natural gas power plant is 1135 lbs/MWh [47]. If California only builds this type of power plants to meet the state's demand, carbon dioxide emission will increase 50,334,669 metric tons more. Results from section 4.2 show that tailpipe emission in 2040 will be around 101 million metric tons if all vehicles on the roads are gasoline. However, it will only be 18 million metric tons if all vehicles are electric or plug-in hybrid. Overall, net emission is reduced 33 million metric tons, with more than two thirds of the projected emission coming from power plants to supply electricity to the entire California population. The state may consider combinations of different energy sources to generate electricity efficiently and be more environment-friendly, but decisions have to take into account various complex factors, including but not limited to financial and demographic situation, available technologies and political effects.

VI. CONCLUSIONS AND RECOMMENDATIONS

Overall, PEVs and PHEVs are one of the popular solutions for the current fueling and emission issues. Analyses and calculations were done based on an assumption that the entire California population is switching to electric vehicles from now until 2040. At the end of this period, California is projected to have around 29 million vehicles on its roads. With all of them being either electric or plug-in hybrid, projected operational costs per vehicle may be reduced to $18,000, in which a single driver may save $1,000 annually, not including battery replacement cost. Carbon dioxide emission level can be cut at least 33 million metric ton from the current level. Moreover, the state can save around 1.65 billion dollars annually from gasoline fueling cost, and electricity consumption of 29 million PEVs and PHEVs is only 0.13% of the total statewide consumption, indicating EVs to be a promising future in using alternative fueling.

Transforming into using PEVs and PHEVs does have two main challenges: building more charging stations and power plants. Until 2040, 673,543 dual charging stations need to be built, costing around $4.9 billion. Although EVs electricity consumption is trivial compared to the total consumption, additional power plants need to be built to supply around 97,770 GWh for the entire state. The suggested number of plants needed was listed, depending on different types of energy sources. However, determining what types to build is a difficult task given that numerous factors need to be considered.

With limitations of EVs discussed in 5.2, the only solution is to invest in research and development, to improve current battery technology. The largest drawback of current EVs is their limited travel range, which is determined by battery technology. If a battery pack is able to provide travel range equivalent to that of a gasoline vehicle, EVs sales are going to see significant growth. Other limitations will soon be obsolete as technologies are evolving rapidly along with increasing average annual income.

Although the cost of building additional charging stations and power plants, as well as the cost of investing in EV technology may be significant, positive impacts of electric vehicles in general outweighs their weaknesses. A saving of $1,000/year for a driver means he or she has more available cash for other expenditures, which in turn helps the retail shopping and services sectors of the economy. Cutting petroleum usage will help the country depend less on this limited energy source, a considerable amount of which is being imported. Lower emission levels give fresher, cleaner air to the environment and improve the overall population's health. This is equivalent to lower expenses for healthcare, happier lives, and more work productivity.

Works Cited

[1] B. Dumaine, "Can Coda's electric car survive?," 12 September 2012. [Online]. Available: http://tech.fortune.cnn.com/2012/09/12/coda-electric-car/. [Accessed 30 03 2014].

[2] P. R. Log, "GBI: Power Discretes Market to 2020 on reports-research.com," PRLOG - Press Release Distribution, 16 09 2010. [Online]. Available: http://www.prlog.org/10935371-gbi-power-discretes-market-to-2020-on-reports-researchcom.html. [Accessed 02 04 2014].

[3] D. Scott, Interviewee, *Experiences in using Chevrolet Volt.* [Interview]. 11 2013.

[4] T. W. S. Journal, "A Green Car Named Desire," 17 09 2013. [Online]. Available: http://online.wsj.com/news/articles/SB10001424127887323981304579079321154539590. [Accessed 1 10 2013].

[5] C. D. o. M. Vehicles, "California DMV Statistics Year 2009," 01 01 2010. [Online]. Available: http://apps.dmv.ca.gov/pubs/newsrel/media_center/california_dmv_statistics.htm. [Accessed 12 04 2014].

[6] S. o. C. -. D. o. M. Vehicles, "Statistics For Publication," March 2014. [Online]. Available: http://apps.dmv.ca.gov/about/profile/official.pdf. [Accessed 30 03 2014].

[7] C. D. o. M. Vehicles, "California DMV Statistics 2012," 01 01 2013. [Online]. Available: http://apps.dmv.ca.gov/about/profile/ca_dmv_stats.pdf. [Accessed 12 04 2014].

