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Vehicle To Grid: Plugging In the Electric Vehicle

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Vehicle To Grid:

Plugging In the Electric Vehicle

by Sean Morash

Academic Readers:
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Thesis Submitted in partial fulfillment of the requirements for a major in the program in Science,
Technology, and Society (STS)

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Introduction

The automobile's basic mode of propulsion has long been the gasoline fueled internal combustion engine. Throughout the past 100 years, various social and international political factors have spurred interest in other technologies, but the gasoline powered internal combustion engine has continued to dominate the automobile landscape. However, recent political mandates have put a new emphasis on the sale of the "zero emission vehicle." In California, concerns about greenhouse gas emissions and long term air quality have lead to the zero emission mandate that effectively requires car manufacturers to sell cars that, "Produce zero exhaust emissions of any criteria pollutant (or precursor pollutant) under any and all possible operational modes and conditions."¹ The requirement renewed interest in battery propelled automobiles that meet the zero exhaust mandate. This paper examines a new technology that may help to improve the economics of the battery electric vehicle (EV). We will see that the new technology, usually referred to as Vehicle to Grid, or simply V2G, has benefits far more broad than the simple economics of purchasing a battery vehicle.

The electric vehicle produces zero exhaust from its muffler, but pundits will be quick to say that the charging of the battery through fossil fueled electrical generation simply moves the problem from the individual vehicles to a centralized generation facility. However, numerous studies have concluded that "The environmental advantages of electric transport are such that even if EVs were initially powered by electricity generated solely from today's relatively dirty coal power plants, EVs would still reduce carbon emissions compared to gas-based vehicles."² Remembering the effects that any battery vehicle relying on the electricity grid for recharge will have on the electric grid is important. Each battery vehicle increases demand for electricity as

¹ California. California Code of Regulations. *FINAL REGULATION ORDER Zero Emission Vehicle Regulation.....*

² "How the Smart Grid Enables Utilities to Integrate Electric...."

well as strains the distribution system in crowded neighborhoods. Depending on the charging system in use, a battery vehicle may represent as much as a full household's electricity demand. Our first question then becomes: Can the electric grid handle the increased demand from the battery vehicle that relies on it to recharge?

The second question follows from the first and is more the focus of our study of the new V2G technology. How might the electric vehicle make it easier for the electric grid? Are there certain times of the day that might be best suited for handling the increased demand from the electric vehicle? And finally, what if the electric vehicle functioned as an active member of the electric grid as both a point of demand and of generation should that be necessary? Might the on-board battery of the electric vehicle be the source of electricity storage that has long been the pursuit of power systems engineers?

The approach of using the electric vehicle in conjunction with the electricity grid is a novel one. Traditional analysis examines both sectors independent of one another. The electricity grid seems in constant search of "cleaner" energy generation and of a way to store that generated electricity to meet times of high demand.³ Meanwhile, the automobile sector is constantly looking for a way to make the "cleaner" technologies economically competitive with the traditional internal combustion engine. This paper posits that V2G is a way to bring both of these desires closer to a reality.

The Current State of the Electric Grid

The current electricity generation, transmission, and distribution systems are constructed to provide instantaneous and reliable electricity to the people of the United States. Throughout the United States, when an individual plugs into a socket, they expect instant electricity. The

³ We will address the storage demands of the grid in far greater detail in subsequent chapters.

organizations and individuals responsible for maintaining this service command more than simple net kilowatts of generation; instead they maintain a complex system that delivers consistent voltage across great distances from a given generation source through varying distances of transmission and distribution wires. Explaining how this electrical system evolved delves into the history of household electricity and, while that would provide an interesting study in the adaptation of a technology across a new infrastructure, goes beyond the scope of this paper. Rather, we will at first be concerned with how the organizations in charge meet these power demands, and then, we turn to our primary goal, to examine an interesting development that could combine the transportation and energy systems while also assisting in meeting the demands of the electrical system.

The traditional electricity generation system is mostly composed of large centralized power plants capable of producing enough electricity to power many thousands of homes. Large coal, natural gas, and nuclear power plants represented 89% of our generation in 2010.⁴ While this model excels at providing baseline power needs for the majority of its customers, it fails in at least two crucial areas: flexibility and storage.

Primarily, a generation system composed of a few large power plants is designed to run those few generators at near capacity to meet a majority of the electricity demand. That basic level of demand is called base load. Additional generators are then engaged in order to meet the times of greatest electricity use across a given area. These peak demand times are usually framed around the standard work day with electricity demand ramping up as people wake up in the morning and ramping up again as they get home at night before scaling down as people head to bed. “While these [base load] plants (especially coal) can vary output, their high capital costs,

⁴ "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." *Fuel Used in Electricity Generation Is Projected to Shift over the next 25 Years*. EIA, 30 July 2012. Web. 10 Oct. 2012.

and low variable costs (largely fuel), encourage continuous operation. Furthermore, technical constraints (especially in nuclear plants) restrict rapid change in output needed to follow load.”⁵ As such, most electricity infrastructures employ the benefits of additional “load-cycling” or flexible-with-load plants. These load-cycling plants function to compliment the larger base plants and ensure that the electricity grid functions as it is intended. The utility industry tends to differentiate between day-to-day variation in load (intermediate load) with the extreme highs referred to as peak load, which constitutes the top 8-12% of load annually and only occurs for 80 to 100 hours a year, but this conflict of semantics ignores the essence of peak load as anything beyond the base generation capabilities. For a better understanding of the daily variation in load examine Appendix A, but realize that this graph is an oversimplification of the day to day process and that most sources vary on what they consider “peak load.”

Normally, utilities practice a technique called “spinning reserves” to keep additional power primed for meeting these extra needs. “Spinning reserve is generation capability that can provide power to the grid immediately and reach full capacity within 10 minutes when called upon.”⁶ Situations that necessitate an adjustment in the frequency of the grid are quite common. Increases in demand from an air conditioning compressor kicking on require some reactionary action on the generation side.⁷ Any of the fluctuations from the services like this are often referred to as ancillary services and the rapid nature of these systems is described as follows:

The power system must balance load and generation, or demand and supply while the energy flow is in the form of real and reactive power. The system

⁵ Denholm, P.; Ela, E.; Kirby, B.; and Milligan, M., "The Role of energy storage with renewable electricity generation" (2010). Publications (E). Paper 5.

⁶ W. Kempton, et al., A Test of Vehicle-to-grid (V2G) for Energy Storage and Frequency Regulation in the PJM System [Online]. Available: <http://www.magicconsortium.org>, 2008.

⁷ It should also be noted here that fluctuation in generation can have much the same effect. Electricity generation from wind is notably unpredictable and could require more frequency regulation. I discuss this in more detail in the subsection titled *V2G and Renewable Energy Solutions: A Partnership*.

*frequency must be kept at, or very near to, its nominal frequency – 60Hz in the United States, or 50Hz in many other countries. Any deviation from this requires action by the system operator. If the frequency is too high, that means there is too much power being generated in relation to load. Therefore, the load must be increased or the generation must be reduced to keep the system in balance. If the frequency is too low, then there is too much load in the system and the generation must be increased or the load reduced....These adjustments are called frequency regulation, or simply “regulation.”*⁸

As one might expect, this additional generation capacity that goes unused for many periods of the day is at a large economic cost. Many utilities have adopted time of use pricing programs designed to both curb electricity consumption during times of peak demand and to help offset the economic differences between operation of these peak generators and baseline units. Determining a ratio for the cost difference between meeting peak power needs and base loads is impossible to compute given the nature of the two. That is, there is inherent cost in increasing output because peak plants do not generate at maximum potential continuously. Fuel used to power these more rapid response generation units is generally more expensive than that used by base generation. Still, the largest cost associated with the “load cycling” plants is in the opportunity cost associated with *not* running these plants at maximum potential output.

The second major problem with the electric grid compounds from the first. The necessity for regulation services is rendered by the lack of storage available to the system. Running the load cycling plants at maximum for an amount of time before shutting them off with a reserve electricity supply available to the distributor would be ideal. However, with little storage

^{8 8} W. Kempton, et al., A Test of Vehicle-to-grid (V2G) for Energy Storage and Frequency Regulation in the PJM System [Online]. Available: <http://www.magicconsortium.org>, 2008.

currently available, the cycling plants must continue to react appropriately to the needs of the system. Energy storage has long been a subject of research within the electricity community as it would take advantage of low-cost periods of generation. Added storage would also become a resource for the voltage regulation needs discussed previously.

Advances in electricity storage were made in the 1970's at least in part as a response to elevated and unstable oil prices. Before that time, the only practical method was pumped storage. That method involved moving water up an elevation in times of cheap energy and then using the potential energy of the water with gravity to drive generators in times of high energy demand. With this reminding us today of Sisyphus in Greek mythology pushing a rock up a mountain, our attention has shifted to more advanced, large capacity batteries. Recent advances from Massachusetts Institute of Technology, especially Professor of Materials Chemistry Dr. Don Sadoway in a liquid materials battery, highlight the new wave of thinking industry wide.⁹ Traditional batteries are not cost-effective on any scale that might be useful in balancing load and generation across an electrical system. With that in mind and many of the battery technologies proving to be only marginal breakthroughs, industry executives have begun to get more creative, even pursuing the possibility of the batteries inside Electric Vehicles as a fleet of batteries capable of providing the same benefits as these other modes of energy storage.

Given the extremely large capital investments necessary to make technical advances to the grid, change is slow. However, the changes that are made are intended to be in place for many years. "The infrastructure built today will remain in operation for 30–40 years."¹⁰ The idea of a better grid infrastructure is in the works with utilities coming into the internet age. The

⁹ Sadoway, Don. "Magnesium–Antimony Liquid Metal Battery for Stationary Energy Storage." *Journal of American Chemical Society* (2012): 1895-897. 6 Jan. 2012. Web. 17 Jan. 2013.

