CalCap Climate Action Course Final Paper

Financing Models of Campus Charging Infrastructures For Electric Vehicles

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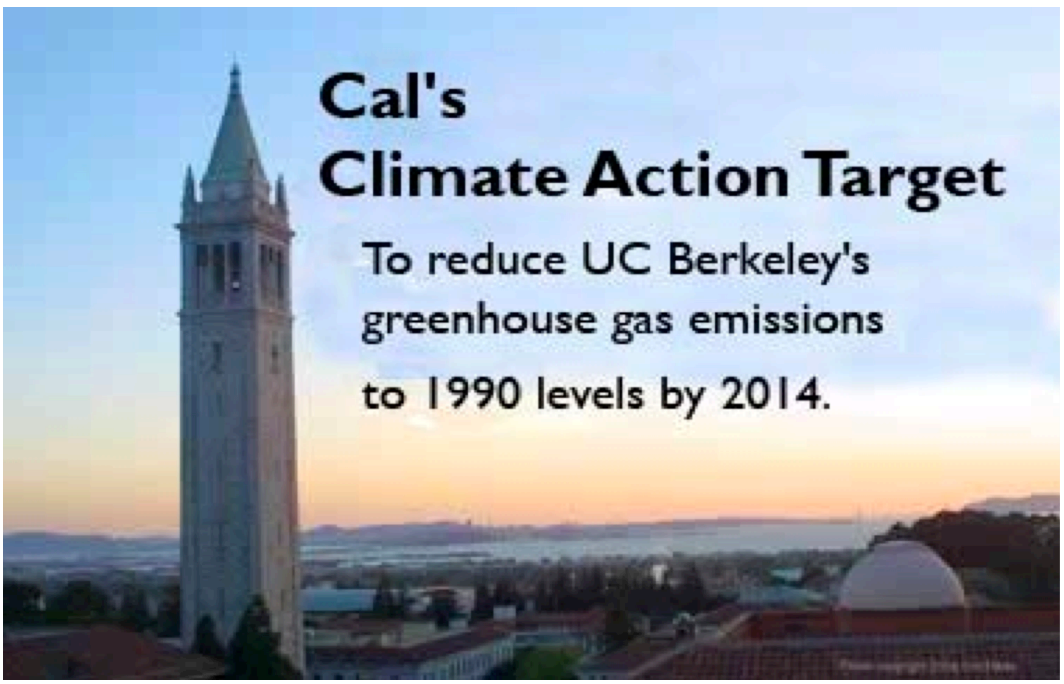
LIST OF ACRONYMS

CD	Charge Depleting
CPUC	California Public Utilities Commission
EV	Electric Vehicle
GEV	Grid-enabled Vehicles
G2V	Grid to Vehicle
ICV	Internal Combustion Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
V2G	Vehicle to Grid

CHAPTER I: BACKGROUND

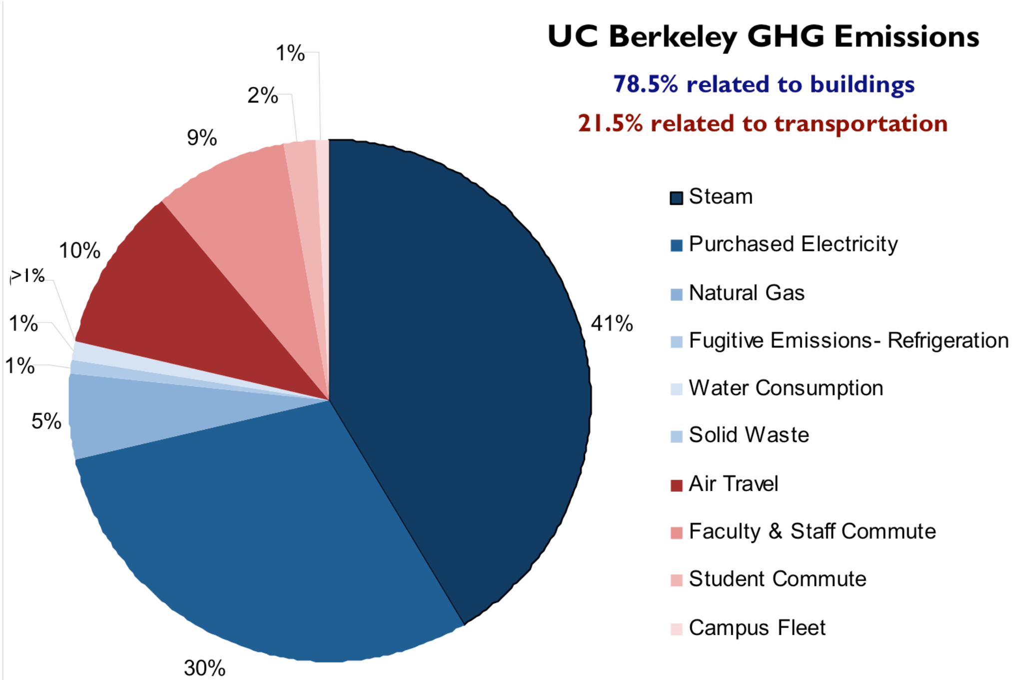
PART 1.1: ABOUT THIS PAPER

This paper is conducted and submitted in partial fulfillment of the course requirements for the Sustainability in Action: Cal Climate Action Course (CalCAP). CalCAP, formed in 2006, is a collaboration of faculty, administration, staff, and students working to reduce greenhouse gas (GHG) emissions at UC Berkeley.



According to the CalCAP 2009 climate action plan, 21.5% of the total UC Berkeley GHG emission is related to transportation, which is the second biggest chunk of campus GHG emission source, only second to building GHG emission.

Figure 1: UC Berkeley GHG Emissions



Source: CalCAP 2009 Climate Action Plan

California is always a leader in mitigating and reducing its greenhouse gas emissions in coordination with our climate change mitigation policies as outlined in AB32. UC Berkeley, one of the most active supporters for California's environmental goal, should carry on our environmental leadership by continuing to address climate change mitigation in automobile exhaust. The 2007 initial work of CalCAP had a greenhouse gas emissions reduction target that reduce GHG emissions to 1990 levels by the year 2014. This goal is six years earlier than State of California and the UC Policy on Sustainability Practices requires. [1]This paper addresses the transportation sector GHG emission by promoting an alternative transportation system, namely electric vehicle. However, no one wants to buy electric vehicles unless there are ubiquitous charging infrastructures; no one would want to invest on installing public charging stations unless there are electric vehicles running on the street. The most crucial issue many potential customers are worried about before purchasing an electric vehicle is where they can charge it up, thus it becomes a "chicken and egg" problem.

Due to the technology limitations, electric vehicles are not suitable for driving long distances and thus are

[1] 2009 Calcap Climate Action Plan

not widely popularized so far. However, with fast technology progress and rising awareness of sustainable development, it will not take much time before massive electric vehicles running on the street.

It is not that our campus chooses electric cars but rather it is the electric cars choose us! Electric cars are fast becoming the choice of preference and also center of public attention all over the world because of the green and energy saving feature.

SECTION 1.1.1: PROBLEM DEFINITION

This paper is interested in exploring what the appropriate role of UC system in supporting the development of electric vehicle charging infrastructure during the early years of EV adoption? Should we finance the private market to promote electric vehicle charging infrastructure development on campus or Berkeley city? If so, how much for the first a few years (2010-2014) of EV adoption and what is the best approach the campus should finance it?

SECTION 1.1.2: GENERAL ASSUMPTION

It is important to put the a few assumptions before the body of the analysis for clarification.

1. There are private sector electric vehicle service providers that are interested in operating public charging stations such as Better Place and Coulomb.
2. It is not clear that the charging service providers have an incentive to build chargers without some sort of support.
3. In the early years, public chargers will likely be undersupplied by the private sector, despite the fact that they are believed to contribute to EV adoption.

CHAPTER II: THE REASONS TO BUILD PUBLIC CHARGING STATIONS ARE SUFFICIENT

PART 2.1: INTRODUCTION TO PUBLIC CHARGING INFRASTRUCTURE

SECTION 2.1.1 WHAT ARE EV CHARGERS

Electric vehicle (EV) public/commercial charging stations are non-residential locations, where vehicles can plug in to an electrical source, usually electrical grid, to re-charge electric vehicle batteries. To be more specific, public charging stations are those built in public accessible places such as public parking lots and highways but commercial charging stations are more found at a business such as commercial buildings and public commercial parking lots, etc. EV charging stations are necessary to support what is expected to be a growing fleet of EVs throughout California. Unfortunately, systematic public charging infrastructure network does not exist so far.

SECTION 2.1.2 TYPES OF EV CHARGERES

EV charging (inductive, conductive, or rapid) is performed at three voltage and current levels. The levels are defined to meet the EV's needs, to meet anticipated future technology needs, and to provide compatibility with distribution systems. The NEC Handbook describes the three charging levels. The following table summarizes the electrical requirements of the three charging levels.

Table 1 Type of EV Chargers

	Voltage (VAC)	Current (Amps)	Power (KVA)	Freq (Hz)	Phase	Standard Outlet
Level 1	120	12	1.44	60	Single	NEMA 5-15R
Level 2	208/240	32	6.7/7.7	60	Single	SAE J1772/3
Level 3 [2]	480	400	192	60	Three	J1772[3]

Source: NEC Handbook

Below are some detailed info abstracted from the City of Pasadena EV Charging Information Sheet regarding different chargers:[4]

Level 1 Charging uses a common 120 Volt, single-phase outlet for a three-prong grounded (NEMA 5-15R) connector with a ground-fault circuit interrupt. Level 1 charging requires 8 to 14 hours to fully charge a vehicle, depending upon EV and battery type. Sometimes this type of charging provided with the vehicle as an alternate backup charging method such as the GM EV1. Level 1 charging requires 12 Amps maximum continuous current with 15 Amps (minimum) branch circuit protection.