[8] U. S. C. Bureau, "Population in California 2010-2013," 2013. [Online]. Available: http://www.census.gov/popest/data/state/totals/2013/. [Accessed 15 04 2014].

[9] E. C. D. M. System, "Electricity Consumption by County," [Online]. Available: http://www.ecdms.energy.ca.gov/elecbycounty.aspx. [Accessed 19 04 2014].

[10] E. A. California, "Electricity Generation," [Online]. Available: http://energyalmanac.ca.gov/electricity/electricity_generation.html. [Accessed 18 04 2014].

[11] U. E. I. Administration, "What is the difference between electricity generation capacity and electricity generation?," [Online]. Available: http://www.eia.gov/tools/faqs/faq.cfm?id=101&t=3. [Accessed 25 04 2014].

[12] U. E. I. Administration, "What is a capacity factor?," [Online]. Available: http://www.eia.gov/tools/faqs/faq.cfm?id=187&t=3. [Accessed 25 04 2014].

[13] U. E. I. Administration, "Glossary," [Online]. Available: http://www.eia.gov/tools/glossary/index.cfm?id=N. [Accessed 29 04 2014].

[14] E. A. California, "Electric Generation Capacity and Energy," [Online]. Available: http://energyalmanac.ca.gov/electricity/electric_generation_capacity.html. [Accessed 19 04 2014].

[15] C. G. I. W. Group, "ZEV Action Plan," 02 2013. [Online]. Available: http://opr.ca.gov/docs/Governor's_Office_ZEV_Action_Plan_(02-13).pdf. [Accessed 04 05 2014].

[16] U. D. o. Energy, "Hybrid and Plug-In Electric Vehicles," [Online]. Available: http://www.afdc.energy.gov/vehicles/electric.html. [Accessed 08 05 2014].

[17] U. D. o. Energy, "All-Electric Vehicles (EVs)," [Online]. Available: http://www.fueleconomy.gov/feg/evtech.shtml. [Accessed 07 05 2014].

[18] B. N. E. Finance, "Electric Vehicle Battery Prices Down 14% Year on Year," [Online]. Available: http://www.newenergyfinance.com/PressReleases/view/210. [Accessed 19 04 2014].

[19] P. America, "Plug-in Vehicle Tracker - What's Comming, When," [Online]. Available: http://www.pluginamerica.org/vehicles. [Accessed 11 04 2014].

[20] K. et.al, "Comparison of Battery Life Across Real-World Automotive Drive-Cycles," [Online]. Available: http://www.nrel.gov/docs/fy12osti/53470.pdf. [Accessed 18 04 2014].

[21] U. D. o. Energy, "Plug-in Hybrids," [Online]. Available: http://www.fueleconomy.gov/feg/phevtech.shtml. [Accessed 08 05 2014].

[22] U. D. o. Energy, "PHEVs compare side-by-side," [Online]. Available: http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=32655&id=33336&id=33398&id=33335. [Accessed 08 05 2014].

[23] F. Economy, "Finding a car," [Online]. Available: http://www.fueleconomy.gov/feg/findacar.shtml. [Accessed 05 05 2014].

[24] U. D. o. Energy, "Alternative Fueling Station Counts by State," [Online]. Available: http://www.afdc.energy.gov/locator/stations/results?utf8=%E2%9C%93&location=&filtered=true&fuel=ELEC&owner=all&payment=all&ev_level1=true&ev_level2=true&ev_dc_fast=true&radius_miles=5. [Accessed 29 03 2014].

[25] U. D. o. Energy, "Developing Infrastructure to Charge Plug-In Electric Vehicles," [Online]. Available: http://www.afdc.energy.gov/fuels/electricity_infrastructure.html. [Accessed 01 02 2013].

[26] C. E. Commission, "California Energy Demand 2014-2024 Revised Forecast," 09 2013. [Online]. Available: http://www.energy.ca.gov/2013publications/CEC-200-2013-004/CEC_200-2013-004-SD-V1-REV.pdf. [Accessed 05 05 2014].

[27] U. S. E. P. O. o. T. a. A. Q. Agency, "Greenhouse Gas Emissions from a Typical Passenger Vehicle," 2011. [Online]. Available: http://www.epa.gov/otaq/climate/documents/420f11041.pdf. [Accessed 18 04 2014].