¹⁰ Sovacool, Benjamin K., and Richard F. Hirsh. "Beyond Batteries: An Examination of the Benefits and Barriers to Plug-in Hybrid Electric Vehicles (PHEVs) and a Vehicle-to-grid (V2G) Transition." *Energy Policy* 37.3 (2009): 1095-103. Print.

communication advances throughout the distribution network has been coined the “smart grid.” Defining a “smart grid” is multifaceted, but in our context the new infrastructure allows for communication from some head end utility manager to various distributed entities. The current model for smart grid includes communication to and from individual electricity meters in an attempt to maximize generation efficiency--to minimize loss throughout the system. The new “smart grid” standard is that meters communicate with a utility manager every 15 minutes about their electricity usage whereas the previous model limited communication to the monthly manual meter reading. Communication is achieved through various models country-wide, with systems of wireless and wired networks marking the predominant thinking. The advanced meter infrastructure replaces the “meter reader” going from house to house with networks of internet-inspired communication. “By providing intelligent monitoring and communications capabilities to an electricity network, a smart grid gives utilities much greater control over all aspects of operations, from generation and distribution to metering and billing.”¹¹

The smart grid allows for greater flexibility with various in-home devices. That is, under given programs, the utility manager can hedge load on the grid in times of great demand by adjusting thermostats or limiting the use of water heaters. Curbing demand performs the same function as increasing generation. Programs like TXU Energy’s iThermostat promise energy savings of up to 15 percent thanks to decreased energy use while downplaying the benefits that TXU Energy gets from that reduction in electricity consumption. Still, “Customer authorizes TXU Energy to cycle their air conditioner off and on during critical peak electric periods for a minimum of two years” appears in the fine print of the first webpage when signing up.¹² Cycling air conditioners on and off adjusts the load for utilities, while exploiting the fact that shifts of a

¹¹ "How the Smart Grid Enables Utilities to Integrate Electric Vehicles." *How-the-Smart-Grid-Enables-Utilities-to-Integrate-Electric-Vehicles*. SilverSpring Networks, 2012. Web. 08 Jan. 2013

¹² <https://brightenithermostat.com/>

few degrees in home temperature have little effect on personal comfort. Programs like iThermostat prove that the advanced meter infrastructure for communication via the smart grid are viable and effective in helping grid operators maximize efficiency.

Incorporating the Electric Vehicle

With widespread adoption of Electric Vehicles possible in the coming years, utilities and researchers have begun to look at the possibility of embracing the electric vehicle as a grid resource in a similar way that iThermostat has handled thermostats. Electric Vehicles have long served as an alternative to the automobile's traditional fossil fueled internal combustion engine. Vehicles powered by an electric motor go back to the origins of automobiles altogether, but a few recent trends have led to increased interest in the EV. Reliance on foreign oil has resulted in unstable gasoline prices and strained foreign relationships with oil exporting countries. A newfound interest in protecting the environment from emissions associated with the burning of fossil fuels has also initiated interest in EVs. Finally, efficiency issues associated with turning energy into miles driven has remained relatively stable in internal combustion engines over the last 20 years, while electric vehicles promise a drivetrain with less energy loss. However, it is the application of these Electric Vehicles as a distributed resource for the electrical grid that excites both researchers and grid managers alike.

Electric Vehicles would be integrated to the grid through a demand response program that helps to curb the peak demand problem. The distributed resources, the batteries within EVs, would function as a generator or load depending on signals from the utility as part of that greater "Smart Grid" approach of demand response. The following is taken from a California utility's website defining demand response: "Demand response programs are designed to enable customers to contribute to energy load reduction during times of peak demand. Most Pacific Gas

and Electric Company (PG&E) demand response programs also offer financial incentives for load reduction during times of peak demand. Major capital investment projects with low utilization are not in the best interest of California businesses or our environment. Instead, by temporarily reducing demand when resources reach capacity, we have a more fiscally and environmentally responsible solution to help protect the environment and stabilize energy systems.”¹³ While the financial implications are downplayed in their publication, PG&E does an excellent job of explaining why demand response is so important. Through “smart charging” practices, EVs have great potential to function within demand response programs.

The concept of using an EV as a grid resource is very simple. The standard mode of charging a vehicle as you would any other appliance is referred to as grid to vehicle (G2V), while the reverse flow from the battery is called vehicle to grid (V2G).¹⁴ The simplest mode of conceptualizing V2G is imagining a scenario where a house loses power while an EV is plugged in. The EV, containing a large battery, would then serve as a generator for the house and power various household items. Remembering that electricity is the continuous flow of energy, the flow from the EV can be sent outside the home and used as a grid resource in times when it is not needed in the house.

There are different levels of EV integration that require different levels of technological advancement and social compromises. First, utilities may chose to treat the EV like an appliance. This scenario effectively reduces the EV to a flatscreen TV or some other household item. A nearsighted approach, treating the EV as any other appliance, ignores both the larger load associated with EV charging and the battery capacity within the vehicle itself. Another practice could be “smart charging” the vehicles. Contained within “smart charging” are a

¹³ "Pacific Gas & Electric - PG&E." *What Is Demand Response?* N.p., n.d. Web. 14 Jan. 2013.

¹⁴ G2V is sometimes referred to as V1G in an attempt to play off of the “V2G.” Other terms include regulation up/regulation down. And more recently, Grid Integrated Vehicle (GIV) has dominated the lexicon.

number of possibilities. Primarily, utilities might hedge EV charging towards times of cheaper generation or lower demand on the grid through cheaper rates made possible by new communication standards. Another smart charging integration possibility is that the utility directly, or through a 3rd party, cycles the charging on and off while the EV is plugged in. In this scenario, the EV owner forfeits some control of the charging of his/her car. That loss of control would necessitate flexibility from the driver, but such an approach would give the EVs the potential to assist in frequency regulation. Finally, full integration would involve the EV serving as both a load and generator at the utility's discretion. This approach is the classic V2G, with charging and discharging based on utility demand.

To maximize EV smart charging capabilities, utilities with a smart grid need the following capabilities: robust, reliable communication infrastructure from utility head end to EV, and demand response programs principally assigned to EVs. To ensure that a demand response program is fully incorporated, the communications infrastructure needs to work. Advances nation-wide in the communications infrastructure have already been made, but forging demand response programs while ignoring EVs leaves the utility at a disadvantage. "A smart grid is the key to 'smart' EV charging, providing the visibility and control needed to protect components of the distribution network, such as transformers, from being overloaded by EVs and ensure electricity generating capacity is used most efficiently. With a smart grid, utilities can manage when and how EV charging occurs while adhering to customer preferences, collect EV-specific meter data, apply specific rates for EV charging."¹⁵

The American Recovery and Reinvestment Act (ARRA) of 2009 helped to spur the development of demand response programs that are at the core of any EV-grid partnership. The

¹⁵ "How the Smart Grid Enables Utilities to Integrate Electric Vehicles." *How-the-Smart-Grid-Enables-Utilities-to-Integrate-Electric-Vehicles*. SilverSpring Networks, 2012. Web. 08 Jan. 2013.

ARRA specified nearly \$4 billion for “utilities, equipment suppliers, regional transmission organizations, states, and research organizations to jump start smart grid deployment and demonstration on a massive scale.”¹⁶ The Department of energy awarded \$1.997 Billion as part of the Smart Grid Investment Grants to projects in Advanced Metering Infrastructure (AMI). “Advanced metering infrastructure (AMI) is a system of smart meters, two-way communications networks, and data management systems implemented to enable metering and other information exchange between utilities and their customers.”¹⁷ That exchange of information is critically important. The value of the EV as a grid resource is not in the pure volume of electricity at the hands of the grid management, but rather the rapid nature of demand response programs.

What is an Electric Vehicle?

Before we delve further into the Electric Vehicle as a grid resource, it is important to realize what constitutes an “Electric Vehicle.” The Nissan Leaf is an example of an entirely battery powered Electric Vehicle that relies on the grid to recharge its battery and is constrained in range solely by battery state of charge. The Leaf is the leading commercially available Battery Electric Vehicle (BEV). The Toyota Prius, a hybrid internal combustion engine (ICE) with a large onboard battery that recharges while the gasoline fueled ICE is running, represents one type of EV, but is fully self sufficient and does not touch the grid. The Chevy Volt represents another approach altogether. The Volt contains a large onboard battery capable of driving the car for some 35-40 miles before the onboard gasoline generator kicks in. The result is that this Plug-in Hybrid Electric Vehicle (PHEV) is fully capable of making long trips, but can also go short distances fueled entirely by the battery without any gasoline. As a combination

¹⁶ United States. Department of Energy. *Guidebook for ARRA Smart Grid Program Metrics and Benefits* . N.p., 7 Dec. 2009. Web. 16 Jan. 2013.

¹⁷ "Smart Grid Investment Grant Program." <http://www.SmartGrid.gov>.

ICE and plug-in battery, the PHEV seems to be the most viable electric vehicle with V2G, a subject to be explored later. An EV contains a battery that is capable of powering and turning the drivetrain of the car. We are most concerned with vehicles that plug into the grid, PHEVs or BEVs, that may change the grid dynamic.

EVs Affect the Grid

“More important factors than cost per kWh [when participating in ancillary services] are: (a) the capital cost of generation or storage equipment, (b) ability to vary output quickly, and (c) ability to operate in these modes without serious maintenance penalties. Vehicles are better than central generators on all three counts.”¹⁸

As for the benefits that an electric vehicle might bring to grid management, consider the problem of grid storage previously discussed. “Large scale inexpensive storage would improve today’s grid, by increasing reliability and reducing power system costs. As the power system develops more renewable generation, the need for electrical storage is likely to increase...

Automobiles contain distributed energy storage; today, that storage is in the form of liquid fuel but we, and much of the industry, anticipate a shift to electricity.”¹⁹ That shift to electricity makes available large scale storage in the form of the battery contained within the electric vehicle.

“The vehicle-to-grid (V2G) concept links two large and independent systems – electrical power generation and light-duty vehicle transportation – for the first time.”²⁰ What excites V2G advocates is the application of the energy from the great number of light duty vehicles in

¹⁸ Kempton, Willett, and Jasna Tomic. "Using Fleets of Electric-Drive Vehicles for Grid Support."

¹⁹ Kempton, Willett, et al. *A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System*.

