Swiss Federal Institute of Technology

Aspects of the Plug-in Hybrid Electrical Vehicles Integration in the Power Grid

- Term paper –
Energy Economics and Policy

Author: Ioana Dabacan

Contents

Introduction

In a world where the pollution factors become have more weight in the evaluation of the product's quality, the transportation industry represents one of the major industries that need to react in a radical way. Electric utilities play an important role in this radical metamorphosis. The electrification of transportation requires utility support within a sustainable framework. However, the effects on the electrical grid must be studied and predicted in order to accomplish an efficient functioning of these vehicles. Connecting these electric transport vehicles to the electric grid enables them to use a ready existent omnipresent infrastructure.

This work analyses the potential of Plug-in Hybrid Electrical Vehicles both as transportation vehicles but also as active sustainers of the electricity grid, identifying also the disadvantages of this technology. The effects on the electricity grid are studied and a prediction model for the electricity demand is presented based on historical data.

Overview on Vehicles

In order to better place the Plug-in Hybrid electric vehicles in their context, the current chapter presents a small overview on the vehicle types considered in this work

Conventional Vehicles

The combustion engine started to be used in cars in 1862, when the German inventor Nikolaus Otto (1) invented the four-stroke internal combustion engine. Powered by an energy-dense fuel, the engine produces energy through an exothermic chemical process. The engine represented a revolutionary discovery at the time, however with time certain issues regarding functioning efficiency, air and noise pollution were raised.

Hybrid Electric vehicles

Hybrid electric vehicles (HEV) are characterized by having two or more distinct power sources for locomotion. In the most common case, hybrid vehicles combine an internal combustion engine and one or more electric motors.
The internal design of the hybrid vehicle allows achieving greater fuel economy and lower emissions than conventional internal combustion vehicles. The multiple power sources that are included in the design of Hybrid Vehicles allow for a better fit between the power needed and the power produced by the engines that serve the car.

Plug-in Hybrid Electric vehicles

The plug-in hybrid electric vehicle (PHEV) also known as plug-in hybrid (PHV) are hybrid vehicles that have an internal combustion engine and an electric motor, the second one relying on the energy stored in batteries. The batteries can be reloaded with energy until full charge by connecting them an external power source (usually simply a normal electric power socket).

The high degree of flexibility of PHEV is due to the 2 types of propulsion systems: internal combustion engine and electric motor and therefore a set of alternative fuels it can use: electricity from the grid and stored in a plug-in rechargeable battery or gasoline.

Plug-in hybrid-electric vehicles can be in addition characterized by a "PHEVx" attribute. In this notation "x" denotes the vehicle's all-electric range (AER) – that represents the distance in miles that a fully charged PHEV can drive based on its internal batteries capabilities. By this definition, a PHEV20 can drive 20 mi (32 km) all electrically on the test cycle before the first internal combustion engine is turned on.

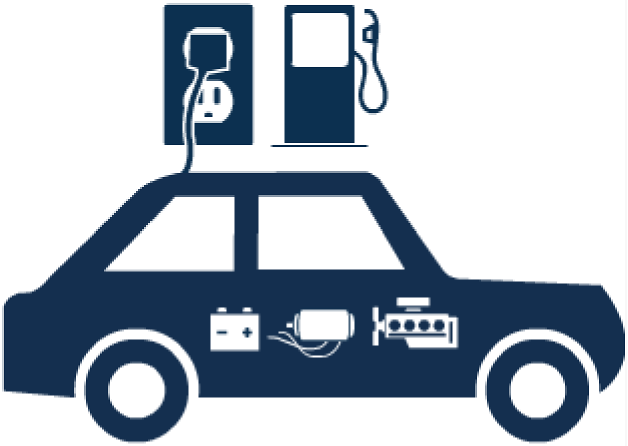

Figure 1 The Plug-in Hybrid Electrical Vehicle's functioning options

The PHEVs can run in different modes: Charge sustaining mode (CS) – when the state of charge of the battery pack fluctuates in a narrow range, Charge depleting mode (CD) – when the electric charging of the battery pack is converted into vehicle motion. The battery's energy (kWh) is used to run the motor to drive the wheels, and the battery pack is discharged. From the point of charging PHEVs would typically depart in CD operation until depleting the battery, and then operate in CS mode. A difference between CS mode in an HEV and PHEV is that the average state of charge (SOC) "window" is much lower for the PHEV. This may have detrimental effects on battery life. The blended mode represents a CD operations strategy in which the engine is run intermittently to provide added power when the battery is not able to provide enough power (2).