When using Level II charging, an EV can be charged in 4 to 6 hours, depending on the EV battery type and capacity. This type of charging requires 208-240 VAC single-phase maximum nominal supply with 32 Amps maximum continuous current with 40 Amps branch circuit protection. Required safety features include grounding or electrical isolation, personnel protection from shock, a no-load make/break interlock, and a safety breakaway for the cable and connector.

Level 3 Charging is commonly known as fast or rapid charging, this type of charging requires high levels of voltage and current to replenish more than half of an EVs battery capacity in as quickly as ten minutes. Level 3 chargers use a 480 VAC, 400 Amp, three-phase electrical service and require the same safety

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[2] Also referred as Direct Current Charger or Fast Charger.

[3] Level 3 chargers have no formal standard yet

[4] The city of Pasadena EV Charging Information. Accessed on 12 Feb. 2010 http://ww2.cityofpasadena.net/waterandpower/program_ev_evcharging_info.asp.

levels as Level II.

Various models of chargers makes the installation of charging stations even harder, so efforts to standardize chargers will be especially significant to ensure network interoperability. This paper only address Level II charging stations since Level III chargers are far more expensive for the first round constructions of EV chargers at the very beginning phase (2010 to 2014).

PART 2.2: PUBLIC CHARGING INFRASTRUCTURE IS NEEDED TO SUPPORT EV USE

This section provides the evidence why the public charging infrastructure is needed and first talks about EVs and its advantages, which serves as the sufficient condition for building charging stations. And the following parts regarding EV technology limitation, which serves as the necessary condition for the public charging infrastructure.

SECTION 2.2.1 EVS HAVE MANY ADVANTAGES THAN OTHER TRANSPORTATION ALTERNATIVES

Grid-Enabled Vehicles (GEVs) include plug-in hybrid electric vehicles (PHEVs) and pure electric vehicles (EVs). Pure electric vehicles are propelled only by an electric motor (or motors) powered by rechargeable battery packs and are regarded as the ultimate transportation mode in the future. PHEVs are the combination of both hybrids and all electrics but fall between them. This paper is trying to find out a good business model for a massive network of public charging stations that all GEVs drivers could benefit from.

Electric vehicles have several advantages over internal combustion engines (ICEs). The use of electricity to displace petroleum consumption in the vehicle fleet leads EVs to the center of the international limelight drawing a lot of attentions lately among different energy, transportation and environmental groups.

The fast rate of petroleum consumption and the increasing greenhouse gas (GHG) emission are the two biggest issues frequently brought up in the spotlight for the global sustainable development. Carbon and other greenhouse gases trap heat in the Earth's atmosphere and are a major cause of global climate change. In California, transportation fuels account for about 40 percent of all greenhouse-gas emissions.[5]

Vehicles in the US consume about eight million barrels of gasoline per day, more than total US daily petroleum production. They account for eighteen percent of national greenhouse gas emissions. Both

[5] "UC experts detail new standard for cleaner transportation fuels". University of California, Berkeley and University of California, Davis. August 2, 2007.

motor vehicle gasoline consumption and emissions have been rising at about 1.5 percent per year.[6] The technology of EVs projects a promising future to alter these trends.

1 ENERGY INDEPENDENCE

First of all, Electric Vehicles have the potential to reduce the world's petroleum consumption since they are powered by electricity that is directly from the power grid and thus are more efficient than gasoline engines. The idea of renewable energy such as wind power and solar power makes EV even more attractive in terms of saving the world's limited fossil fuels.

Figure 2: Well-to-Wheel Efficiency

Technology	Example Car	Well-to-Wheel Efficiency (km/MJ)
Natural Gas Engine	Honda CNG	0.318
Hydrogen Fuel Cell	Honda FCX	0.348
Diesel Engine	VW Jetta Diesel	0.478
Gasoline Engine	Honda Civic VX	0.515
Hybrid (Gas/Electric)	Toyota Prius	0.556
Electric	Tesla Roadster	1.145

Source: Martin Eberkard and Marc Tarpenning[7]

2. ENVIRONMENTALLY FRIENDLY

More than the gasoline savings, EVs also have zero tailpipe emissions and thus could substantially reduce the greenhouse gas emissions; though how much less depends on the source of power on the local electricity grid.

[6] Daniel M. Kammen, Samuel M. Arons, Derek M Lemonie, etc. Making Plug-In Hybrid Electric Vehicles Cost-Effective, 2009. No. 34, page 6.

[7] Eberhard, Martin and Tarpenning, Marc. "The 21st Centrury Electric Car", Tesla Motors, October 6, 2006.

Figure 3: Well-to-Wheel CO2 Emission

Technology	Example Car	Well-to-Wheel CO2 Emission (g/MJ)
Natural Gas Engine	Honda CNG	166.0
Hydrogen Fuel Cell	Honda FCX	151.7
Diesel Engine	VW Jetta Diesel	152.7
Gasoline Engine	Honda Civic VX	141.7
Hybrid (Gas/Electric)	Toyota Prius	130.4
Electric	Tesla Roadste	46.1

Source: Martin Eberkard and Marc Tarpenning[8]

3. THE POTENTIAL FOR VEHICLE-TO-GRID APPLICATIONS

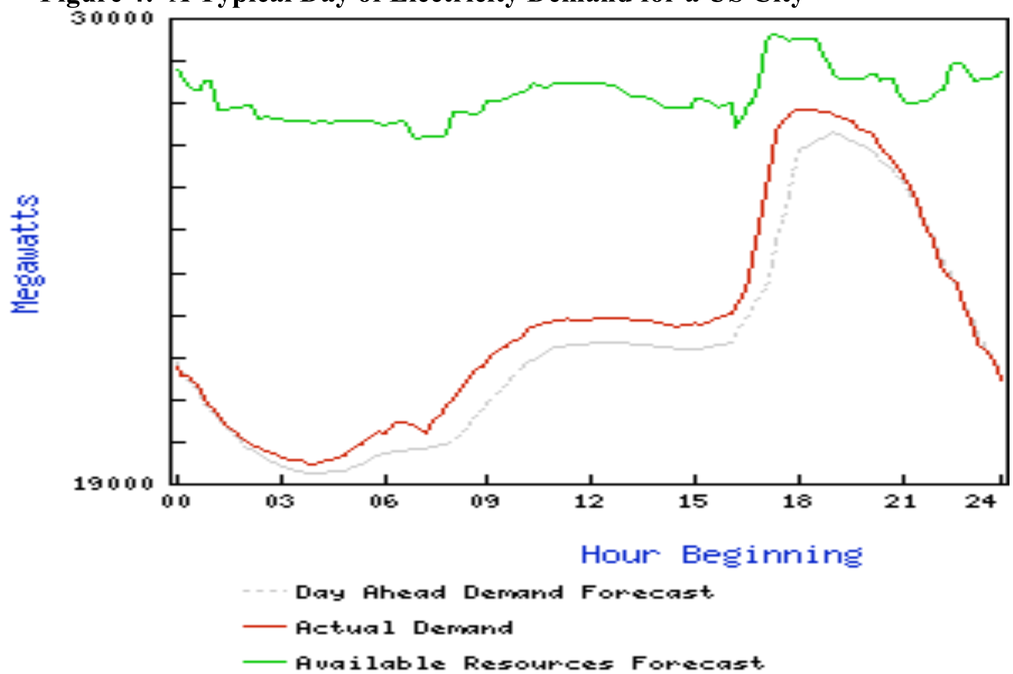
V2G is to receive electricity from the electric grid and also to send electricity onto the electric grid, so PHEVs could act as mobile energy storage. In the US, peak hours appear when the biggest drivers of load, air conditions, lightening are turned on during hot afternoons as show in the chart below.[9] Some experts also proved that the US grid should be able to support millions of PHEVs in the near future without requiring additional capacity.[10]

[8] Eberhard, Martin and Tarpenning, Marc. “The 21st Centrury Electric Car”, Tesla Motors, October 6, 2006.

[9] California daily electricity demand. Accessed on Jan 31, 2010 <http://www.caiso.com/outlook/SystemStatus.html>.

[10] Lemoine, M Derek and Kammen, M Daniel. Economic Assessment of All-Electric. Energy and Resources Group, University of California.2009

Figure 4: A Typical Day of Electricity Demand for a US City



Advantages of developing V2G include an additional revenue stream for cleaner vehicles, increased stability and reliability of the electric grid, lower electric system costs, and eventually, inexpensive storage and backup for renewable electricity. The total potential net benefits estimated from V2G is up to $2,000 per year per vehicle. [11]

4. QUIET OPERATION AND BETTER PERFORMANCE

Electric Vehicles also provide smoother and quieter ride, which makes it easier for drivers to hear any unusual noises, if that should occur. In addition to that, the chart below shows that EVs actually have better performance than the other alternatives.

[11] Kempton, Willett and Tomic, Jasna, etc. Vehicle-to-Grid Power: Battery, Hybrid, and Fuel Cell Vehicles as Resources for Distributed Electric Power in California. California Environmental Protection Agency, 2001.