²⁰ Leo, Mark, Kripal Kavi, Hanns Anders, and Brian Moss. *Ancillary Service Revenue Opportunities from Electric Vehicles via Demand Response*. Study. 2011

America. Consider that: “Placing a 15 kW battery in each of the existing 191 million automobiles in the United States would create 2865 GW of equivalent electricity capacity if all the vehicles supplied power simultaneously to the grid—an unlikely occurrence. However that amount was more than twice the total nameplate capacity of all American electric generators in 2006.”²¹ For some frame of reference, the Chevy Volt houses a 111 kW battery.²² Further excitement stems from studies that have shown that cars are used for their driving purpose just 4% of the day. The other 96% is spent parked.²³ “V2G may provide a means by which to utilize the spare power capacity available in each parked vehicle.”²⁴ However, most studies assume that within any aggregation of EVs, fewer than 96% can be guaranteed to be available for V2G functions.²⁵ Some models assume 80% of the total EV fleet is plugged in at any given time. The sheer size of the fleet of cars in America and that they might be able to perform some function while idle, means big things for whatever that function may be.

“By drawing on and supplying power to the power grid, electric vehicles could displace the use of petroleum and mitigate pollution and security issues related to oil extraction, importation, and combustion. It could also improve the economics and technical performance of the electric utility industry and generate revenue to owners of plug-in hybrid electric vehicles (PHEVs).” The economics of that revenue to owners is yet unclear, but the value to the electric utility industry is in ancillary services. “Participation in ancillary service markets appears to be an appropriate use of electric vehicles.”²⁶ Should Electric Vehicles participate in any grid-related program that exploits their dispersed batteries, they would still need to maintain their function as

²¹ Sovacool, Benjamin K., and Richard F. Hirsh. "Beyond Batteries: An Examination of the Benefits and Barriers to Plug-in Hybrid Electric Vehicles (PHEVs) and a Vehicle-to-grid (V2G) Transition."

²² "GM-VOLT : Chevy Volt Electric Car Site." <http://gm-volt.com/full-specifications/>

²³ Kempton, W., and J. Tomic. "Vehicle-to-grid Power Implementation..."

²⁴ Turton, H., and F. Moura. "Vehicle-to-grid Systems for Sustainable Development: An Integrated Energy Analysis." *Technological Forecasting and Social Change* 75.8 (2008): 1091-108. Print.

²⁵ Papavailliou, Anthony; et al. "Electric Power and Distribution for Electric Vehicle Operations"

²⁶ Kempton, Willett, and Victor Udo. "A Test of Vehicle-to-Grid (V2G) for Energy Storage...."

a transportation device. Today's commercially available BEVs house batteries of about 80 kW in size.²⁷ Contrast that with the 1000s of MW associated with the standard fossil fuel generation plant. Swinging the EV charge level from full to empty could provide value to utilities, but would compromise the anytime freedom of being a vehicle owner. We will touch on this again later as it relates to the plug-in hybrid vehicle (PHEV), but for now, let's examine the ancillary services market.

“Ancillary services account for 5-10% of electricity cost, or \$12 billion per year in the US; 80% of these payments are for regulation and spinning reserve.”²⁸ Ancillary services are broken down into a few other categories that go beyond the scope of this paper, but the EV would be ideal for regulation, while its potential for any type of spinning reserve is marginal. The EV niche is in its rapid response nature and not in its ability to be a mini power plant. The EV will be best used in assisting in the smallest of voltage and frequency demands and in utility diction that is regulation.

Other estimates about the value of ancillary services peg the number at \$20 billion annually.²⁹ Either way, currently the market for ancillary services is dominated by robust generators that are capable of ramping production either up or down quickly. Many of the large generation facilities do similar ramping, but ancillary services are defined by their rapid nature. Estimates from a report by BetterPlace, a corporate leader in EV technologies, and the University of Michigan indicate that the revenue opportunities for demand response for EV based programs (V2G) increases with increased EV penetration. Here we see another classic circular motivation;

²⁷ <http://www.nissanusa.com/leaf-electric-car/battery>

²⁸ Kempton, Willett, and Victor Udo. “A Test of Vehicle-to-Grid (V2G) for Energy Storage...”

²⁹ Leo, Mark, Kripal Kavi, Hanns Anders, and Brian Moss. *Ancillary Service Revenue Opportunities from Electric Vehicles via Demand Response*. Study. 2011

one where EV sales and adoption might benefit from initial EV sales and adoption.³⁰ Still, exactly what that revenue opportunity means to EV owners ready to participate in the programs is yet undetermined. Further, there are concerns that with EVs entering the ancillary services market, the market will become over-saturated and devalue the shifts in electricity.

Whether it is through participation in ancillary services or because of the increase in demand from additional EV load on the grid, the EV and grid need to be aware of each other. Simply put, “EVs will fundamentally change how electric utilities do business.”³¹

We might argue that utilities are already changing how they do business. We’ve seen shifts away from the traditional paradigm of a few fossil fueled power plants providing all of the base generation. Thus far, solar panels represent the dominant form of “distributed generation,” the term most commonly associated with the territory wide dispersion of generation facilities. Consider that Public Service Electric and Gas (PSE&G) will soon need to keep track of the electricity output variation of approximately 200,000 individual solar units, many of them on utility telephone poles, as part of their Solar 4 All initiative.³² San Diego Gas and Electric had 20 power generators a decade ago. Today it has 2,000 and many of them are outside the utility's direct control.³³ The increased pressure on utilities to adapt to the more widespread solar and wind generation likely spells good fortune for the V2G outlook. “The smaller scale of generation from each vehicle may lead to difficulties in compatibility with existing systems based around large generation units.”³⁴ However, with utilities growing accustomed to dealing

³⁰ *ibid*

³¹ "How the Smart Grid Enables Utilities to Integrate Electric Vehicles." *How-the-Smart-Grid-Enables-Utilities-to-Integrate-Electric-Vehicles*. SilverSpring Networks, 2012. Web. 08 Jan. 2013.

³² Navarro, Mireya. "Solar Panels Rise Pole by Pole, Followed by Gasps of 'Eyesore'." *Nytimes.com*.

³³ Berst, Jesse. "Why Distributed Energy Is Your next Big Headache (and What EPRI Says to Do)." *Smartgridnews.com*.

³⁴ **Turton, H., and F. Moura. "Vehicle-to-grid Systems for Sustainable Development: An Integrated Energy Analysis." *Technological Forecasting and Social Change* 75.8 (2008): 1091-108. Print.**

with smaller generation sources and understanding the benefits that these sources might bring, the even smaller scale of EV integration seems the next logical step.

The effect of a single Electric Vehicle on a household might prove useful, but means very little in terms of a utility-wide scale.³⁵ The V2G idea is entirely novel in that it requires widespread adoption of EVs because “the battery of a vehicle is a very small resource whose impact on the grid is negligible. The battery storage of an individual [EV] is too small to impact the grid in any meaningful manner.”³⁶ The concept of V2G warrants attention when you aggregate the effects of many EVs together.

Exactly how that coupling may occur is yet undecided, as different models exist. One involves utility management of a fleet of EVs through some subsidiary program. In this scenario, “It is assumed the utility can perform load scheduling during off-peak times to shift EV charging in real time to balance energy supply and demand.” This is the classic grid integrated vehicle concept with a codependence between vehicle and grid. Full vehicle integration is not predicated on utility ownership of the charging equipment as some authors have suggested.³⁷ Rather, it is entirely plausible, and likely the most effective means, that the owner of the EV also own the charging equipment and opt into the subsidiary programs at their discretion. A blurring of the utility’s line with the homeowner occurs when the utility provides the EV charging equipment. More problems arise when the charging equipment is paid for by all of the customers of a utility, but only used by those with EVs. Classically, utilities have built infrastructure improvements into basic surcharges across customer wide billing, but with the

³⁵ Based on a 24 kWh battery, like the one housed in the Leaf, and the average daily American electricity use of 31 kWh, the potential for the battery functioning as a household generator is obvious.

³⁶ Guille, Christophe, and George Gross. "A Conceptual Framework for the Vehicle-to-grid (V2G) Implementation."

³⁷ SilverSpring Networks. *The Dollars – and Sense – of EV Smart Charging: Thinking Through the Options for Utility Integration of Electric Vehicles.*

specificity of EV ownership and financial opportunities, that is yet unresolved. We will delve into the additional customer wide problems later on. As it stands, Level 2 EV charging stations must be installed professionally and could be seen by some as an investment in property value.³⁸ It is for these reasons that the bill for the EV charging stations should remain with the EV owner at least while the electric vehicle represents a small market share.

Another model for mass vehicle integration includes a third party aggregating the power potential of the EVs and selling those potential shifts in generation/load to the grid operator in large blocks. This model involves a third party and similar problems of EV charging ownership could arise. Further, the market and profitability of this type of service is untested. However, the buying and selling of energy is a concept integral to utility operation. Utilities are constantly buying electricity from each other and even from customer-owned rooftop solar. Treating an aggregation of EVs as an energy source similar to that of any other energy generation makes logical sense to utilities while leaving the problems of actually procuring and guaranteeing the energy shifts at the hands of the third party.

Finally, utilities may chose to not couple the EVs. The approach treats EVs as an appliance, similar to any other appliance that might be plugged into the grid, such as a large refrigerator or air conditioning unit. “If utilities treat EVs like an appliance, they lose the ability to do smart charging and are likely to incur costs for adding generation, transmission and distribution capacity and procuring additional energy at peak times to service EV charging.”³⁹ They also lose out on any V2G capabilities and minimize their understanding of the total effect that EVs have on their system. This model seems unlikely as the utility would likely at least

³⁸ EV supply equipment (chargers) are generally broken down into Level 1 and Level 2. Level 1 is standard charging in a basic household outlet. Level 2 requires professional electrician installation and promises to charge the EV in about half the time.

³⁹ SilverSpring Networks. “*The Dollars – and Sense – of EV Smart Charging...*”

attempt to curb charging to more appropriate times of low demand. Exactly how that is done requires some initiative from the utility, either through an education program or implementing dynamic and time specific pricing plans.

Metering

The value of V2G services is not in the specific net metering of the battery in the same way it is with a house outfitted with solar. In that model, the utility buys electricity from the solar panel at times when it is producing more power than the house is using and then sells it back overnight, or in times of greater need. Essentially, “The customer has to pay only for the net amount of electricity used from the utility over-and-above the amount of electricity generated by their solar system.”⁴⁰ V2G is exciting because of its quick response to peak issues and not because of its sheer electricity power. It is for that reason that net metering of the EV may not be the ideal. Still, the exact economics of the situation are more complex and delve into proprietary utility information. Net metering of V2G may be the next best alternative in the short term.