In order to profit of their electrical feature in every drive, Plug-in hybrids generally operate in charge-depleting mode at startup, utilizing first their electric energy stored in the battery pack. If the drive is long enough, the PHEVs would switch to charge-sustaining mode after the battery has reached its minimum state of charge (SOC) threshold, exhausting the vehicle's all-electric range (AER). However this is only one functioning scenario, others exist and will be discussed further on in this work.

The potential of Plug-in Hybrid Electric Vehicles

The potential of Plug-in Hybrid Electric Vehicles relies on the fact that most of the cases the automobiles are needed are for short trips that could be covered with the All-Electric Range for PHEVs. Data offered by the National Household Survey in USA shows that vehicles are used in 60% of the cases for trips shorter than 30 miles and in 84% of cases for trips shorter than 60 miles (3).

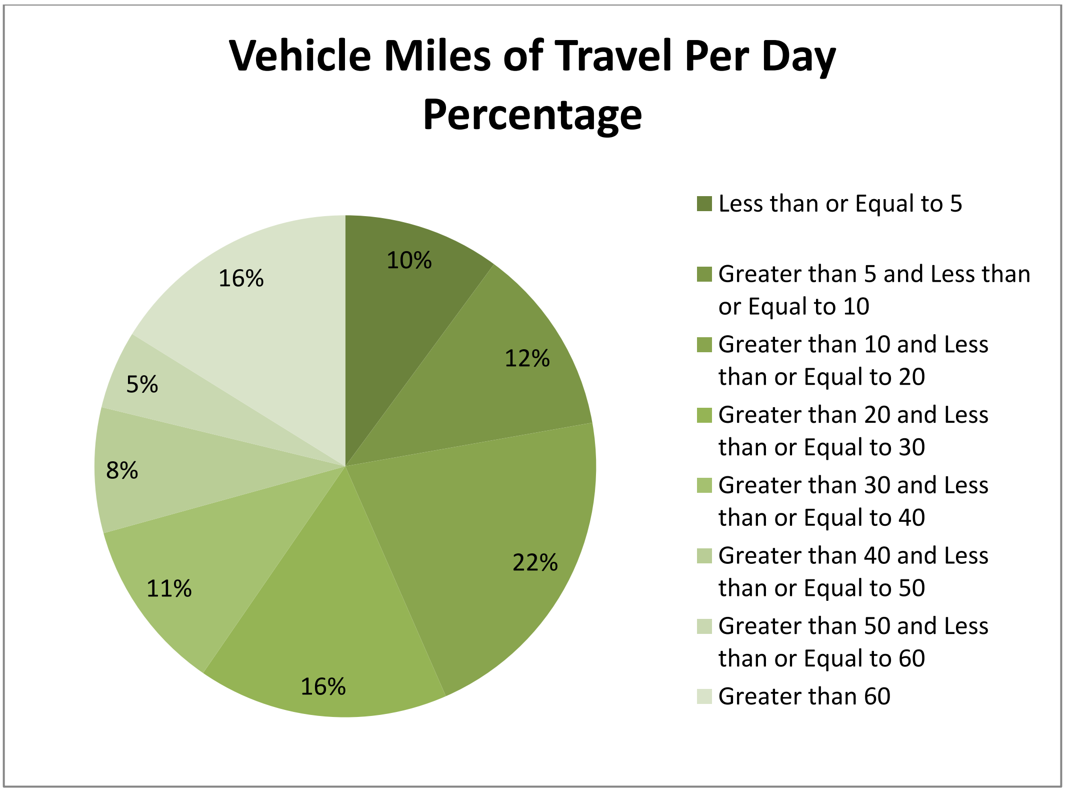

Figure 2 Vehicle Miles of Travel Per Day Percentage

Therefore PHEVs offer an all-electric alternative for most of the trips of the regular owner. Although PHEVs will likely be more expensive than similar conventional and hybrid vehicles, some cost can be recovered through fuel savings, a federal tax credit, or state incentives.