Figure 5: Vehicle Performance

Technology	Example Car	Well-to-Wheel CO2 Emission (g/MJ)
Natural Gas Engine	Honda CNG	166.0
Hydrogen Fuel Cell	Honda FCX	151.7
Diesel Engine	VW Jetta Diesel	152.7
Gasoline Engine	Honda Civic VX	141.7
Hybrid (Gas/Electric)	Toyota Prius	130.4
Electric	Tesla Roadster	46.1

Source: Martin Eberkard and Marc Tarpenning[12]

SECTION 2.2.2 RANGE ANXIETY AND HOME CHARGING LIMITATION

1. THERE IS STILL TECHNOLOGY LIMITATIONS FOR EV RANGE

With the current technology, a typical EV could run 100 miles to 200 miles on all-electric charge before needing to recharge. [13]However, for most available EV models on the market, the range is still between 60 miles to 100 miles. While electric cars are not everywhere yet, many major auto manufactures, including Honda, Ford, GM, Toyota and Chrysler have either introduced or are planning to introduce some type of electric vehicle to key markets in the U.S. in the near future. Tesla, the officially in-production US EV has a range of 244 miles per charge if drive in normal conditions (mixed city and highway conditions in a range of temperatures) results in "real world" [14]Nissan plans to market its electric

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[12] Eberhard, Martin and Tarpenning, Marc. "The 21st Centrury Electric Car", Tesla Motors, October 6, 2006. California daily electricity demand. <http://www.caiso.com/outlook/SystemStatus.html>.

[13] US Department of Energy. Accessed on Feb 2nd, 2010 <http://www.fueleconomy.gov/Feg/evtech.shtml>

[14] Tesla Motors Website. Accessed on Feb 2nd, 2010. http://www.teslamotors.com/electric/plugging_in.php

vehicle Nissan Leaf later this year and Nissan Leaf runs a 100 miles on a single charge.[15] Compared with a traditional ICV, which could run on an average 400 miles after a single fill-up, the technology of EV batteries are in dire need of improvements. Currently, the biggest limitation for drivers thinking about making the transition to EVs is the absence of a reliable network of charging facilities to increase the range of these vehicles and to alleviate any fear of "running out of juice."

2. MOST STUDENTS DO NOT HAVE ACCESS TO HOME CHARGING

IBM's Vice President for Energy & Utilities reminded attendees at a recent grid-to-vehicle conference that only a fraction of vehicle owners park their car in a garage that they own overnight, especially urban dwellers.[16] Since most of our population is students, so the majority of the population commuting to campus lives in the shared use/multi dwelling unit environment. In order for campus commuters to achieve their tremendous potential, there needs to be a charging infrastructure that provides charging for those without traditional garages; and options for those who rely on public and study place or workplace charging.

CHAPTER III: SHOULD THE CAMPUS FINANCE PUBLIC CHARGING INFRASTRUCTURE

This chapter examines if the UC campus should finance public charging infrastructure by examining the current EV suppliers' status in reality and studying the market failure of the charging infrastructure in theory through economic analysis from both consumer and supplier's perspectives.

PART 3.1: NO CLEAR BUSINESS MODEL FROM CURRENT CHARGER SUPPLIERS IN PRACTICE

There are some private charging companies such as Better place[17] and Coulomb Technologies[18] that promise to meet the public charging infrastructure needs, however, there are no clear business model that could guarantee them to be successful without a third party's support given the high capital cost of

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[15] "Introducing the Nissan Leaf Electric Vehicle". *Bloombergy Business Week*. August 02, 2009. Accessed on Feb 2nd, 2010 <http://www.businessweek.com/autos/autobeat/archives/2009/08/post_4.htm>

[16] Josie Garthwaite, "Think Plug-in Cars Will Charge Up at Home? Think Again". *Earth2Tech*, May 28, 2009. Accessed on Feb 17, 2010 <http://earth2tech.com/2009/05/28/think-plug-in-cars-will-charge-up-at-home-think-again/>.

[17] A global provider of electric vehicle networks and services http://www.betterplace.com/

[18] A major supplier of electric vehicle charging station infrastructure http://www.coulombtech.com/

public/commercial charging equipment (Table 6), long economic payback period (Table10) and uncertainty and risks involved in this business.

The profitability of this industry is highly related to the utilization rate of the charging facility so the number one driver of benefits is really the number of vehicles. However, there is no guarantee of success for the shift in the transportation sector at this stage of the change given the fact that EVs failed to prosperous in 1990s even if people think it was time EV should made its debut. Nobody knows for sure if this time the EV will embrace its real spring or another premature death. There needs to be some third-party intervention at this phase in the game. Otherwise it is going to be a chicken-and-egg problem that does not get solved.

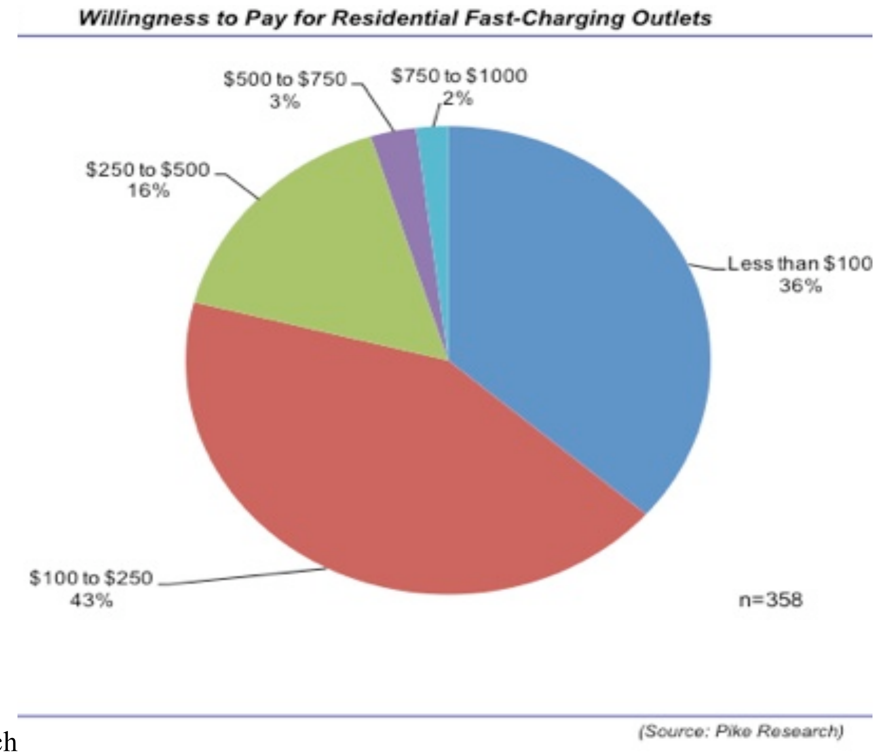
PART 3.2: IN THEORY, MARKET FAILURE

SECTION 3.2.1: EXTERNALITY

EV public charging infrastructures have external benefit in supporting environmental protection and energy independence and energy savings. Normally if there are external benefits in a certain products, too little of the good would be produced by private markets as producers and buyers do not take into account of the external benefits to others or the society as a whole. Every one will benefit from the clean air due to the EVs replacement of ICVs that resulted from a well-established EV public charging infrastructures, however, no individuals nor private markets want to pay for this social benefits and thus a thin market of EV public charging infrastructure comes into being.

The survey below, which was conducted in the second quarter of 2009, with 1,041 U.S. consumers, shows that only five percent of survey respondents indicated they would be willing to pay the going rate – $500-800 – for a residential outlet. This indicates that people are unwilling to pay the extra even for home charging outlets, not to mention the public/commercial charger which cost $5,000 not including variable cost. So a third party such as our university or local government should be involved in promoting public charging infrastructure due to its positive externalities.

Figure 6: Willingness to pay for residential Fast-Charging Outlets



Source: Pike Research

SECTION 3.2.2: PRIVATE MARKET COULD NOT SUSTAIN IN THE SHORTTERM

From both public charging consumers and suppliers' perspectives, the private market of public charging could not be prosperous in the short-run (shown in the following section). Thus, if a third party pushes the market a little bit by giving some kinds of aids, the market could stand up by itself in the future.

1. FROM CONSUMERS' PERSPECTIVE:

In order to attract consumers to charge at public charging stations, the charging price needs to be competitive. Consumers will not be willing to charge at public charging stations if they have alternatives charging that cost them less for the same range of miles travelled. From a back-of-the-envelope calculation, the EVs only cost $0.03 per mile if we don't count the battery cost, much lower than the Gas fed vehicles, which cost $0.10 per mile. (Table 2)

If we don't count the battery cost, the EV charging price could be very competitive ranging from $0.03 to $0.10. At the price $0.03 public charging has a 0 profit whereas at the price of $0.10 public charging has a 233% electricity premium. However, the battery cost could not be omitted from this calculation. For a while yet, all electric cars will be way too expensive due to their costly batteries. The i-MiEV will run roughly $30,000 to $40,000, or about twice what a gas-powered version would. A Tesla costs $108,000 to start. [19]And its battery pack will still cost about $20,000 in 2020.[20] Nissan Leaf battery pack alone somewhere between $10,000 and $24,000.[21] According to the newly released price from Nissan, including the $7,500 federal tax credit for which the Nissan Leaf will be fully eligible, the consumer's after-tax net value of the vehicle will still be $25,280. The Manufacturer's Suggested Retail Price for the 2011 all-electric, zero-emission Nissan LEAF is $32,780.[22] However, the battery pack will be leased separately at $349 at the very beginning and the real price might be closer to $40,000 before tax-credit discounts. Given the high incremental cost of the EV battery, the real EV cost per mile is $0.15, which is even higher than the $0.10 cost of gasoline vehicles charging.