Basic in-home charging of an EV at a cheaper rate is something that could make the financials of purchasing an EV more appealing. With smart charging and even simply overnight charging, the prospect of a discounted rate for EV charging makes sense from a utility perspective. However, accounting for different loads through a single meter on the side of the house is nearly impossible. How could the utility differentiate between the air conditioner turning on and the EV charging through that single meter? The answer lies in multiple meters. Ben Rankin, Senior Consultant at Enernex Smart Grid Labs, explains, “You want portability for [the EV] to be useful. The problem is the metering portion of it. Wherever that person is needs

⁴⁰ *Net Energy Metering In California*. State of California, California Energy Commission & California Public Utilities Commission

to be a net metering capability. You could theoretically put it in the car. From a technical perspective, you can absolutely put a meter in a car, but a utility doesn't trust that."

The utility is more comfortable with an additional meter along the side of the house that accounts for the EV within its own circuit. Dr. Aaron Snyder, Director of Enernex Smart Grid Labs, states, "From a utility perspective, that's the easiest thing to do because the meter is something they're used to dealing with, they already have the software that handles the meter and a reading. They can modify the billing simply." Whether the new bill arrives in a separate envelope or contained within an additional portion of the standard bill is a minute inconvenience and will likely be handled differently according to utility practices.

Billing and metering for simply charging EVs is still an unresolved issue. EV owners want full capability to travel and fuel up (charge) without much inconvenience to their schedule as compared with the ICE. The standard gas-station paradigm for the petroleum fueled car has yet to be adopted by utilities. According to Dr. Aaron Snyder, "The one model that would be easiest for all of us who use cars to charge, the gas station and Visa model, they have decided not to adopt." Dr. Snyder goes on, "They can't explain it. That 2.5% that credit card companies charge might be all the profit margin there is." While the exact profit margin for EV charging is unclear, the basic gas station model does not seem to be an option.

A model for keeping track of EV charging practices is through registering that vehicle and maintaining an account with a given utility for billing purposes. However, problems arise when you consider charging in different utility jurisdictions without registering in those districts. Leaving the meter on the car would require storage memory to keep tabs on the different utilities that are due money. In a way, the meter would be doing the job of the credit card in bookkeeping. Further, it remains unclear how the billing would work across utilities. A

possible solution, and likely the best solution, is that the charging station keep records of use in much the same way a telephone company keeps track of minutes no matter where the phone is used. Leave the haggling, rate differentiation, and accounting up to that third party if the gas station model doesn't work.

Driver Compromise

If EVs, and to a greater extent V2G, are going to become a reality, both driver and utility need to understand the growing pains. “Central to the viability of V2G are the needs and desired functions of the two human parties—the driver and the grid operator. The driver needs enough stored energy on-board (electric charge or fuel) for driving needs. The grid operator needs power generation to be turned on and off at precise times.”⁴¹

The driver needs enough energy stored in the vehicle to make whatever trip is necessary at whatever time they want. The viability of V2G is dependent on maintaining ease of use for vehicle operators. The vision for V2G is that the vehicle owner simply plugs in their car whenever it is not being driven and the EV is actively charging and interacting with the grid. Most ideal would be that the vehicle owner does little to participate in the programs other than plugging in the car when not in use. Still, a given driver needs the flexibility and freedom of driving whenever and wherever--the norm since the automobile's inception. Interrupting the travel plans of a driver because of a lack of charge in a vehicle facilitated by a grid operator cannot happen.

“Flexibility is possible with plug-in hybrids as long as the fuel storage is sufficient to meet driver-specified minimum range—the battery could swing from full to empty, as the plug-

⁴¹ Kempton, W., and J. Tomic. "Vehicle-to-grid Power Implementation..."

in hybrid can still operate on fuel only.”⁴² “To win the cooperation [and acceptance] of people, PHEVs truly need to be designed so lifestyles and behaviors are not altered. The hardware must be designed so vehicle owners do not need to expend effort to figure out optimal times to recharge their vehicles or sell power back to the grid.”⁴³

It seems that the PHEV eliminates any issues in generating an algorithm for what makes an appropriate state of battery charge for each of the individuals in a society. What may be appropriate for one person, may not be for another. Across utility wide adoption of EVs, configuring individual state of charge algorithms seems a waste, but plug-in hybrids that can function without any battery range eliminate that need. Reducing the PHEV’s battery to a grid resource might defeat the purpose of a battery-only driving range if you forget that the goal of these programs is still to charge the EV, just more strategically. The PHEV would be an ideal technology for V2G because of its ability to cater to both the needs of the grid operator and remain functional for the driver.

The frequent switching of the state of charge may cause a decrease in battery storage capacity over time, or battery degradation. Battery degradation is critically important for utilities, car manufacturers and drivers alike. Should V2G prove to harm the long-term capacity of batteries, who is charged with the bill of replacing the battery seems an issue. As utilities are taking advantage of the car battery and seem responsible for the constant shift in battery charge, they might chose to offer programs of battery replacement. The value of the V2G service may be such that replacing batteries makes little economic sense for the utility. Initial language in the ISO/RTO Council plug-in EV (PEV) report suggests that utilities are not interested in paying for

⁴² Kempton, W., and J. Tomic. "Vehicle-to-grid Power Implementation..."

⁴³ Sovacool, Benjamin K., and Richard F. Hirsh. "Beyond Batteries..."

EV batteries.⁴⁴ “PEV owners will need to balance the desire for payments associated with participating in ISO/RTO-related products against concerns about battery life impacts.”⁴⁵ By having customers opt in to EV programs, utilities may skirt the battery degradation issue by leaving the EV owner liable.

Still, research into the battery degradation associated with V2G is yet unclear. “In a study presenting the results of a V2G test for frequency regulation, the investigators noticed that, at the end of a one week test, the capacity of the tested battery had increased.”⁴⁶ “Statistical analyses show that using a PHEV battery for V2G energy incurs approximately half the capacity loss per unit energy processed compared to that associated with more rapid cycling encountered while driving.”⁴⁷ That is, the battery degradation associated with discharging for V2G purposes are about half of what they would be for a similar discharge incurred from driving. Still, it is not as if V2G is replacing driving functions. V2G is adding stress to the battery that otherwise would be parked.

It is generally regarded that, as batteries go through varying states of charge and recharge, battery life is compromised over the duration of the process. However, “Much of the V2G literature asserts that V2G cycles are shallow and inconsequential.”⁴⁸ The recent thought process is that with V2G participating in ancillary services, the depth of discharge of the battery is relatively small and therefore the effect on the life cycles of the battery is small.⁴⁹ Davion Hill suggests that if battery degradation issues are as minimal as some studies have portrayed, then

⁴⁴ The ISO/RTO Council is comprised of 10 Regional Transmission Organizations (RTOs) and Independent System Operators (ISOs). ISOs and RTOs are in charge of maintaining the transmission systems that provide electricity to two thirds of the population of the United States and half of Canada. They provide for demand response development, bulk transmission reliability, including regulation services.

⁴⁵ “Assessment of Plug-in Electric Vehicle Integration with ISO/RTO Systems.” *Isorto.org*.

⁴⁶ Guille, Christophe, and George Gross. “A Conceptual Framework for the Vehicle-to-grid (V2G) Implementation.”

⁴⁷ Peterson, Scott, Jay Apt, and Jay Whitacre. “Lithium-Ion Battery Cell Degradation Resulting from Realistic Vehicle and Vehicle-to-Grid Utilization.”

⁴⁸ Hill, Davion. “Fleet Operator Risks for Using Fleets for V2G Regulation.”

⁴⁹ Hill, Davion. “Fleet Operator Risks for Using Fleets for V2G Regulation.”

the V2G model for adjusting the economics of the PHEV is “attractive.”⁵⁰ The fact is that further research needs to be done on the effects of V2G on car batteries. I’m optimistic about that area of research, especially when one considers only a few V2G-enabled cars have been the subject of studies.

V2G and Renewable Energy Solutions: A partnership

“The most important role for V2G may ultimately be in emerging power markets to support renewable energy.”⁵¹

“By managing EV charging, utilities are able to reduce peak demand impacts, optimize intermittent renewable generation such as wind, and coordinate that generation with EV charging.”⁵² As part of a larger strategy, it appears that EVs and renewable energy technology will benefit from one another’s technical progress. First, let’s understand some of the issues associated with wind and solar integration. “The remote or challenging location (i.e. offshore) and especially the intermittent character of the wind resources present formidable barriers to utilization on the scale required by a modern industrial economy.”⁵³ That is, one of the larger impediments to wind and solar integration on a larger scale is the inflexibility in reacting to demand. Wind energy tends to peak production overnight in the hours before and after 4:30 a.m. and valleys at around 5:30 p.m. Meanwhile, solar peaks around 1:00 p.m.⁵⁴ It is important to realize that while these peaks and valleys are at least somewhat predictable there is little that can

⁵⁰ Hill, Davion. "Fleet Operator Risks for Using Fleets for V2G Regulation."

⁵¹ Kempton, W., and J. Tomic. "Vehicle-to-grid Power Implementation..."

⁵² **"How the Smart Grid Enables Utilities to Integrate Electric Vehicles." *How-the-Smart-Grid-Enables-Utilities-to-Integrate-Electric-Vehicles*. SilverSpring Networks, 2012. Web. 08 Jan. 2013.**

⁵³ Cavallo, Alfred. "Controllable and Affordable Utility-scale Electricity from Intermittent Wind Resources and Compressed Air Energy Storage (CAES)."

⁵⁴ Papavailliou, Anthony; et al. "Electric Power and Distribution for Electric Vehicle Operations"

be done to shift them. The nature of these two resources is that they take advantage of the natural shifts in solar and wind patterns.