PHEV as an efficient transportation mean

The potential for PHEVs to displace fleet petroleum consumption derives from several factors.

PHEVs are potentially well-matched to motorists' driving habits – in particular, the distribution of distances traveled each day. As shown by the previous graph most of the trip length requirements can rely only on all-electric PHEV range.

PHEVs have the good market position as they combine the advantages of the Hybrid Electrical Vehicles and the Battery–powered Electrical Vehicles, at the same time moderating their disadvantages.
HEVs are designed to attain high fuel economy, but their design originates as a combustible based car, therefore they are not primarily intended for fuel flexibility. In comparison, the PHEVs are designed in

such a way to optimize the petroleum-electrical energy consumption in a very flexible way. BEVs are only relying on battery and therefore the battery storage capability limits the driving range. Also the battery costs and long recharging times are negative aspects that are characteristic for such vehicles. Plug-in Hybrids have a smaller battery which balances the battery cost and recharging times versus the option of utilizing the combustion engine. This combination of characteristics determines a high demand for PHEVs.

Therefore PHEVs represent a strong alternative to the current vehicle fleet and have high potential to gain a high market share in the coming years.

However, PHEV technology implies its challenges. There has been a high effort in perfecting the existing technologies or researching new ones for energy storage, however the progress in this field is slow. The batteries that would serve higher needs than the ones currently used for the HEVs would considerably increase the battery volume and price. Another issue that has been a research topic is the battery life, that unless the battery is optimally used, the efficient functioning life is drastically diminished. . These factors will affect the convenience and efficiency of PHEVs through their purchase price, maintenance and ownership cost.

PHEV as a new value stream

The transportation vehicles typically serve the user for a small period of time and sit idle for most of the time. Except for the vehicle sharing services, not much has been done to increase the actual usage time of each vehicle. In order to provide an additional usage for the idle vehicles, the paper "Integration of Electric Drive Vehicles with the Electric Power Grid - a New Value Stream" (4) introduces the concept of Plug-in Electric vehicles that can have a supporting role in stabilizing the electrical grid demand.

Electric vehicles that can be connected to the grid can be utilized as power sources in their stationary time because they have the systems and the capability to generate AC power.

The utilization of the idle vehicles to provide valuable electric power functions can produce a positive net revenue stream that would be even more valuated at the peak consumption electricity times. This powerful economic incentive to own an electrically-propelled vehicle can have a big impact on the number of electrical cars purchased. The production of valued electric power services from electrically-propelled vehicles is a possibility that was studied. The range of possible services is broad: and includes mobile AC power, backup power for homes or businesses, power generation during peak demand periods, and grid ancillary services such as spinning reserves, regulation, automatic generation control, reactive power, and transmission stabilization. Most of these functions have proved to create economic value when procured from non-vehicular sources.

The electric automotive economies of scale represent a good model for generating energy for the following reasons: Vehicle-based generation of electricity would be clean because the engines must comply with automotive emission standards. It would be low in cost due to automotive economies of scale. The parking location of the automobiles is fortunate as they are idle usually where the high demand for peak energy: at work sites during the day and at residences in the evening. The power they can provide will be highly available because the average automobile is idle for more than 20 hours a day. Finally, the vehicle-based generating resource will be affordable. Furthermore, since the asset cost of the propulsion system is primarily allocated for transportation, only the incremental cost of battery wear-out and system deterioration need be covered by the vehicle-to-grid functions.