Table 2: Charging/Refilling Cost Comparison (See Appendix B)

Count Battery Cost	Gasoline Charging	EV Charging	Maximum Premium
No	**$.10/mile**	**$.03/mile**	**233%**
Yes	**$.10/mile**	**$.15/mile**	**N/A**

As indicated in the chart above, gas charging costs 10 cents per mile, which may serve as an upper bound on the price consumers are willing to pay to charge their vehicles. Disregard the battery cost, electricity charging cost only 3 cents per mile. It seems that there is a big room for high premium rate up to 233%; however, this premium rate is implausible since the expensive battery cost changes the whole equation. Once the expensive EV battery is defrayed over time on top of the otherwise cheap electricity, public EV charging will exceed the gas-charging price by five cents per mile and thus will no longer be competitive to consumers.

In order for public charging to be economic for consumers, they need to be able to charge their vehicles inexpensively. The chart below shows that the government needs to subsidize the battery at $0.10 per

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[19] Keegan, Matthew. "Industry Darling Tesla Motors Builds 500th Roadster," Matt's Musings. June 5, 2009. March 2nd, 2010. < www. matthewkeegan.com/2009/06/05/industry-darling-tesla-motors-builds-500th-roadster/>.

[20] "What's New: Fast Forward 2020: The Myth of the EV Future – Feature." Car and Driver. February, 2010. Accessed Feb. 28, 2010. <http://www.caranddriver.com/features/10q1/fast_forward_2020_the_myth_of_the_ev_future-feature>.

[21] Dennis, Lyle. "2011 Nissan LEAF Price". All Cars Electric. Aug. 3, 2009. Accessed on Feb. 15, 2010. <http://www.allcarselectric.com/blog/1033846_2011-nissan-leaf-price>.

[22] "Nissan Delivers Affordable Solutions for Purchase, Lease of All-Electric Nissan LEAF"R.R. Newswire. March, 2010. Accessed on March 27, 2010. http://www.prnewswire.com/news-releases/nissan-delivers-affordable-solutions-for-purchase-lease-of-all-electric-nissan-leaf-89512777.html.

mile when the utilization rate is 10% and $0.06 per mile when the utilization rate is 30% to cancel out the 10-year-levelized battery cost. If a battery could power 100,000 to 120,000 miles in its lifetime, then the EV battery subsidy should be between $ 6,000 and $ 12,000.

Table 3: Level 2 Chargers Assume 10 Years Payback Period

Utilization Rate	Premium Rate	Bill Price	Government Subsidy
10%	**183%**	**$0.08/mile**	**$0.10/mile**
30%	**61%**	**$0.05/mile**	**$0.06/mile**

Under President Obama's pledge, so far EV consumers are eligible for up to $7,500 in federal tax credits for plug-in hybrid and battery electric vehicles, a subsidy designed to offset the high cost of batteries under Obama's pledge.[23] Additionally, there is a $5,000 statewide tax rebate and carpool-lane access in California.[24] From consumers' perspective, it seems the government is giving out the right amount to subsidize EV batteries for the short term. In the long run battery cost has high potentials to drop dramatically due to the fast technology improvement. So the government financing support will not be stranded to an endless abyss since the market has vigor in the long run and it is still optimistic that public charging industry could sustain in the long run. In summary, from the consumers' perspective, in order for the public charging stations to overcome the short-term difficulties, consumers needs Government subsidies for extra battery cost to make EV charging as competitive as the Gasoline charging.

2. FROM EV CHARGING INFRASTRUCTURE SUPPLIERS' PERSPECTIVE:

Like Better Place and Coulomb Technologies, all EV charging infrastructure suppliers have the same problem formerly mentioned such as costly chargers, unprofitable market and high risks. The suppliers have to face fierce competition from home charging as well. PG&E offers special rates to encourage EV market development and electricity use during nighttime, off-peak hours when the utility has surplus distribution capacity. EV charging is a natural match for time-of-use (TOU) rates since most EV users—in both residences and fleets—find that the most convenient (and sometimes the only) time to charge their vehicle is overnight. [25]

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[23] "Federal EV Tax Credit Must Be Changed". Weird. October 19, 2009. Accessed on Jan 29, 2010 http://www.wired.com/2009/10/federal-ev-tax-credit-must-be-changed.html.

[24] "Nissan Delivers Affordable Solutions for Purchase, Lease of All-Electric Nissan LEAF"R.R. Newswire. March 2010. Accessed on March 27, 2010. http://www.prnewswire.com/news-releases/nissan-delivers-affordable-solutions-for-purchase-lease-of-all-electric-nissan-leaf-89512777.html.

[25] "EV Charging Essentials". PG&E EV Infrastructure Installation Guide. Accessed on March 23, 2010. <http://www.pge.com/includes/docs/pdfs/about/environment/pge/electricvehicles/ev4pt2.pdf>.

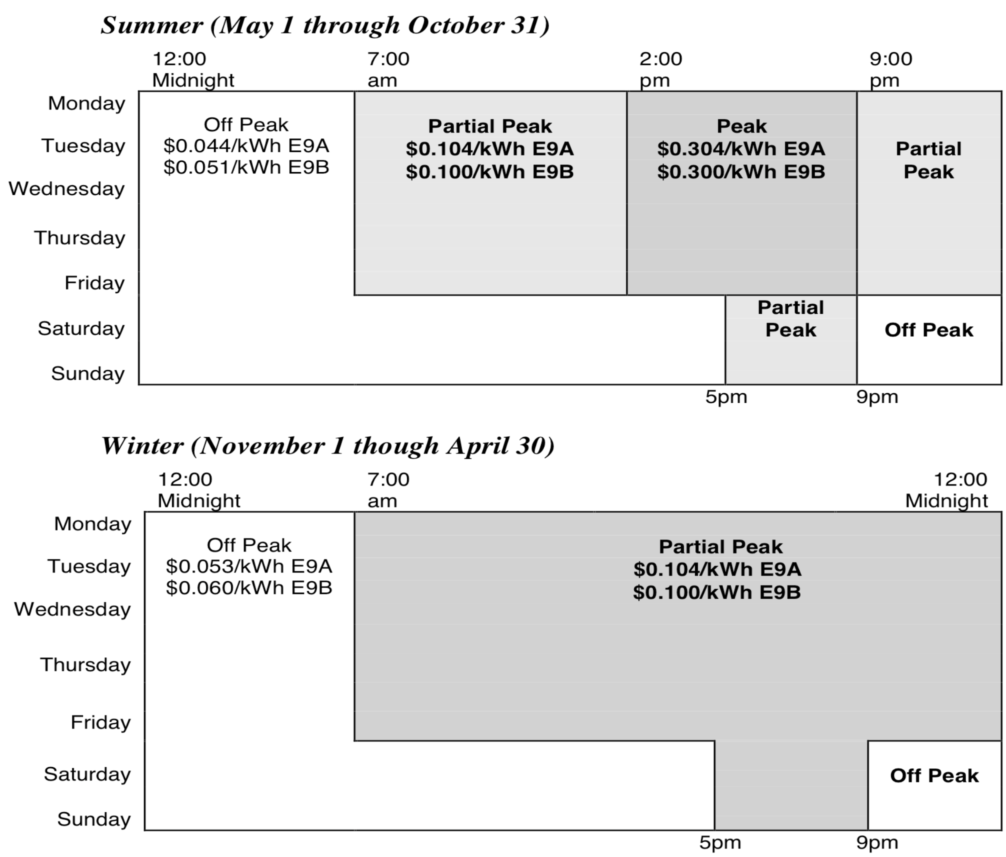
The off-peak electricity price range from $0.04 to $0.06 per KWH in different seasons, for the purpose of this analysis we use $0.05 per KWH. So home charging price is 0.05/2.9=$0.017 for every mile traveled, therefore there is no way the public charging stations could compete with home charging. (0.017<0.03) There is no doubt that home charging will be the dominant source of EV charging and the low price of home charging only makes people strongly avoid public charging from public charging facilities.

The low price will influence people's charging choice but they are not determinant since public charging is additional to home charging and they are necessary in that:

1. Home charging is not enough for long distance travel
2. Not every one has home charging access
3. Sometimes people unable or forget to charge at home so they have to use public charging infrastructure

In this paper, we assume that 80% of the EV electricity is from home charging and only 20% is from public/commercial charging stations. We only use the home charging price standard as a strong factor to estimate the utilization rate, not a strong factor for the evaluation of the maximum price or profitability of public charging.

Figure 7: Home charging price from PG&E



Source: PG&E

For both level 2 and level 3 chargers, after adding up all kinds of costs, suppliers cannot be profitable without a third party's financing support in the short term since their payback period is too long to attract any private investors. A 5-year-payback is necessary to have a profitable and attractive market and a 3-year-payback will be ideal to ensure a fast growing suppliers market. Again, same as discussed in the consumer's perspective section, in the long term, when more people own an EV and the utilization rate grows to a higher level, suppliers could be profitable and more and more suppliers will come to the market.

In summary, from the suppliers' perspective, even the government is subsidizing the battery cost for consumers; the high capital cost of EV charging equipment still causes problems for a profitable charging market. In addition, the reality that mass production of EVs only start this year and the new market's low market share of EVs will give rise to a low utilization rate and uncertain risks of public charging stations. In addition, home charging will lower the utilization rate of public chargers too.