The standard model for the peak electricity demand predicts highest demand between 4 and 8 p.m. That peaking is shifted away from the optimal hours for solar and wind generation, a problem that has led to frustrations from grid management in integrating renewable resources. Denmark likely represents the maximum wind integration strategy capable today: “Denmark, with great effort and good links to the European grid, obtains a yearly average of nearly 20% of its electrical power from wind.”⁵⁵ The frustrations stem from the continued lack of storage within the power grid. “A simple strategy to integrate PV [Photovoltaic solar panels] into the grid is to meet peak load by storing from the solar peak to the load peak.” That source of storage has yet to come to fruition. A sufficient source of storage that could ensure all wind and solar energy is used optimally would maximize renewable potential.⁵⁶ With the proposition of using the EV as a mobile grid resource, or battery for excess energy, we see here that the EV and renewables may find themselves in a good partnership going forward.

To cope with storage issues, a common practice in wind farms involves wind curtailment. Within periods of high wind overnight, some wind farms find that their generation capabilities overload the grid and they are forced to reduce production by strategically impairing the aerodynamics of the wind turbines or shutting some down altogether.⁵⁷ Exact records on the total wind power curtailed and the logic behind that curtailment are not kept, but in ERCOT (Electric Reliability Council of Texas) in 2009, the average annual wind curtailment was around

⁵⁵ Cavallo, Alfred. "Controllable and Affordable Utility-scale Electricity from Intermittent Wind Resources and Compressed Air Energy Storage (CAES)."

⁵⁶ Wind and Solar production that lead to the curbing of other generators and reducing their efficiency is not ideal when we consider the utility as a whole.

⁵⁷ Rose, Stephen and Jay Apt, "The Cost of Curtailing Wind Turbines for Frequency Regulation and Ramp-Rate Limitation." Carnegie Mellon University

16%.⁵⁸ Meanwhile, in the Midwest ISO, the regional transmission organization serving all or parts of 11 states, it is estimated that about 1% of total wind generation was curtailed in 2009. These figures are likely to increase with increased penetration of wind generation.⁵⁹ Grid managers look to avoid curtailing wind generation because “the revenue lost due to curtailment may be greater than the cost of procuring the same primary frequency regulation from traditional sources such as gas turbines or hydroelectric power plants, or using an energy storage technology such as a battery to store a reserve of energy.”⁶⁰ Realizing that wind curtailment is still a common occurrence despite its cost helps to underscore the need for more viable frequency regulation.

Wind power is curtailed both because of pure storage issues and frequency regulation. “The rapid variability of wind power on short time scales can cause the grid frequency to deviate significantly from its nominal value.”⁶¹ With increased penetration of renewables, the demand for ancillary services rises.⁶² V2G can help to smooth these fluctuations in output from the wind farms. Without delving into the vehicle manufacturer’s optimized charging cycles that typically vary according to level of charge, the fluctuation in voltage along the power lines could theoretically be handled with an integrated EV approach. Should EVs prove capable of handling the variability of wind farms, wind turbine curtailment would become a much smaller issue.

“This analysis suggests that V2G could play a role as storage for intermittent renewables, even when renewables become half (or more) of total electrical generation.”⁶³ By providing both the frequency regulation and the demand of power overnight, EVs promise to have a large effect

⁵⁸ Rogers, J. and S. Fink, and K. Porter, "Examples of wind energy curtailment practices,"

⁵⁹ *ibid.*

⁶⁰ Rose, Stephen and Jay Apt, "The Cost of Curtailing Wind Turbines for Frequency Regulation and Ramp-Rate Limitation."

⁶¹ *ibid.*

⁶² Leo, Mark, Kripal Kavi, Hanns Anders, and Brian Moss. *Ancillary Service Revenue Opportunities from Electric Vehicles via Demand Response.*

⁶³ Kempton, W., and J. Tomic. "Vehicle-to-grid Power Implementation..."

on wind power. Wind generation development could increase when its problem of assisting in the peak demand times of the day is resolved. EVs can provide the necessary demand for wind generation to become a more economically viable option. With increasing pressure to shift away from fossil fueled generation, an increased demand for overnight wind generation will be welcome for grid operators. Wind generation at the expense of cheaper base generation is not ideal. However, if EVs provide the necessary uptick in overnight demand to make wind generation viable without retracting from base generation, the new generation makes sense.

Moreover, charging EVs solely by electricity from renewable generation would represent the ultimate in environmentally friendly, zero-emission transportation. That possibility will require the partnership of both solar and wind because of the intermittency of the two and convenience concerns of EV owners. A Cal Berkeley study indicated that, “An investment in 60 MW of wind power and 60 MW of solar power can satisfy the energy needs of 580,000 vehicles.”⁶⁴ However, that study’s assumptions are questionable and their outlook is admittedly optimistic. The point remains that solar and wind alone could provide the necessary electricity to fuel a large number of EVs.

Authors Jasna Tomic and Willett Kempton cite the United State’s network of fossil fuel generation as contributing to the previous non-necessity of storage in the energy grid: “Storage has been a side benefit of our habit of carrying energy as molecules rather than electrons. We believe that those days are numbered. While future vehicles will always require storage to perform their function, future electric generation will no longer come with free storage.”⁶⁵ In becoming more widespread together, EVs and renewables appear likely to benefit from one another by providing complementary services. EVs will function as the cheap source of storage

⁶⁴ Papavailliou, Anthony; et al. “Electric Power and Distribution for Electric Vehicle Operations”

⁶⁵ Kempton, W., and J. Tomic. “Vehicle-to-grid Power Implementation...”

that was previously held in the stacks of soon-to-be-burned coal or in the gas tanks of the modern automobile.

EVs and renewables should be planned together. “The prospect of V2G is to carry us along both these paths together, more quickly and economically than has been thought possible when planning either system in isolation.”⁶⁶ In this sense, V2G has been applied to the electrification of cars altogether. Meanwhile, the mutual benefits that EVs and renewables would gain from their awareness of the other cannot be ignored. Aside from the obvious environmental publicity that both are sure to imply, each may well prove part of the solution for wider integration of the other.

The Transformer Problem

“It is not adequate to have only sufficient generation capacity during off-peak hours to assure a system’s ability to absorb EV loads without adverse effects. The constraints at the distribution level must be studied properly”⁶⁷

Approximately 160 million vehicles in the United States could be powered solely from unused generation capacity.⁶⁸ That figure has many problems, but does a good job in describing the wealth of generation capacity that goes unused. One of the problems is that the bottleneck for accommodating that extra generation lies at least in part in the distribution system constraints. In fleshing out the widespread adoption of EVs, it becomes obvious among scientists that a few EVs in a territory or a neighborhood do not pose a serious distribution

⁶⁶ Kempton, W., and J. Tomic. "Vehicle-to-grid Power Implementation..."

⁶⁷ Rahman, S., and G. B. Shrestha. "An Investigation into the Impact of Electric Vehicles on the Electric Utility Distribution System."

⁶⁸ "How the Smart Grid Enables Utilities to Integrate Electric Vehicles." *How-the-Smart-Grid-Enables-Utilities-to-Integrate-Electric-Vehicles*. SilverSpring Networks, 2012. Web. 08 Jan. 2013.

infrastructure threat from a technical perspective. A study out of Virginia Tech suggested that only when EV penetration reaches 20% do serious distribution concerns arise.⁶⁹ When multiple EVs are linked to a single transformer, then the life of that transformer might be diminished. Dr. Aaron Snyder explains why curbing EV charging to overnight may prove problematic for multi-home transformers:

“They [utilities] fill in the valley [of the electricity demand curve], which is good because then they are not wasting a lot of electricity, but it may limit the amount of time the transformer can cool. The transformer cooling period went from 10PM-7 AM [9 hours]; now it’s only cooling 7AM-4PM [9 hours] but it’s hardly cooling at that because the load will vary throughout the day. It creates a little more stress on the transformer. Now, they have generally overbuilt (allowed leeway). Until all 4 homes on that transformer have an EV, it’s generally not a problem.”

The transformer is representative of the distribution system as a whole. The electrical system is built with safeguards--most of which are automated sensors--to prevent surges that might lead to electrical fires, explosions or incidences where live wires might be left in the open. The concern is that the increased demand from widespread EV adoption will trip many of these safeguards and render the electricity system outdated. From generation through the substation, transformer and even outlets within the house, the voltage and current of our electricity is highly specified to 120V of alternating current (AC). That specificity is necessary for electronics to charge and function properly. A concern is that added demand from widespread EV adoption might be interpreted as a larger problem from these safeguards. “Higher system loading could

⁶⁹ Rahman, S., and G. B. Shrestha. "An Investigation into the Impact of Electric Vehicles on the Electric Utility Distribution System."

impact the overall system reliability when the entire infrastructure is used near its maximum capability for long periods.”⁷⁰ The increased load of the EV could look like a downed wire and trip something within the substation that could leave entire neighborhoods without electricity. These worries regarding the periodic loss of electricity are predicated on our reliance on electricity in America, but again, the question of why the electrical grid is held to such a high standard is outside the scope of this paper. The actual distribution upgrades made necessary by the EV is unclear. However, the issue of payment for any update to the necessary equipment and distribution network to potentially facilitate V2G is real.

When purchasing an EV, are you then responsible for the possible infrastructure damages that the EV might cause or the infrastructure upgrades that it could necessitate? That proposition doesn't seem fair, but neither does the idea that those infrastructural upgrades are billed into the larger management and operational costs and paid for by every member of a given utility. Further, where does the EV owner draw the line? Currently, when someone purchases an EV and wants Level 2, 240V charging in their home for whatever reason, it is at the expense of the homeowner. But, what if that charging directly affects the larger distribution network? It makes sense that the responsibility for homeowner electrical upgrades ends within home. These social implications of widespread EV adoption seem more the product of utility concerns with the public reception of what could be referred to as an “EV surcharge” utility wide on the bill.⁷¹ Surely, some people within a given territory will be unhappy that they are paying for others to drive their EV, but that line of thinking belies the actual small effect on the monthly bill.

⁷⁰ Kintner-Meyer, M.; Schneider, K.; Pratt, R. *Impacts assessment of plug-in hybrid vehicles on electric utilities and regional U.S. power grids, Part 1: Technical analysis.*

⁷¹ Assuming operation and management costs are so affected as to prompt an increase in rates. This proposition is yet undetermined.