[28] U. E. I. Administration, "Motor Vehicle Mileage, Fuel Consumption, and Fuel Economy," [Online]. Available: http://www.eia.gov/totalenergy/data/monthly/pdf/sec1_17.pdf. [Accessed 18 01 2014].

[29] U. E. I. Administration, "Annual Energy Outlook 2014: Market Trends - Transportation sector energy demand," [Online]. Available: http://www.eia.gov/forecasts/aeo/MT_transportationdemand.cfm. [Accessed 19 04 2014].

[30] U. D. o. T. F. H. Administration, "Out Nation's Highways: 2008," [Online]. Available: http://www.fhwa.dot.gov/policyinformation/pubs/pl08021/fig4_5.cfm. [Accessed 28 04 2014].

[31] U. E. I. Administration, "Petroleum and other Liquids," 04 07 2014. [Online]. Available: http://www.eia.gov/petroleum/gasdiesel/. [Accessed 11 01 2014].

[32] U. D. o. Energy, "Benefits and Considerations of Electricity as a Vehicle Fuel," [Online]. Available: http://www.afdc.energy.gov/fuels/electricity_benefits.html. [Accessed 18 04 2014].

[33] U. E. I. Administration, "Annual Energy Outlook 2014," [Online]. Available: http://www.eia.gov/forecasts/AEO/. [Accessed 18 04 2014].

[34] Edmunds, "Decoding Electric Car MPG," [Online]. Available: http://www.edmunds.com/fuel-economy/decoding-electric-car-mpg.html. [Accessed 09 05 2014].

[35] IRS, "Plug-In Electric Drive Vehicle Credit (IRC30D)," 13 02 2014. [Online]. Available: http://www.irs.gov/Businesses/Plug-In-Electric-Vehicle-Credit-%28IRC-30-and-IRC-30D%29. [Accessed 29 04 2014].

[36] P. I. America, "State & Federal Incentives," [Online]. Available: http://www.pluginamerica.org/incentives. [Accessed 08 05 2014].

[37] C. E. P. Agency, "California Clean Vehicle Incentives," [Online]. Available: http://www.arb.ca.gov/msprog/zevprog/factsheets/clean_vehicle_incentives.pdf. [Accessed 28 04 2014].

[38] Wikidot, "US Energy Use," 28 10 2010. [Online]. Available: http://energyfuture.wikidot.com/us-energy-use. [Accessed 29 04 2014].

[39] C. A. R. Board, "Air Pollution in California," [Online]. Available: http://www.arb.ca.gov/msprog/zevprog/factsheets/driveclean.pdf. [Accessed 29 04 2014].

[40] U. E. I. Adminstration, "State-Level Energy- Related Carbon Dioxide Emissions, 2000 - 2010," 13 05 2013. [Online]. Available: http://www.eia.gov/environment/emissions/state/analysis/. [Accessed 29 04 2014].

[41] U. D. o. E. -. E. E. &. R. Energy, "Plug-In Electric Vehicle Handbook for Workplace Charging Hosts," [Online]. Available: http://www.afdc.energy.gov/uploads/publication/pev_workplace_charging_hosts.pdf. [Accessed 29 04 2014].

[42] L. GoSpace, "Our Electric Vehicle Charging Stations," [Online]. Available: http://www.gospacego.com/Products.asp?type=cs&products=ChargePoint&selected=ChargePoint-CT2020. [Accessed 29 04 2014].

[43] A. Aerovironment, "Charging for Multi-Unit Homes," [Online]. Available: http://evsolutions.avinc.com/products/multi-unit/multi-station_charging. [Accessed 30 04 2014].

[44] U. D. o. E. -. E. E. &. R. Energy, "Alternative Fueling Station Locator," [Online]. Available: http://www.afdc.energy.gov/locator/stations/#results?utf8=%E2%9C%93&location=california&filtered=true&fuel=ELEC&owner=all&payment=all&ev_level1=true&ev_level2=true&ev_dc_fast=true&radius_miles=5. [Accessed 29 04 2014].

[45] E. A. California, "California Power Plants," [Online]. Available: http://energyalmanac.ca.gov/powerplants/index.html. [Accessed 08 05 2014].

[46] E. A. California, "California Electricity Statistics and Data," [Online]. Available: http://energyalmanac.ca.gov/electricity/. [Accessed 29 04 2014].

[47] U. E. P. Agency, "Electricity from Natural Gas," [Online]. Available: http://www.epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html. [Accessed 29 04 2014].