CHAPTER IV: HOW MUCH SHOULD THE CAMPUS INVEST?

After answering the question "should the campus finance the public chargers?" this section deals with the question "how much the campus needs to pay". By cost analysis and break-even analysis we will calculate for the minimum amount of campus support for each single charger that could guarantee an optimistic market and a conservative market for profitable public/ commercial EV charging industry. The numbers of EVs are projected at the very beginning of this section. Through an EV to charger ratio analysis, the number of chargers could be estimated and thus the total amount of money needed from a third party could be estimated in different scenarios.

PART 4.1: FINANICIAL ANALYSIS

SECTION 4.1.1: PROJECTED EVS ON CAMPUS BY 2014

UC Berkeley only had 5 EVs being used as commuter cars out 3400 vehicles staff/faculty used in 1996 according to the staff/faculty transportation survey. [26]Though we are not clear how many EVs are being used as commuter cars for both faculty and students in UC Berkeley, the number will not exceed 50 to be conservative.

Energy independence and green consciousness lead the new era on an alternative transportation track the

[26] Staff/faculty Transportation Survey, 1996. Accessed on Feb 22nd, 2010. <http://pt.berkeley.edu/sites/pt.berkeley.edu/files/content/Staff%20Transportation%20and%20Parking%20Survey.pdf>

history never really took. “This is the game-changer for our industry,” said Carlos Ghosn, Nissan’s president and chief executive. He predicted that 10 percent of the cars sold would be electric vehicles by 2020.[27]

The industry consensus is that 3 Million Electric Vehicles will be in the global market by 2015, with 6 Million charging stations.[28] The US market is projected to be a third of that, at 1 Million Vehicles and 2 million stations. One million vehicles is the goal set by the Obama Administration last winter. [29] Known as an early adopter state, California is assumed to have about 25% of the new American car markets, and most forecasts show about a 200,000 to 300,000 in the US by 2015.

Let’s assume 200 EVs will be used as commuters’ cars in UC Berkeley for conservative scenario and 500 EVs as an optimistic scenario by 2014.

SECTION 4.1.2: UTILIZATION RATE AND CHARGER TO EV RATIO ANALYSIS

As we said in the home charging section that it is assumed 80% of the EV electricity is from home charging and only 20% is from public/commercial charging stations. So each EV will need 744.8KWH from public/commercial charging stations (See Appendix C). In a low utilization scenario (10% utilization of EV charging stations), each EV charger output only 4,380KWH electricity, whereas in a high utilization scenario (30% utilization of EV charging stations), there will be 13,140KWH electricity transmitted to EVs (Also see Appendix C). Since the total KWHs needed from public/commercial charging stations are fixed, the utilization rate and the EV to charger ratio must be negatively correlated.

Table 4: Charger to EV Ratio Analysis

Utilization Rate	1%	10%	20%	30%	40%
Public Charger to EV Ratio (Round to the nearest tenth)	1	0.2	0.1	0.1	0.0

From the chart above, it is clear that a 40% utilization is not likely to happen because the charger to EV ratio is almost zero if we round the figure to the nearest tenth digit; Similarly, an one to one ratio of

27 Woody, Tood and Krauss, Clifford. “Cities Prepare for Life With the Electric Car.” *The New York Times*. Feb. 14, 2010. Accessed on Feb. 15, 2010< http://www.nytimes.com/2010/02/15/business/15electric.html>.

28 “Electrification Roadmap: Revolutionizing Transportation and Achieving Energy Security” Electrification Coalition, Washington, DC, November 2009.

29 Lowenthal, Richard and Quinn, Colleen. “Before The Public Utilities Commission of the State of California”. Brief of Coulomb Technologies, INC. February 8, 2009

charger to EV is not plausible neither because we don't want the utilization to as low as 1%. So the utilization ratio should be 10% to 30% to ensure a reasonable charger to EV ratio. In the rest part of this paper, a 30% utilization rate will be considered as a high-utilization market and a 10% utilization rate will be considered a low-utilization market of public/commercial charging industry.

Table 5: In a high utilization market (30% utilization rate)

Year 2014	Pessimistic	Optimistic
Number of EVs	200	500
Chargers Need if 30% utilization rate	20	50
Chargers Need if 10% utilization rate	40	100

SECTION 4.1.3: COST ANALYSIS

The cost of Public/commercial charging infrastructure contains two parts: the fixed cost and the variable cost. In this part, a detailed cost analysis will be provided with concrete numbers by addressing the two cost components respectively.

1. FIXED COST FOR LEVEL II CHARGERS

The fixed cost of Public/commercial charging infrastructure is made of the charger cost and the installation cost (Appendix D).

Total Fixed Cost= Charger Cost + Installation Cost (Including the grid-upgrading cost)

Table 6: Level II Charger Fixed Cost

Level II Charger Fixed cost	($)
Charger	2,500
Installation (Include grid-upgrading)	2,500
Total fixed cost	5,000

2. VARIABLE COST FOR LEVEL II CHARGERS

The total variable cost contains two parts: the electricity cost and the maintenance cost.

Total Variable cost = Electricity Cost + Maintenance Cost

Table 7: Level II Charger Annual Variable Cost

Variable cost	10% Utilization Rate	30% Utilization Rate
Electricity	438	1314
Maintenance	175	175
Total variable Cost	613	1,489

The electricity cost is correlated with the utilization rate. In the high-utilization scenario, the electricity cost is $438 and in the low-utilization scenario, the electricity cost is $1314. (Appendix D).

3. TOTAL COST PER CHARGER OVER CHARGER LIFETIME FOR UNSUBSIDIZED SCENARIO

Unsubsidized scenario here in this paper means the EV charging market runs on itself financially to achieve the maximum profit without any third party financial support. The maximum electricity premium rate is 100% for level II chargers, which this paper adopts in its calculations given the EV charging industry is profit-driven.

Table 8: Level II Charger Unsubsidized Total Cost with 100% Electricity Premium Rate:

Utilization Rate	10%	30%
Total Fixed Cost	$5,000	$5,000
Total Annual Variable Cost	$613	$1,489
Total NPV of Variable Cost	$4,733	$6,498
Total NPV of Cost over 10 Years	$9,733	$11,498

SECTION 4.1.4: UNSUBSIDIZED PAYBACK PERIOD CALCULATION

The payback period calculation is based on unsubsidized scenario. Payback period measures the period of time required for the return on an investment to recover the sum of the original investment. It is often widely used in investment areas such as energy efficiency technologies since it is an easy and useful investment analysis tool. In this paper, we use discounted payback period formula to more accurately account for the time value of money.

Discounted Payback Period = Total Fixed Cost/ NPV of Annual Cash Inflows

1. ANNUAL CASH INFLOWS

Annual Cash Inflows = Annual Revenue - Annual Variable Cost

Both the utilization rate of chargers and the electricity premium rate are determinant factors of the annual revenues. For the level 3 chargers, the highest electricity premium rate could be up to 233%, therefore, the premium rate for level II chargers should be much lower since level II charger needs almost 10 to 16 times more time than the level III charger does to charge the same-size battery. Let’s assume the cap for level II charger’s electricity premium rate is at most 100%.

If an operator were to charge an electricity premium of 100 percent, they would receive revenues (less overhead) of just $263 per year when the utilization is 10% and $1139 when the utilization is 30%. (Appendix E)

Table 9: Annual Cash Inflows

Utilization Rate	KWH Per Year	Consumer Payment Per Year (100% Electricity Premium Rate)	Annual Cost of Electricity and Maintenance	Annual Cash Inflows
10%	4,380	$876	$613	$263
30%	13,140	$2,628	$1,489	$1,139

2. DISCOUNTED PAYBACK PERIOD

The lifetime of a public charger is 10 years, therefore, a 10-year payback period only guarantees not losing money for investors; and no investment will be made if the payback period is as long as 10 years. A 5-year payback would be necessary to guarantee a profitable and competitive market and a 3-year payback would be ideal for the public charging industry to be prosperous quickly. We could see from the chart below that if the electricity premium is 100% as we discussed in the former section, the discounted payback period is 5 years when the utilization period is 30% and up to 61 years when the utilization rate is 10% (See Appendix E). Since the utilization rate is estimated to be 10% to 30%, so in a low-utilization market, a third party has to finance the public charging market, which could not survive on its own. This reconfirms last chapter's main point that some aids are needed from a third party such as the government.

Table 10: Unsubsidized Discounted Payback Period with 100% Electricity Premium Rate

Utilization Rate	Discounted Payback Period
10%	61 Years
30%	5 Years

SECTION 4.1.5: UNSUBSIDIZED BREAK-EVEN ANALYSIS AND SENSITIVITY ANALYSIS

In this section, a break-even analysis is provided for 3 years, 5 years and 10 years payback period.

When the utilization rate of chargers is only 10%, the electricity premium rate has to be very high to achieve a 3-year payback or a 5-year payback. Even for the most conservative 10-year payback, it requires a 183% premium rate, which is far higher then the 100% maximum premium rate we have assumed. Only when the utilization rate reaches 30%, the 5-year payback rate becomes smaller than 100%.