Distribution safeguards are another impediment to Vehicle to Grid reverse flow of energy. Those same safeguards that protected against surges in voltage are also prepared only for one way, traditional flow of energy. Should the V2G idea come to fruition, some of that equipment would need to be updated. This would be ingested into operation and management costs because any V2G program would be with the cooperation of the utility. Still, the utility would presumably factor these expenses into their decision to pursue a V2G program. Would the potential gains in ancillary services justify renovating of systems?

EV projections

We must remember that the electric vehicle is still somewhat off from realizing its potential as a replacement for the internal combustion engine. The economics of the two still markedly favor the internal combustion engine. However, with new legislation pushing American car manufacturers towards progressive higher miles-per-gallon goals, and regulations mandating zero emission vehicles, the electric vehicle is likely to soon be a more common sight. In his 2011 State of the Union address, President Obama called for putting one million electric vehicles on the road by 2015. According to a report from the ISO/RTO Council assessing plug-in hybrid integration with their systems, "It is feasible that one million PHEVs might be deployed in the U.S. by 2017."⁷² Still, Obama's progressive goal would require more rapid development than what we have seen to this point. An Obama tax credit of \$7,500 to the first 200,000 families who chose to purchase PHEVs was intended to spur growth in the field. However, in 2012 only about 50,000 PHEVs were sold.⁷³ Many projection models show some sort of exponential growth modeled after the sales of the Prius ten years prior. Further, sales are currently and will

⁷² "Assessment of Plug-in Electric Vehicle Integration with ISO/RTO Systems." *Isorto.org*.

⁷³ Voelcker, John. "Plug-In Electric Car Sales Triple In 2012 As Buyers, Models Increase."

likely remain unevenly distributed across the US. “Assuming that historical Prius adoption trends are a good proxy for estimating regional PEV penetration, the project team estimates that PEVs will be distributed more densely on the West Coast and Northeast than in the Midwest and Southeast, and that metropolitan areas will have higher concentrations than rural areas.”⁷⁴

Projections for developing technologies are rarely reliable, but provide some insight. Should we expect rapid growth and an explosion of EVs? According to the projections, EVs will take their market share slowly going forward. According to a Pike Research study, the growth rate of PHEVs is expected to be 30% compounded annually. That rate results in a nationwide sales total of 400,073 vehicles in 2020 when 2.1% of total vehicle sales are expected to be PHEVs. That number varies by geography: 4.5% in California, 3.5% in New York, 1.9% in Florida, and 1.4% in Texas.⁷⁵ Boston Consulting Group projects in 2020 that 26% of the new vehicles sold will be hybrid cars similar to the Prius. Another 3% will be PHEV and 1.9% will be Pure BEV.⁷⁶ Southern California Edison, a large utility serving much of the Los Angeles area, has projected a mid-case of 5% penetration, or 0.5 million PHEVs and BEVs in its service territory by 2020.⁷⁷ The Energy Information Agency, a branch of the United States Department of Energy, releases an Annual Energy Outlook that appears to be a bit more pessimistic. By 2020, they project that just .6% of the light-duty vehicles will be PHEVs. Their projection for Prius-style electrically powered cars is a bit less glum: 3.3% of cars on the road. The EIA projections continue out to 2040, where PHEVs represent 2.8% and hybrid cars are 7.7% of the market.⁷⁸ It’s important to remember that these EIA figures do not represent the number of cars

⁷⁴ "Assessment of Plug-in Electric Vehicle Integration with ISO/RTO Systems." *Isorto.org*.

⁷⁵ "Pike Research Electric Vehicle Geographic Forecasts Comments." *Pikeresearch.com*.

⁷⁶ Cunningham, John Shamus. "An Analysis of Battery Electric Vehicle Production Projections."

⁷⁷ "MIT Energy Initiative: The Future of the Electric Grid."

⁷⁸ United States. Energy Information Agency. Department of Energy. *AEO2013 EARLY RELEASE OVERVIEW*. N.p., 5 Dec. 2012. Web. 11 Jan. 2013.

sold, but rather the number of cars on the road. Cars that were purchased earlier are phased out and new sales trends become more evident as the years progress.

The projections combined with the earlier reports that the distribution system, as currently assembled, can handle up to 20% adoption rates suggest that grid management needs to do little over the course of the next few years. However, “V2G systems may have the potential to transform both energy and transport systems in profound ways, by promoting the deployment of alternative vehicle technologies.”⁷⁹ Turton and Moura’s model of the PHEV automobile market share with V2G capabilities is a full 10% higher than without by 2100. That timeframe is also consistent with their model for the installation of the necessary V2G infrastructure. With participation in V2G programs, the economics of purchasing an EV would be more competitive. Exact figures on the payout from utilities to EVs participating in V2G is anything but concrete at this point. However, that some V2G program could make the EV more appealing economically certainly makes sense. With a multitude of factors affecting the public reception of EVs, including foreign oil prices, government incentives, unforeseen technological advancements, and potential V2G economic benefits, projecting EV sales is not an exact science.

Utilities are being forced to plan for EV adoption because of the possible EV effects on the grid. Principally, utilities need to ensure the reliability of their infrastructure to cope with the potential additional load that EVs might pose. Incurring the unplanned costs of replacing overstrained infrastructure and losing on the potential gains of V2G, as well as being perceived as the bottleneck to EV adoption, represents additional unwanted publicity for utilities. Given a sophisticated, well-planned approach to widespread EV adoption, utilities could take advantage

⁷⁹ Turton, H., and F. Moura. "Vehicle-to-grid Systems for Sustainable Development: An Integrated Energy Analysis." *Technological Forecasting and Social Change* 75.8 (2008): 1091-108. Print.

of increased profit of the new electricity demand while incurring disproportionately small increases in operating cost.

Where V2G is Now

“Well lets be honest, nobody’s doing it yet. They’re doing it in pilot, if they’re even doing it there. It’s still not a reality.”

-Dr. Aaron Snyder

V2G is possible. Research into V2G is well underway. University of Delaware Professor Willett Kempton holds commercial patents that have drawn the interest of at least two car manufacturers, a national government and three electric utilities for potential licensing and manufacturing of the technology.⁸⁰ The first proof of concept was introduced on October 27, 2007 to the Federal Energy Regulators Commission (FERC) Commissioners in Washington D.C.⁸¹ An American company was set to start V2G testing in real markets in Denmark in September 2011.⁸² The results of these tests are yet unknown, but Denmark was chosen because of its high integration of renewable generation that might make V2G more useful.

V2G has yet to become a reality for a number of reasons. Chief among them is the lack of EVs across the United States where the electric grid sets the example from a technical perspective for the rest of the world. V2G is only valuable as a grid resource given the aggregation of a number of plug-in vehicles, but any significant number of vehicles has yet to appear in any single utility territory. We have created a bit of a paradox wherein the EV could

⁸⁰Fehrenbacher, Katie. "The Father of Vehicle-To-Grid Charges Toward Commercialization."

⁸¹ Kempton W.; et al., A Test of Vehicle-to-grid (V2G) for Energy Storage and Frequency Regulation in the PJM System [Online].

⁸² Briones, Adrene; et al. *Vehicle-to-Grid (V2G) Power Flow Regulations*

be more widespread given V2G, but V2G does not make economic sense until the EV is more widespread.

Legislation could help to spur interest in both V2G and the EV. A legislative hurdle to more widespread EV adoption has been cleared in some states. The sale of electricity is only permitted by utilities across the United States, but with EVs and EV charging stations becoming more relevant, the market for the resale of electricity may become appealing. In Colorado, legislation was passed this summer that allows for the resale of electricity after property owners pay a \$5,000 fee. The law is intended to open the market and encourage entrepreneurs who were previously incapable of charging for the electricity they provided.⁸³ Consumers have been slow to buy EVs in part because of a poor charging infrastructure; to this point, filling up anywhere outside of the home is a difficult proposition.

Another legislative hurdle has been passed. The PJM interconnect, a regional transmission organization (RTO) covering from Virginia and Ohio over to the East Coast, lowered its requirement for the frequency regulation market from 1 megawatt down to 100 kilowatts.⁸⁴ The frequency regulation market operates with demand signals from utility head end, in this case some management software at PJM, that requests a curbing of electricity. Pre-arranged facilities respond to these requests, but under new smart grid programs, many more entities can be a part of the frequency regulation equation. The smaller scale promises to open the V2G market as smaller initial capital investments are necessary to demonstrate V2G benefits in response to frequency regulation requests. According to Scott Baker, a business analyst in the applied solutions division at PJM, one might need just 20 EVs to reach the 100 kW threshold.⁸⁵

⁸³ Finley, Bruce. "Electric-Vehicle Drivers in Colorado to Get a Charge Out of New Law."

⁸⁴ Carson, Phil. "V2G: Are We Ready?" *Intelligent Utility* Sept. 2012: 13-15. Print.

⁸⁵ *ibid*

The reality is that V2G is some way off from regular practice. Issues of payment, battery state of charge and degradation, and communication infrastructure need to be resolved before V2G can become a reality. Projections to have a viable V2G infrastructure in place slate that for 2100. With ARRA money towards advancements in smart grid communications, some areas may already be suited to integrate EVs into load control, or demand response programs such as the thermostat initiative that we discussed earlier, with true V2G reverse flow of electricity much further off. If one is looking for a time frame for when V2G becomes reality, the answer depends on the level of grid integration required for “V2G.” As defined in this paper the term V2G applies to most any partnership between grid and vehicle, and by that definition. V2G should become reality almost immediately.

Combining all of the issues discussed above and reaching some sort of coherent prediction for the future of V2G proves difficult. With so many variables, stakeholders and while operating within the financial and technological scale that would be overhauling both the transportation and electric distribution systems, making any kind of prediction regarding the eventual outcome of V2G seems a waste. However, if we ever see a legitimately grid integrated vehicle, the first implementation of that will be in fleets of work vehicles participating in smart charging. Work trucks, city buses and even forklifts follow a very strict schedule. Participating in any vehicle to grid program would be easier for these vehicles as many of the driver concerns of overnight charge level for your personal vehicle are eliminated. The work vehicle is not constricted by the freedom associated with the personal vehicle that makes vehicle owners anxious about fluctuations in charge level. Further, business owners seem most likely to pursue any program that might increase profits.