[48] U. S. E. I. Administration, "California Electricity Profile 2010," U.S. Energy Information Administration, 2012.

[49] U. E. P. Agency, "Energy and You," [Online]. Available: http://www.epa.gov/cleanenergy/energy-and-you/. [Accessed 31 03 2014].

[50] U. E. P. Agency, "eGRID 9th edition Version 1.0 - Year 2010 Summary Tables," 02 2014. [Online]. Available: http://www.epa.gov/cleanenergy/documents/egridzips/eGRID_9th_edition_V1-0_year_2010_Summary_Tables.pdf. [Accessed 05 03 2014].

[51] U. E. I. Administration, "Electric Power Monthly with Data for January 2014," [Online]. Available: http://www.eia.gov/electricity/monthly/pdf/epm.pdf. [Accessed 07 03 2014].

[52] U. o. C. Scientists, "Environmental Impacts of Coal Power: Air Pollution," [Online]. Available: http://www.ucsusa.org/clean_energy/coalvswind/c02c.html. [Accessed 31 03 2014].

[53] C. D. o. M. Vehicle, "Top Ten DMV Facts," 01 01 2010. [Online]. Available: http://apps.dmv.ca.gov/pubs/newsrel/media_center/index.htm. [Accessed 12 04 2014].

[54] C. D. o. M. Vehicle, "Top Ten DMV Facts for 2012," 01 01 2013. [Online]. Available: http://dmv.ca.gov/pubs/newsrel/media_center/index.htm. [Accessed 12 04 2014].

APPENDICES

All appendices below were the results of the cooperation between Khoa Nguyen and Aris Papaioannou.

1. Interview with Ms. DEBORAH SCOTT

Ms. Scott purchased her Chevy Volt (a 2012 model) in December of 2011 in California at a price of $39,000. The Chevy volt is a hybrid car, which means that it can run using power both obtained from its battery and its gas engine. However, the gas tank is not connected to the drivetrain, but is there to provide extra power when the battery is running low or to completely take over when the battery is empty. When the battery is running low the user can feel the vehicle's response to be more sluggish. After a full charge, the Chevy Volt has a range of 40 miles on average by just using its battery. After attending the Seminar by the director of R&D at A123 systems, we recognized how temperature affects the battery's performance (very low and very high temperatures). That was the reason we specifically asked Ms. Scott if she notices any difference in her vehicle's performance and available mile range in very cold days. She said that in very cold days (around 35 Fahrenheit degree or under) she would get 26 miles or maybe lower from the battery. During spring season, she can get approximately 50 miles. In addition, extra energy was needed to be spent to keep her car's interior warm, and as there was no engine, the outside of the car remained very, very cold. Even when the car was charging or after it was fully charged but not operating, under very cold weather the car would use power to keep the battery warm.

We also asked Ms. Scott if she noticed any difference in her battery's performance (range, life cycles, charging time) since she first bought it compared to now, but since her battery is so new she said that it has been the same. At WPI, and in various public places, she charges her vehicle at 240 Volts output which translates up to 4 hours for the vehicle to be fully charged. At home, she uses 110 Volts and therefore needs about 8 hours for full charge. So far she has not had any maintenance costs besides the typical ones (change of tires).

On average she paid $20 dollars a month to charge her vehicle at home (as she can deduct from her monthly electric bill). Ms. Scott believed that it was very important and beneficial for charging stations to be located where she worked, as in that way she managed to commute from her house to work using only the battery, and thus saving gas money and reducing emissions. She charged her vehicle once at WPI and once at home overnight unless she had to travel where she would use one of the public stations (which she could locate through a phone application) many of which she did not have to pay for besides the normal parking fee for occupying the spot. When asked if she realized a difference in cost in operating a hybrid vehicle compared to a gasoline vehicle, she said that she estimated that now she saved approximately $200 dollars a month (which would go towards paying for gasoline) which translated to the considerable amount of $2400 a year.

Her overall experience with the Chevy Volt hybrid was very satisfactory. She particularly liked how the driving and performance feels (a very strong and responsive car), how the technology was so well integrated allowing her to communicate with her car and do certain functions remotely using just her smartphone (like turning the heating on prior to entering the car so that it was already warm when she got there) and, of course, that she was being environmentally considerate. However, she did not like that the car was a 4-seater since the battery occupied a lot of space in the back of the car and the car remained very cold on the outside since there was no engine to keep it warm.