Table 11: Break-Even Electricity Premium Rate for 3, 5& 10-Year Payback (In Miles)

Utilization Rate (%)	$ Per mile (3 Year Payback)	Premium (3 Year Payback)	$ Per mile (5 Year Payback)	Premium (5 Year Payback)	$ Per mile (10 Year Payback)	Premium (10 Year Payback)
10%	0.151	404%	0.115	283%	0.085	183%
20%	0.091	202%	0.726	142%	0.058	92%
30%	0.071	135%	0.585	95%	0.048	61%
50%	0.054	81%	0.047	57%	0.041	37%
100%	0.042	41%	0.039	29%	0.036	19%

Table 12: Break-Even Electricity Premium Rate for 3, 5& 10-Year Payback (In KWH)

Utilization Rate (%)	$ Per KWH (3 Year Payback)	Premium (3 Year Payback)	$ Per KWH (5 Year Payback)	Premium (5 Year Payback)	$ Per KWH (10 Year Payback)	Premium (10 Year Payback)
10%	0.438	404%	0.334	283%	0.247	183%
20%	0.264	202%	2.105	142%	0.168	92%
30%	0.206	135%	1.697	95%	0.139	61%
50%	0.157	81%	0.136	57%	0.119	37%
100%	0.122	41%	0.113	29%	0.104	19%

PART 4.2: OUTSIDE AID FOR ATTRACTIVE PAYBACK PERIOD

SECTION 4.2.1: ELECTRICITY PREMIUM RATE AND AIDS NEEDED FROM OUTSIDE PER CHARGER

In summary, if it is assumed that Level II charge station owners can recoup a 100 percent margin at most on the cost of electricity consumption, that any individual charge station is utilized 30 percent of the time in the high-utilization scenario and 10 percent in a low-utilization scenario, then a third party needs to subsidize at both scenarios when we assume a 3-year payback period in a single charge station. For the 5-year payback period on the investment, only the optimistic scenario does not need outside aid. According to the chart below, when the utilization rate is 10%, the outside support needed is $701 per charger per year. (See Appendix E)

10% UTILIZATION RATE

Table 13: Financial Aid Need Per Charger if the Utilization Rate is 10%

Payback Period	3-year Payback Period	5-year Payback Period
Electricity Premium Rate	404%	283%
Bill Price $/mile	$0.151	$0.115
Maximum Premium Rate	100%	100%
Maximum Bill Price $/mile	$0.06	$0.06
Outside Support $/mile	$0.091	$0.055
Outside Support $/KWH	$0.264	$0.160
Outside Support $/Charger/Year	$1,156	$701

30% UTILIZATION RATE

Table 14: Financial Aid Need Per Charger if the Utilization Rate is 30%

Payback Period	3-year Payback Period	5-year Payback Period
Electricity Premium Rate	135%	95%
Bill Price $/mile	$0.071	$0.585
Maximum Premium Rate	100%	100%
Maximum Bill Price $/mile	$0.06	$0.06
Outside Support $/mile	$0.011	N/A
Outside Support $/KWH	$0.032	N/A
Outside Support $/Charger/Year	$420	N/A

SECTION 4.2.2: TOTAL THIRD PARTY SUPPORT

If we assume by 2014, the utilization rate is 30%, then we need 20 chargers on campus for a pessimistic EV market and 50 chargers on campus for an optimistic market. Whereas when the charger utilization rate is 10%, our campus will need 40 chargers in a pessimistic EV market and 100 chargers in an optimistic market.

Table 15: EVs and EV Charger Number Projection

Year 2014	Pessimistic	Optimistic
Number of EVs	200	500
Chargers Need if 30% utilization rate	20	50
Chargers Need if 10% utilization rate	40	100

Therefore, the total financial aid varies with different utilization rate and scenarios. The total financial aid is summarized in the tables below.

Table 16: Financial Aid Need Each Year from 2010 to 2014 in a High-utilization Market (30% utilization rate)

No. of EVs	No. of Chargers Need	Outside aid (If 3-year Payback) ($420/charger)	Outside aid (If 5-year Payback) (Don't Need Support)
500	50	$21,000	$0
200	20	$8,400	$0

Table 17: Financial Aid Need Each Year from 2010 to 2014 in a High-utilization Market (10% utilization rate)

No. Of EVs	No. Of Chargers Need	Outside aid (If 3-year Payback) ($1,156/charger)	Outside aid (If 5-year Payback) ($701/charger)
500	100	$115,600	$70,100
200	40	$46,430	$28,040

CHAPTER V: CONCLUSIONS AND RECOMMENDATIONS

PART 5.1 CONCLUSION

Having a massive shift from ICVs to EVs is an irreversible trend given the increasing volume of climate change and energy independence. However, the revolutionary change from fill-up to charge-up will not be easy. The foregoing part of this paper has already answered two questions regarding the development of the public/commercial charging stations on campus.

Question 1: Should the campus finance the private market to promote EV public/commercial charging infrastructure development? The answer to this question is definitely a "yes" because: first, the chicken-and-egg problem underlying high risks for both charging station consumers and suppliers will not be solved without a third party support and reassurance. Second, the costly chargers give rise to a huge capital cost to private investors, which exclude most investors from investing. Third, the payback period is longer than the charger lifetime when the utilization rate is under 30%, which means the private market is doomed to be a failure as a result of the unprofitable nature. Finally, the expensive EV battery makes the otherwise cheaper charging-up less attractive compared with the old-fashioned fill-up and the low-price home charging leads the public charging to a less competitive position too.

Question 2: How much the campus should finance for the first a few years (from 2010 to 2014) of EV adoption? The answer to this question could be found in Table 16 and Table 17. However, the results from such an analysis vary considerably in response to changes in the key assumptions such as the utilization rate and electricity premium rate, etc. Please also refer to Table 11 and Table 12 for some sensitivity analysis when some of the assumptions vary in a plausible range.

Now it is clear how much the campus should finance the charger market. We still have one more question to deal with-- Question 3: What is the best approach the campus should finance it? In the recommendation part below we will try to answer this question.

PART 5.2 RECOMMENDATIONS

Besides the main takeaways from this paper regard the public-private partnership (Recommendation 1), there are a few other things that should be taken care of (Recommendation 2 to 4). A pervasive network of EV public/commercial charging infrastructure is needed to satisfy consumer demand for refueling of their EVs and thus allay range anxiety and make consumers more comfortable about purchasing grid-enabled vehicles. Both from the analysis conducted in this paper and lessons learnt from the past experience of public charging infrastructure development, in order to achieve the goal of designing a powerful network, a few things should be carefully dealt with.

Recommendation 1*: The campus should definitely finance the private market of public/commercial charging infrastructure but with the cooperation of other parties too.*

The reason behind this recommendation is obvious by now. The whole paper has been examining the rational of a third party aid or finance to the private market. However, it does not mean the campus should finance the whole amount of aid ourselves. In fact, there are a bunch of other groups such as EV automakers, utilities and local government who might be very interested in developing the charging stations. So a separate market analysis would be necessary to find out which stakeholders the campus could best work with.

Recommendation 2*: Standardize chargers so that all kinds of EVs could be connected compatibly to the chargers at any charging stations.*

Section 2.1.2 of this paper provides detailed informations for different level chargers. Various models of chargers makes the installation of a uniformed charging stations even harder, so efforts to standardize chargers will be especially significant to ensure network interoperability. Besides, high compatibility of public chargers will further ensure customers' accessibility to the nearest charging stations and thus make the charging network more powerful. To achieve this goal, the cooperation between charger producers and EV automakers are sufficiently significant.

Recommendation 3*: Make good use of economy of scale for building and producing the chargers to bring the charger cost down.*

Since the fixed cost is very high, it will be good if we could take advantage of mass installation and the suppliers take advantage of mass production. The grid upgrading will be cheaper for more chargers installed at the same time. For charger producers, under the structured model of a third party aid, they could initially share the burden by taking advantage of subsidies to ensure sales are profitable from day one. The challenge will be to get costs down to a sufficient level by the time incentives start to scale back since the financing is only designed for the very beginning years of charger market, namely from 2010 to 2014. Mass production must take action to effectively bring down the expensive charger cost. The affordability is the key to attract more investors to be involved in the market and contribute to a more competitive market.

Recommendation 4*: Conduct periodic reviews of the charging market and reflect on lessons learnt and improve the implementation process.*

A review after a period of implementation would be essential for further development of this market. Since the public/commercial charging market is still new to most of us, the market is full of unforeseeable risks. On the one hand, efforts should be made to popularize public/commercial-charging stations, however, on the other hand, the action must not be taken without due care and attention of the adoption and development pace of EVs on campus. A period review will be very helpful for future market to reflect on lessons learnt and adjust the implementation and development strategy for the long-term market.

APPENDICES

APPENDIX A: ASSUMPTIONS

Table 27: Assumptions table:

Electricity cost of $.10 per kWh
Installation costs $2,500
Annual maintenance cost $174.6
Discount Rate 0.05
Gasoline charging cost $.10 per mile
Gasoline price $3.00 per gallon
Gasoline car travel 30 miles per gallon

Gas to mechanical energy efficiency 25%
Grid to battery to EV efficiency 80%
One gallon gas store 33 KWH energy
EV travels 2.9 miles per KWH
EV charging cost \$.03 per mile
EV battery cost \$.12 per mile (\$12,000/100,000 miles)
Public Charging Station Provides 20% of the total Electricity Demand of EVs
The electricity premium rate should not exceed 100% for level II chargers

APPENDIX B: COST PER MILE TRAVELED BY EVS

APPENDIX B.1. COST OF CHARGING FORMULA

Price= Price of electricity from power utility.