“It may turn out that, even with technical problems resolved, the V2G concept may not gain widespread acceptance.”⁸⁶ It could be that EVs never take a firm grasp in the automobile market share or that the value to the ancillary services is not sufficient to justify any necessary grid enhancements. However, V2G should become a reality and with at least some regional electrical grids already capable of most of the communication necessary for V2G, that reality is sooner rather than later.

How V2G becomes a reality

Thus far, we have examined some of the benefits that V2G might bring, the impediments to its implementation from a technological perspective and through a social lens, and suggested that V2G might be most necessary and successful in an electric system that relies more significantly on wind and solar. However, I have not spelled out a plan for how V2G comes into existence. I’ve made it clear that more research needs to be done regarding its effects on the vehicle battery technology, the electric distribution system and on the potential effects V2G might have economically. That is step one. Should step one prove that a grid integrated vehicle is worthwhile and that the impediments are minor obstacles to a greater good, step two is developing an automobile that suits the needs of the stakeholders involved. A new electric infrastructure to replace fuel stations would be unnecessary if we continue with the argument from earlier that the PHEV, with its plug in battery for short range and fuel tank for longer trips, is the appropriate technology for both our needs as consumers and for the V2G idea. Outfitting a PHEV with V2G technology shouldn’t prove too difficult, but settling on a standard across

⁸⁶ Sovacool, Benjamin K., and Richard F. Hirsh. "Beyond Batteries..."

vehicle manufacturers and utilities nationwide could involve some haggling as addressed in the section regarding metering.

The next step is in making sure that there are no real impediments to V2G, such as the legislation that prohibited the sale of electricity from person to person. The first steps in the legislative process of allowing V2G has begun. Further legislation is needed that might encourage V2G is needed. The distinction between legislation allowing and legislation that encourages V2G is important for the ultimate fate of V2G. The net metering convention for rooftop solar panels has helped to guarantee the value of solar panels. A similar convention that guarantees the value of smart charging or V2G programs would be a good first step.

Currently, a maximum of \$7,500 is available federally for purchasing any plug-in vehicle that “draws propulsion energy from a battery with at least 5 kilowatt hours of capacity” depending on battery size.⁸⁷ That’s a good start, but the education of the general population on the benefits of the electric vehicle are lacking. More needs to be done in educating society on the availability and convenience of the electric vehicle. Too often, Americans are simply unaware of the EV technology available to them. That is, how any of the EVs differ or what might make them a more appealing choice for a specific lifestyle. These things need to be more common knowledge.

The entity most responsible for educating the population has to be the one with the most to gain from EV sales: car manufacturers. Should car manufacturers begin an endeavor to sell EVs in earnest, they must develop a good car and market it appropriately. Finally, the event that could instigate the most V2G interest is vehicle manufacturing advertisement. If one of the large vehicle manufacturers develops a car with V2G capabilities and begins to educate the public on

⁸⁷ "Internal Revenue Bulletin - November 30, 2009 - Notice 2009-89."

the potential benefits of V2G in shifting the economic decision making, it seems that utilities would accommodate V2G and it would soon become a reality. The technology for smart charging is already largely in place from a utility perspective, and that alone could help to make things cheaper for potential electric car owners. A vehicle manufacturer deciding that V2G is the difference in their selling EVs or not selling EVs could be all that needs to happen.

There's little doubt that V2G could alter the way we conceive of electric vehicles, but people need to learn about it first. Educating the population on the electric vehicle and the commercially available technologies is important. The responsibility of the education falls on vehicle manufacturers as they convince the population to purchase the EV and consequently participate in V2G. Their basic responsibility is to produce quality vehicles and let people know about them through advertisement.

Conclusion

The possible gains to be made from a smart V2G approach should not be understated. "The V2G concept excites advocates because it offers mutual benefits to the transportation and the electric power systems. It could assist the former by reducing petroleum use, strengthening the economy, enhancing national security, reducing strain on petroleum infrastructure, and improving the natural environment. It could help the latter by providing a new demand for electricity, ideally during the parts of the day when demand remains low. Moreover, it could add capacity to the electric grid during peak times without the need for the utility industry to build new power plants."⁸⁸

The above quote does an excellent job of explaining the many benefits of V2G. This paper has focused largely on the V2G effect on the electric power system, while largely

⁸⁸ Sovacool, Benjamin K., and Richard F. Hirsh. "Beyond Batteries...."

assuming the benefits to the transportation system. However, the transportation ramifications may be more telling and more central to the pursuit of V2G in the first place. When considering V2G, one is best served realizing the summation of the many benefits to the many sectors. Its benefits to the electrical grid are interesting and necessary, but to this point, the roles that the EV could fill have been accomplished via more traditional means. However, the effect of V2G, really the electric vehicle as a whole, is most important in its role to reduce dependence on the modern fossil fueled automobile. Such a replacement would benefit the environment in ways that go beyond the extent of this paper. It is imperative that, while this paper has focused so largely on the benefits associated with V2G and the electricity grid, implicitly it is about the benefits of widespread EV adoption and the direct benefits to society of a transition to the electric vehicle. While the focus has been on a specific niche that the EV could fill, one must be careful not to confine the EV into this niche role. Its benefits to society by replacing the fossil fuel automobile paradigm may be greater than its participation in V2G.

Largely, Americans seem more aware of the issues regarding the transportation sector and the petroleum infrastructure than the electrical grid and the coal reserves. That awareness, however accurate to the true concerns of experts, is telling of the factors that may bring electric vehicles to commonplace. In turn, the electrical system should be prepared to respond and take advantage of increased EV penetration should any of those factors become more important in the coming years. To this point, it does not seem appropriate to say that V2G alone will make the difference in individual decisions to buy an EV, but that V2G will be a benefit of increased EV penetration or as a part of some larger circumstances.

A definition of the V2G ideas, reframed with the concepts that have already been addressed would prove useful in our conclusion. V2G is about taking advantage of the battery

inside the electric vehicle to use as a grid resource. It is about displacing the cost of expensive utility batteries by having customers purchase the batteries for the automobile function, while realizing that personal vehicles are used for their driving function just 4% of the time.⁸⁹ V2G is about increasing efficiency by increasing communication. Finally, V2G is about realizing that different problems can be solved by a common solution given appropriate planning and forethought. V2G, should it become a reality, will be because of appropriate planning and foresight in addressing problems in both the transportation sector and the electricity grid. This paper represents some assemblage of this planning to this point.

The ultimate value of the advantages that V2G could bring in frequency regulation and in turn the economics of purchasing an EV are unknown at this time and should be further evaluated as V2G may prove to be an important economic difference maker. However, the great number of challenges still standing in its path make the flow of electricity from the EV battery unlikely to be commonplace anytime soon. Once the issue of V2G's effect on the EV's battery life is resolved and the true value of the frequency regulation is settled, a more accurate assessment of the economics of V2G and the potential ramifications on EV sales can be made. Until then, we are left to explain the potential of the technology in bringing our transportation and electricity distribution systems together into an age of better communication. Environmental incentives should spur interest, but if assisting the grid makes the EV a financially competitive mode of personal transportation, there would be mutual benefits for both parties.

⁸⁹ ⁸⁹ Kempton, W., and J. Tomic. "Vehicle-to-grid Power Implementation..."

Bibliography

- Andersson, S.-L., A.k. Elofsson, M.d. Galus, L. Göransson, S. Karlsson, F. Johnsson, and G. Andersson. "Plug-in Hybrid Electric Vehicles as Regulating Power Providers: Case Studies of Sweden and Germany." *Energy Policy* 38.6 (2010): 2751-762. Print.
- "Assessment of Plug-in Electric Vehicle Integration with ISO/RTO Systems." *Isorto.org*. The ISO/RTO Council, Mar. 2010. Web. Jan. 2013.
- "BATTERY." *Nissan USA*. N.p., 2012. Web. Jan. 2013.
<<http://www.nissanusa.com/leaf-electric-car/battery>>.
- Berst, Jesse. "Why Distributed Energy Is Your next Big Headache (and What EPRI Says to Do)." *Smartgridnews.com*. N.p., 12 Dec. 2012. Web. 28 Dec. 2012.
- Briones, Adrene; et al. *Vehicle-to-Grid (V2G) Power Flow Regulations and Building Codes Review by the AVTA*. Idaho National Laboratory. United States Department of Energy, Sept. 2012. Web. Jan. 2013.
- California. California Code of Regulations. *FINAL REGULATION ORDER Zero Emission Vehicle Regulation: 2009 through 2017 Model Years*. N.p., 22 Mar. 2012. Web. 23 Apr. 2013. <<http://www.arb.ca.gov/msprog/zevprog/2011zevreg/attachb1.pdf>>.
- Carson, Phil. "V2G: Are We Ready?" *Intelligent Utility* Sept. 2012: 13-15. Print.
- Cavallo, Alfred. "Controllable and Affordable Utility-scale Electricity from Intermittent Wind Resources and Compressed Air Energy Storage (CAES)." *Energy* 32.2 (2007): 120-27. Web.
- Cunningham, John Shamus. "An Analysis of Battery Electric Vehicle Production Projections." Thesis. Massachusetts Institute of Technology, Dept. of Mechanical Engineering, 2009. [Web.mit.edu](http://web.mit.edu). June 2009. Web. Jan. 2013.
- Denholm, P.; Ela, E.; Kirby, B.; and Milligan, M., "The Role of energy storage with renewable electricity generation" (2010). Publications (E). Paper 5.
- Fehrenbacher, Katie. "The Father of Vehicle-To-Grid Charges Toward Commercialization." *GigaOM The Father of VehicleToGrid Charges Toward Commercialization*. N.p., 13 May 2010. Web. 20 Jan. 2013
- Finley, Bruce. "Electric-Vehicle Drivers in Colorado to Get a Charge Out of New Law." *The Denver Post* [Denver] 24 June 2012: n. pag. 24 June 2012. Web. 14 Jan. 2013.
- "GEOL3650: Energy: A Geological Perspective: Laboratory: Coal: China, Energy and Kyoto - II. Upgrading a Coal-fired Power Station." University of Wyoming Department of Geology,