2. Interview with Prof. JOHN ORR

From our meeting with Professor Orr, we obtained some more technical information on the specifics of how electricity transmits from the generator in the factory to the charging station that is directly connected to the electric or hybrid vehicle. A mechanical (usually rotating) device, called the generator, is used in the factory to generate the electricity and from there it passes through a transformer and a transmitter where its voltage ranges between 69 and 500 kV. Then it passes through another transformer which lowers the voltage somewhere between 6 and 50 kV, the typical value is 13.8 kV, to end up to a distributor. From there it passes through another transformer which brings it down to 120V, 240V or 480V depending on the type of the charging station and then it is used to charge the vehicle. Therefore, one very important consideration is how to minimize transmission losses while delivering high power. They are estimated to be on average about 10% from end-to-end (so from the output voltage value of the generator to the output transformer value of the charging station). The 480V, being at a higher voltage, gives out more power than the rest of the voltage output values. Some other topics that came up from our discussion with Professor Orr were the 'Smart Grid' which refers to the effort to reduce generating stations and replacing them with distributors. How to store the energy efficiently using a pump hydro and a reservoir located on a hill in which case the potential energy of the falling water is used to generate electricity. Also environmental concerns arise with issues like producing the battery, disposing of it, and, of course, generating the electricity for it. Professor Orr gave a hint about power plant emission, such as if the electricity for the battery comes from a coal-powered plant then it is 'dirtier' than simply using gasoline vehicles. Besides, Professor John Orr recommended us to look up more information in library to figure out his suggestion about electricity consumption and emissions.

3. Interview with Ms. LIZ TOMASZEWSKI

From our meeting with Ms. Liz Tomaszewski we obtained the following information based on our questions. There are currently two fully functional EV charging stations located on the WPI campus. They are both duals, meaning that each has two parking positions so that two vehicles can use the station to recharge at the same time. However, not all four spots are active (or live) so there are three spots, in total, available for recharge use. The first charging station, located next to Goddard Hall, was built in April of 2012 from *Coulomb Manufacture* and the second one which is located at parking garage on Park Avenue was introduced to the campus in January of 2013 and was made by the same manufacturer. WPI received a grant which covered the infrastructure, implementation, maintenance, and any charging costs for those two charging stations and therefore the user is not required to pay anything for using the station. Both stations have similar technical specifications (AC Type 2) with a charging output of 240 volts which translates to an average time of four hours to fully charge an electric vehicle. The two charging stations are not connected with each other; however they do use the same electricity grid.

The daily power consumption to use the charging station, according to Ms. Tomaszewski's estimations, is $0.65 per user, and is considered a negligible amount which further justifies the fact that no charge fee is required from the user. Also, note that the charging stations are available to the whole public and not just the WPI community.

Now, when it comes to organizational issues and whether or not they EV owners are able to always use the stations, the statistics (obtained from a special application by *chargepoint* which shows relative daily usage, trends in the usage of the charging stations and other useful data) show that WPI is on average at half capacity and has never been on full capacity. What this practically means is that on a daily basis, for example, an average of two people will use the charging stations. Therefore, as Ms. Tomaszewski said there is no current need to open up the fourth available charging spot. Through the chargepoint network EV users are able to be informed when their vehicle is done charging. Finally Ms. Tomaszewski said that in case demand rises then the fourth charging spot will be available, and if it is further needed a new charging station will be implemented (a superfast one is also a possibility). However, there have been occurrences where non-EV's have been found to be occupying charging spots. Those instances fall under the campus police authorities to give tickets and maintain order. Last but not least, after our request on the specific daily (permanent) number of EV's that use the WPI charging stations, Ms. Tomaszewski contacted WPI police which informed her that there is only one registered (a Chevy Volt).

The technical specifications of charging station will not be listed here but we do have information on those (provided from Ms. Tomaszewski).

4. **Feedback from California's government**

Mr. Swanton confirmed that California will not have troubles with off-peak electricity consumption when the large amounts of EVs or PHEVs are charged at the same time. Next, California is going to add several renewable power plants and upgrade the entire power plant system to be more efficient and clean. Besides, Mr. Swanton said, "To many people, the single occupant access sticker for California's carpool lanes is a bigger deal than the rebates." Finally, he shared that rebates and tax credits helped bring the cost of early introduction vehicles down to a reasonable cost and the new technology that will help build market share rapidly.