Energy = Amount of energy your battery charging system uses (in Kilowatt hours)

Total cost to charge batteries = Energy x Price Per KWh

APPENDIX B.2. COST PER MILE FORMULA

Cost = Total Cost of a full charge of your EV's batteries.

Range = Total Range of your EV from a full charge, in Miles, Kilometers or any other distance measurement.

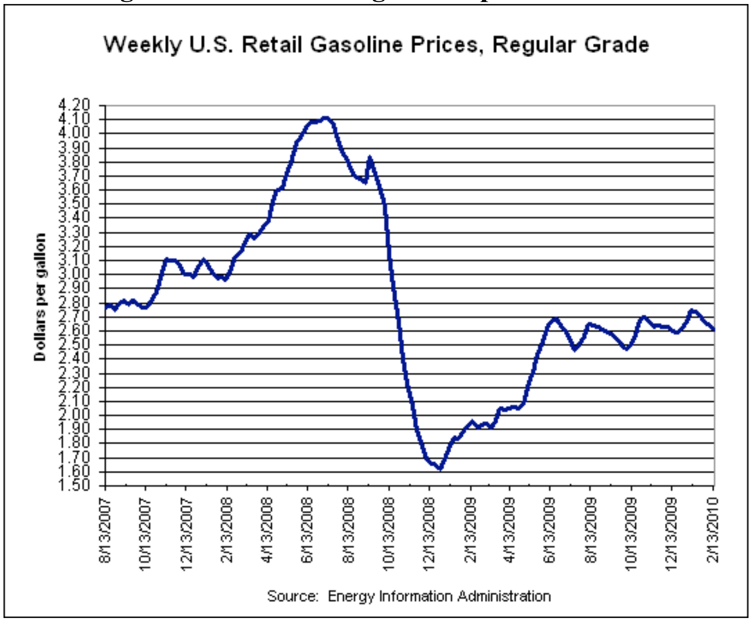
Cost Per Mile=Cost/ Range

APPENDIX B.3. COST PER MILE FOR INTERNAL COMBUSTION VEHICLES

B.3.1. OIL PRICE

Average U.S. retail gasoline price has a big variance from \$1.6 per gallon to \$4.1 per gallon. The most recent oil price is around \$2.6 and \$2.7 per gallon as shown below:

Figure 10: U.S. retail gasoline prices



California has a slightly higher price for gasoline. The average price of gasoline for California is around \$2.9 per gallon according to EIA[30], so our calculation uses the rounded \$3 for the cost per gallon of gasoline.

B.3.2. MILES TRAVELED PER GALLON BY ICVS

According to the National Highway Traffic Safety Administration[31] source that the fuel economy performance is as follows: the average US fleet fuel economy performance is 28 mpg (Figure 9) until 2010. Corporate Average Fuel Economy (CAFE) standard now is 27.5 miles per gallon for cars and 24mpg for light trucks

The calculation in this paper uses the rounded 30 mpg but open to change in the future. If Obama's upgraded CAFE standards were adopted as expected, the required fleet car average for fuel efficiency would be 35.5 miles per gallon by 2016. Obama's national CAFE standards – would begin with 2012 model cars.[32] Following President Obama's campaign, California wishes to enact 43 miles per gallon on

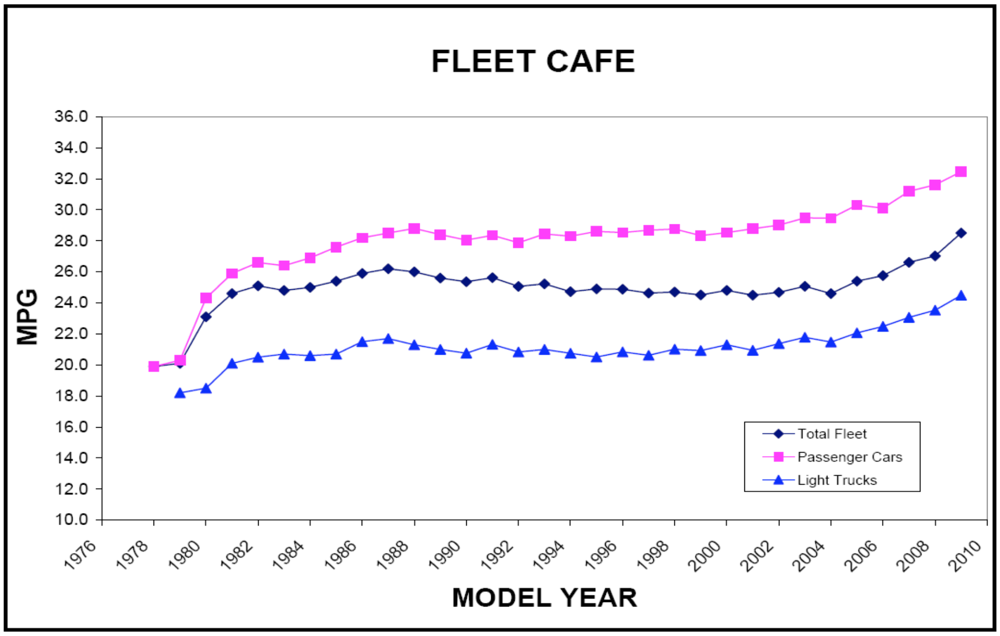
[30] U.S. Retail Gasoline Price. Accessed on Jan. 28, 2010 <http://www.eia.doe.gov/oil_gas/petroleum/data_publications/wrgp/mogas_home_page.html>.

[31] Fuel Economy Performance. Accessed on Jan. 28, 2010 <http://www.nhtsa.dot.gov/portal/site/nhtsa/menuitem.43ac99aefa80569eea57529cdba046a0/>.

[32] Tarlow, Steven. "President Obama's CAFE Standards Will Reduce Auto Emissions". Personal Money Store. May 19, 2009. Accessed on Jan. 24, 2010 < http://personalmoneystore.com/moneyblog/2009/05/19/cafe-standards-car-emissions/>.

average by 2016, which is far higher than the 35 miles per gallon by 2020 target of the Energy Act of 2007. [33] Since all these are plans that are not in progress yet, 30 mpg is being used in this paper.

Figure 11: Fleet CAFE



Source: National Highway Traffic Safety Administration[34]

B.3.3. COST PER MILE FOR ICVS

According to the Cost Per Mile formula, the cost per mile for gas engine vehicle equals the quotient of gas cost per gallon and the miles traveled per gallon. So the gas engine vehicles cost is $3/ 30 (price per gallon/ miles per gallon mpg), which equals to $0.10 per mile traveled.

APPENDIX B.4. COST PER MILE FOR EVS

B.4.1. ELECTRICITY PRICE

Electricity cost is 8 cents a kilowatt-hour from a coal power plant (probably higher in the future if the climate legislation is implemented); 11 cents a kilowatt-hour from natural gas plant; 10 cents a kilowatt-

[33] The average miles per gallon for cars, trucks, and SUVs. Accessed on Jan. 28, 2010 <http://www.project.org/info.php?recordID=384>.

[34] Fuel Economy Performance. Accessed on Jan. 28, 2010 <http://www.nhtsa.dot.gov/portal/site/nhtsa/menuitem.43ac99aefa80569eea57529cdba046a0/>.

hour from wind plants[35] This paper uses 10cents for one kWh electricity. (Also see Appendix A).

B.4.2. MILES TRAVELED PER KWH BY EVS

Gas to mechanical energy efficiency is 25% and grid to battery to electric motor efficiency is 80%, therefore if ICVs could travel 30 miles per gallon than the EVs travels 96 miles per gallon of oil. [36]
There is 33 KWH energy stored in one-gallon gas.[37] (Also see Appendix A). So EVs run at 2.9 miles per kWh (96 mpg/33 KWH per gallon).

B.4.3.COST PER MILE FOR EVS

According to the Cost Per Mile formula, the cost per mile for EVs equals the quotient of electricity cost per kWh and the miles traveled per kWh. So the EVs cost $0.1/ 2.9 (price per electricity/ miles per KWH), which equals to $0.03 per mile traveled.

B.4.4. COST PER MILE WITH BATTERY COST

Compared with the cost per mile of ICVs, EVs are very competitive and thus seems very attractive to consumers. However, the very reason people are hesitant to buy an EV is because the very expensive cost of the EV itself, namely its costly battery.
The cost of EV battery is currently between $10,000 and $25,000. [38] An average of the two makes it $17,500 per EV battery. According to Igot's paper, the traditional ICE cost $3,000[39], so the incremental cost of EV battery is $14,500.
According to Figure 12, the cost increments for a midsize PHEV20 and a PHEV60 are estimated at $8,000 and $13,000 respectively. This is the capital increment for buying a PHEV than buying a traditional vehicle of the same vehicle lifetime. Again, if the calculation takes an average of the two numbers, the average incremental cost for a PHEV is $10,500.

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[35] Wald. L Matthew. "Cost Works Against Alternative and Renewable Energy Sources in Time of Recession". *The New York Times*, 2009. Accessed on Jan. 29, 2010 < http://www.nytimes.com/2009/03/29/business/energy-environment/29renew.html>.

[36] (30/ 25%) * 80%=96 miles per gallon

[37] "Electric Car Cost Per Mile". Ecoworld. Accessed on Jan 28, 2010 <http://www.ecoworld.com/energy-fuels/electric-car-cost-per-mile.html>.