- n.d. Web. 23 Apr. 2013.
<http://www.gg.uwyo.edu/content/laboratory/coal/economics/electricity_intro/demand/peak.asp?callNumber=14276>.
- "GM-VOLT : Chevy Volt Electric Car Site." *GMVOLT Chevy Volt Electric Car Site*. N.p., n.d. Web. 26 Jan. 2013. <<http://gm-volt.com/full-specifications/>>.
- Guille, Christophe, and George Gross. "A Conceptual Framework for the Vehicle-to-grid (V2G) Implementation." *Energy Policy* 37.11 (2009): 4379-390. Print.
- Hill, Davion. "Fleet Operator Risks for Using Fleets for V2G Regulation." *Journal of Energy Policy* 41 (2012): 221-31. Feb. 2012. Web. Jan. 2013.
- "Home, Work or on Vacation - Control Your Home's Temperature from Just about Anywhere." *Manage Your Home Temperature with The Brighten IThermostat Remote Thermostat Control*. TXU Energy, n.d. Web. 10 Oct. 2012. <http://www.brightenithermostat.com>
- "How the Smart Grid Enables Utilities to Integrate Electric Vehicles." *How-the-Smart-Grid Enables-Utilities-to-Integrate-Electric-Vehicles*. SilverSpring Networks, 2012. Web. 08 Jan. 2013
- "How Much Electricity Does an American Home Use?" www.eia.gov. Energy Information Agency, 6 Dec. 2011. Web. 27 Jan. 2013.
- "Internal Revenue Bulletin - November 30, 2009 - Notice 2009-89." Internal Revenue Service, 30 Nov. 2009. Web. 23 Apr. 2013. <http://www.irs.gov/irb/2009-48_IRB/ar09.html>.
- Leo, Mark, Kripal Kavi, Hanns Anders, and Brian Moss. *Ancillary Service Revenue Opportunities from Electric Vehicles via Demand Response*. Study. 2011
- Kempton W.; et al., A Test of Vehicle-to-grid (V2G) for Energy Storage and Frequency Regulation in the PJM System [Online]. Available: <http://www.magicconsortium.org>, 2008.
- Kempton, Willett, and Jasna Tomic. "Using Fleets of Electric-Drive Vehicles for Grid Support." *Journal of Power Sources* 168 (2007): 459-68. Web.
- Kempton, W., and J. Tomic. "Vehicle-to-grid Power Implementation: From Stabilizing the Grid to Supporting Large-scale Renewable Energy." *Journal of Power Sources* 144.1 (2005): 280-94. Print.
- Kempton, Willett, and Victor Udo. *A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System*. Rep. University of Delaware, Pepco Holdings, PJM Interconnect, Green Mountain College, Jan. 2009. Web. Sept. 2012.

- Kintner-Meyer, M.; Schneider, K.; Pratt, R. *Impacts assessment of plug-in hybrid vehicles on electric utilities and regional U.S. power grids, Part 1: Technical analysis*. Pacific Northwest National Laboratory: Richland, WA, 2006.
- "MIT Energy Initiative: The Future of the Electric Grid." N.p., Dec. 2011. Web. Jan. 2013. <<http://mitei.mit.edu/publications/reports-studies/future-electric-grid>>.
- Navarro, Mireya. "Solar Panels Rise Pole by Pole, Followed by Gasps of 'Eyesore'." *Nytimes.com*. New York Times, 27 Apr. 2011. Web. Jan. 2013.
- "Net Energy Metering In California." *Net Energy Metering In California*. State of California, California Energy Commission & California Public Utilities Commission, n.d. Web. Jan. 2013.
- "Pacific Gas & Electric - PG&E." *What Is Demand Response?* N.p., n.d. Web. 14 Jan. 2013. <http://www.pge.com>
- Papavailliou, Anthony, Andrew Lee, Phil Kaminsky, Ikhlaq Sidhu, Burghardt Tenderich, and Shmuel Oren. *Electric Power and Distribution for Electric Vehicle Operations*. Global Ventures Lab of University of California Berkely. Web. Nov. 2008
- Peterson, Scott, Jay Apt, and Jay Whitacre. "Lithium-Ion Battery Cell Degradation Resulting from Realistic Vehicle and Vehicle-to-Grid Utilization." *Journal of Power Sources* 195.8 (2009): 2385-392. Apr. 2010. Web. Jan. 2013.
- "Pike Research Electric Vehicle Geographic Forecasts Comments." *Pikeresearch.com*. Pike Research, Fall 2012. Web. Jan. 2013.
- Rahman, S., and G. B. Shrestha. "An Investigation into the Impact of Electric Vehicles on the Electric Utility Distribution System." *Journal of Power Delivery* 8.2 (1993): 591-97. Web.
- Rogers, J. and S. Fink, and K. Porter, "Examples of wind energy curtailment practices," NREL, Subcontract Report NREL/SR-550-48737, 2010.
- Rose, Stephen and Jay Apt, "The Cost of Curtailing Wind Turbines for Frequency Regulation and Ramp-Rate Limitation." Carnegie Mellon University, Department of Engineering and Public Policy, 2010.
- Sadoway, Don. "Magnesium–Antimony Liquid Metal Battery for Stationary Energy Storage." *Journal of American Chemical Society* (2012): 1895-897. 6 Jan. 2012. Web. 17 Jan. 2013.
- SilverSpring Networks. *The Dollars – and Sense – of EV Smart Charging: Thinking Through the Options for Utility Integration of Electric Vehicles*. Redwood, CA. 2012

"Smart Grid Investment Grant Program." *SmartGrid.gov*. US Department of Energy, n.d. Web. Oct. 2013.
<http://www.smartgrid.gov/recovery_act/overview/smart_grid_investment_grant_program>.

Snyder, Aaron, and Ben Rankin. Personal interview. 16 Oct. 2012.

Sovacool, Benjamin K., and Richard F. Hirsh. "Beyond Batteries: An Examination of the Benefits and Barriers to Plug-in Hybrid Electric Vehicles (PHEVs) and a Vehicle-to-grid (V2G) Transition." *Energy Policy* 37.3 (2009): 1095-1103. Print.

Tomic, J., and W. Kempton. "Using Fleets of Electric-drive Vehicles for Grid Support." *Journal of Power Sources* 168.2 (2007): 459-68. Print.

Turton, H., and F. Moura. "Vehicle-to-grid Systems for Sustainable Development: An Integrated Energy Analysis." *Technological Forecasting and Social Change* 75.8 (2008): 1091-108. Print.

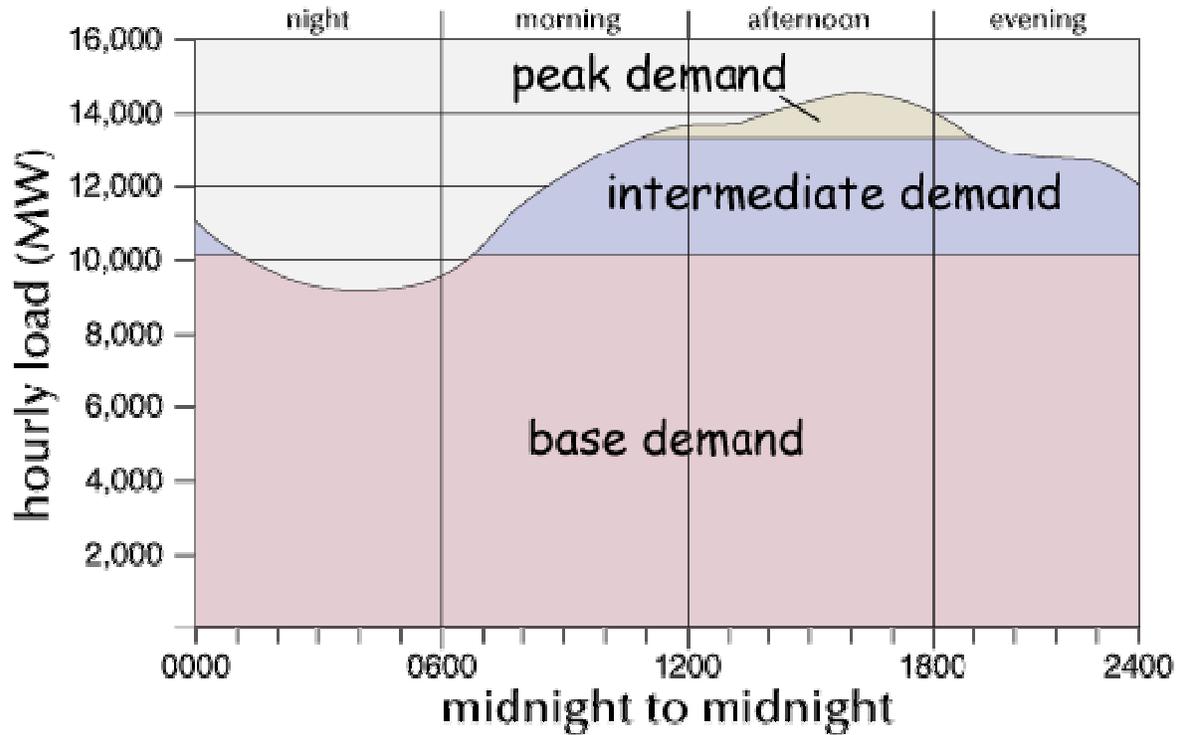
United States. Department of Energy. *Guidebook for ARRA Smart Grid Program Metrics and Benefits*. N.p., 7 Dec. 2009. Web. 16 Jan 2013.

United States. Energy Information Agency. Department of Energy. *AEO2013 EARLY RELEASE OVERVIEW*. N.p., 5 Dec. 2012. Web. 11 Jan. 2013.

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. "*Fuel Used in Electricity Generation Is Projected to Shift over the next 25 Years*." EIA, 30 July 2012. Web. 10 Oct. 2012.

Voelcker, John. "Plug-In Electric Car Sales Triple in 2012 As Buyers, Models Increase." *GreenCarReports.com*. N.p. 3 Jan 2013. Web. Jan 2013.

Appendix A



Source:

http://www.gg.uwyo.edu/content/laboratory/coal/economics/electricity_intro/demand/peak.asp?callNumber=14276&SubcallNumber=0&color=993300&unit=