[38] "Introducing the Nissan Leaf Electric Vehicle". *Bloombergy Business Week*. August 02, 2009. Accessed on Feb 2nd, 2010 <http://www.businessweek.com/autos/autobeat/archives/2009/08/post_4.htm>

[39] Igot, Forsythia. "Face Off: Internal Combustion Engine versus the Hydrogen Fuel Cell". *Montgomery College Student Journal of Science and Mathematics*. Volume 1, September 2002.

Assume 75% of the short-term market is GEVs are PHEVs and only 25% of them are EVs, then the weighted incremental cost of GEVs $11,500. [40]

Figure 12: Price difference between different vehicles

Vehicle	Curb Mass (kg)	Engine Power (kW)	Motor Power (kW)	DOH	Battery Energy (kWh)	P/E Ratio (1/h)	SOC Window	Fuel Cons. (L/100km)	Elec. Cons. (Wh/km)	Retail Cost (US$)
CV	1429	122	---	---	---	---	---	10.3	---	23,392
HEV0	1412	77	36	32%	1.5	32.8	37%	7.4	---	26,658
PHEV2	1412	77	36	32%	1.5	32.8	37%	7.2	7	27,322
PHEV5	1445	78	41	34%	3.5	15.7	39%	7.0	17	28,365
PHEV10	1481	79	42	35%	6.6	8.5	41%	6.5	32	29,697
PHEV20	1531	81	43	35%	11.8	4.9	47%	5.7	58	31,828
PHEV30	1569	82	44	35%	15.9	3.7	53%	5.0	78	33,533
PHEV40	1598	83	45	35%	19.0	3.2	59%	4.5	96	34,839
PHEV50	1618	84	45	35%	21.6	2.8	66%	4.1	108	35,857
PHEV60	1636	84	46	35%	23.6	2.6	73%	3.7	120	36,681

Source: department of energy

The battery lifetime is between 80,000 miles[41] and more than 100,000 miles for other cars such as XS500 Sedan.[42] In real world use, some fleet Toyota RAV4 EVs have exceeded 100,000 miles (160,000 km) with little degradation in their daily range.[43] In this paper, 100,000 miles are used for calculation. The incremental battery cost per miles traveled by EVs is $0.12 ($11,500 /100,000 miles).

Remember the cost per mile traveled by ICVs is only $0.10. If the originally competitive electricity cost per mile of EV $0.03 is added up with the battery cost per mile $0.12, then the total cost per mile of EVs will come to $0.15, which is far more expensive than the ICVs cost per mile. No consumers would choose to spend a lot more money on the same distance to be traveled, assuming all consumers are rational.

APPENDIX C: CHARGER TO EV RATIO ANALYSIS

A level II charger charging at 5 kWh per hour could in theory provide 120 kWh of electricity per day and 43,800 kWh per year to EVs. [44] In a low utilization scenario (10% utilization of EV charging stations),

[40] (1/4) * $14,500+ (¾) * $10,500=$11,500

[41] Moore, T., "Producing a Near-Term EV Battery," EPRl Journal, pp. 6-13, ApriVMay 1994.York, N.Y., 1983.

[42] XS500 Sedan. Accessed on Jan 27, 2010 < http://xprizecars.com/2008/05/miles-electric-vehicles-xs500.php >.

[43] Knipe, TJ et al. "100,000-Mile Evaluation of the Toyota RAV4 EV" *Southern California Edison, Electric Vehicle Technical Center report.* 2003. Accessed on Jan 27, 2010 <http://evchargernews.com>.

[44] 5KWH*24h*365d=43,800KWH

each EV charger output only 4,380KWH electricity, whereas in a high utilization scenario (30% utilization of EV charging stations), there will be 13,140KWH electricity transmitted from a level II charger.[45]

EV could travel 2.9 miles per KWH. According to Roadmap, the average travel range is 30 miles per day. Therefore, total KWH used per day is 30 miles/2.9 miles per KWH=10.3KWH and 3724KWH for a year. As we said in Chapter II that it is assumed that 80% of the EV electricity is from home charging and only 20% is from public/commercial charging stations. So each EV will need 3724*20%=744.8KWH from public/commercial charging stations. Since the total KWHs needed from public/commercial charging stations are fixed, the utilization rate and the EV to charger ratio must be negatively correlated as indicated in Table 6.

APPENDIX D: CHARGING STATION COST ANALYSIS

APPENDIX D.1. FIXED COST OF LEVEL II CHARGING STATIONS

The fixed cost of Public/commercial charging infrastructure is made of the charger cost and the installation cost (both installation and grid-upgrading cost).

Total Fixed Cost= Charger Cost + Installation Cost (Including the grid-upgrading cost)

Level II electric vehicle supply equipment (EVSE) is highly dependent upon location, but currently range up to $5,000 per unit.[46] Firms today are selling Level II public EVSEs for around $2,000 to $3,000. Assume $2,500 per level II chargers.

Level II charger needs installation fees ranging from $500 to $1,500 if an electrical panel upgrade is not needed, and around $2,500 if an upgrade is required.[47] So the total fixed cost is $5,000 per Level II charger.

For Level III chargers, the fixed cost is much higher, which is up to $60,000 with $40,000 charger cost and $20,000 installation cost. This paper only looked at the Level II charger in the very beginning years of EV charging market.

[45] 43,800KWH*$0.10* 10%=4,380KWH

43,800KWH* $0.10*30%=13,140KWH

[46] "Electrification Roadmap: Revolutionizing Transportation and Achieving Energy Security" Electrification Coalition, Washington, DC, November 2009.

[47] "EV Charging in Single Family Residences" Pacific Gas & Electric Company, Electric Vehicle Infrastructure Installation Guide," Chapter 4, March 1999. Accessed on Jan. 27, 2010 <www.pge.com/includes/docs/pdfs/shared/environment/pge/cleanair/ev6pt4.pdf>.

APPENDIX D.2. VARIABLE COST OF LEVEL II CHARGING STATIONS

The total variable cost contains two parts: the electricity cost and the maintenance cost.

Total Variable cost = Electricity Cost + Maintenance Cost

The electricity cost is correlated with the utilization rate. In the high-utilization scenario, the electricity cost is $438 and in the low-utilization scenario, the electricity cost is $1314.

A single standard level II charger charging at 5 kWh per hour could in theory provide 120 kWh of electricity per day or 43,800 kWh per year to EVs.[48] Given that they will not be used continuously, however, the true amount is likely to be considerably lower. The electricity cost is correlated with the utilization rate. In the high-utilization scenario, a 30% utilization rate is used and a 10% utilization rate is used in the low-utilization scenario. Average retail electric prices in the United States vary substantially by region, but the U.S. average is approximately 10 cents per KWH. So if assume a 10% utilization rate, the electricity cost would be $438 per year and if assume a 30% utilization rate, then the electricity cost would be $1,314 per year. [49]

For the maintenance Cost, the current electrician rate is about $29.14 per hour and according to Coulomb that a public/commercial charger needs 0.5 hour per week for maintenance. Therefore, the annual maintenance cost is $174.6. [50]

APPENDIX E: EV CHARGING STATION PROFITABILITY

APPENDIX E.1. ANNUAL REVENUE ANALYSIS

Annual revenue comes from the electricity payment of the EV users. For a level II charger, 100% electricity premium rate is maximal. If we use 100% for our analysis and the electricity costs the suppliers $438 and $1,314 under a market of 10% and 30% utilization rate respectively, then the consumer payment would be $876 and $2,628 respectively.[51]

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[48] 5KWH*24h*365d=43,800KWH

[49] 43,800KWH *30%*10cents= $1,314

43,800KWH*10%*10cents=$438

[50] 0.5hours *12 weeks* $29.14 =$174.6

[51] $438*(1+100%)=$876

$1,314*(1+100%)=$2,628

APPENDIX E.2. ANNUAL CASH INFLOWS

Annual Cash Inflows = Annual Revenue - Annual Variable Cost

The annual cash inflows equal the annual revenue less the annual variable cost. The annual revenue is $876 and $2,628 respectively under a market of 10% and 30% utilization rate respectively. Therefore the annual cash inflows are just $263 per year when the utilization is 10% and $1,139 when the utilization is 30%.

APPENDIX E.3. PAYBACK PERIOD ANALYSIS

Discounted Payback Period = Total Fixed Cost/ NPV of Annual Cash Inflows

Payback period measures the period of time required for the return on an investment to recover the sum of the original investment. It is often widely used in investment areas such as energy efficiency technologies since it is an easy and useful investment analysis tool. In this paper, we use discounted payback period formula to more accurately account for the time value of money.

P=U {[1-(1+r)^(-n)]/r}[52]
P: the total fixed cost per charger
U: cash inflows
r: discount rate (0.05)
n: discounted payback period
Solve for n: n=-ln(1-P*r/U)/ln(1+r)

The payback period is 61 years when the utilization is 10% and 5 years when the utilization is 30%.

APPENDIX E.4. OUTSIDE AID NEEDED FOR ATTRACTIVE PAYBACK PERIOD

If the EV charging market utilization rate is below 30%, then an outside aid is needed to achieve an attractive 5-year payback period. When the utilization rate is 10%, in order to achieve a 5-year payback, the electricity premium rate should be 283%, however, the maximum electricity premium rate is only 100%. Therefore, an extra of $0.16 per KWH is needed and thus $701 is needed per charger per year.[53]

[52] $5,000=$263 {[1-(1+0.05)^(-n)]/0.05} n=61

$5,000=$1,139 {[1-(1+0.05)^(-n)]/0.05} n=5

[53] 5kwh*24h*365d*10%*$0.16=$701

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