A commercial vehicle-to-grid power system is envisioned in paper (4). It includes compatible onboard vehicle power systems, vehicle-to-grid power infrastructure similar to that for charging electric vehicles, communications and control links between the vehicle and the power operator, and electronic commerce systems for handling micro transactions between each vehicle and the ultimate power user. The variety of types of electrically propelled vehicles could provide the services that correspond to

their capabilities. Ranging from uninterruptable power systems offered by the vehicles that possess a significant energy stored in their batteries to valuable grid ancillary services.
In the broader sense, there has been discussion of how the future power grid will evolve toward open standards, with grid access points, even down to the consumer level, used for buying and selling 'packets' of energy, in a similar way to communication with data packets over the internet. Grid connected vehicles could be a major player in this new open energy grid architecture.

In the analysis of the opportunities for plug-in hybrid electric vehicles all the possibilities need to be taken into account: transportation mean function is the primary one but other significant ones like the one of an energy generator, should be considered when fully characterizing the usability of those objects. Even if not realistic for a small number of items, the idea could become applicable when the electric vehicle fleet would reach a significant number. And that number could be easier reached when one would envision other means to minimize the investment return time.

Disadvantages

The disadvantages of plug-in hybrids are generally related to the additional purchasing cost, weight, and size of a larger battery pack. As they require plug-in recharging stations, additional investment is needed in order to respond to future demands. Some studies analyze the emissions that would symbolically shift to the power plants that produce the electricity corresponding to the PHEV demand. Finally, the availability of lithium is a concern as the efficient battery technology relies on this chemical component.

According to a 2010 study by the National Research Council (5), the cost of a lithium-ion battery pack is about USD 1,700/kW•h of usable energy, and considering that a PHEV-10 requires about 2.0 kW·h and a PHEV-40 about 8 kW·h, the manufacturer cost of the battery pack for a PHEV-10 is around USD 3,000 and it goes up to USD 14,000 for a PHEV-40 (6). According to the same study, even though costs are expected to decline by 35% by 2020, market penetration is expected to be slow and therefore PHEVs are not expected to significantly impact oil consumption or carbon emissions before 2030, unless a fundamental breakthrough in battery technologies occur.

Even though generally switching to electrically based transportation is associated with a decrease in pollution level, in some areas the adoption of PHEVs might have the opposite impact. A study by the ACEEE predicts that widespread PHEV use in heavily coal-dependent areas would determine an increase in local net sulfur dioxide and mercury emissions. This was inferred having the data from the most coal plants currently supplying power to the grid. (7). Clean coal technologies could create power plants which supply grid power from coal without emitting significant amounts of such pollutants, but the higher cost of the application of these technologies may increase the price of coal-generated electricity. The fuel source for the electrical grid is the most important determinant in the degree of pollution. From a human health perspective, shifting pollution away from large urban areas may be considered a significant advantage. (8).

According to a 2009 study by The National Academy of Science, the PHEVs impact in a smaller manner the climate damages compared to the other technologies (9).Efficiency of plug-in hybrids is also impacted by the overall efficiency of electric power transmission. Analyzing the life cycle of air pollution emissions, natural gas vehicles are currently the lowest emitter.

Current technology for plug-ins relies on the lithium-ion battery. Therefore as the demand for PHEVs will increase so will the demand for lithium, heavy metals and other rare elements (such as boron and cobalt) required for the batteries. Some of the largest world reserves of lithium and other rare metals are located in countries with strong resource nationalism, unstable governments or hostile to U.S. interests. The political system has a high influence also in the decision to adopt electrical transportation technologies. The raising concerns about the risk of replacing dependence on foreign oil with a new dependence on hostile countries to supply strategic materials can have a negative impact on the PHEV popularity (10).

Currently, the main deposits of lithium are found in China and South America throughout the Andes mountain chain. In 2008 Chile was the leading lithium metal producer, followed by Australia, China, and Argentina. In the United States lithium is recovered from brine pools in Nevada. Approximately half the world's reserves are located in Bolivia, and Bolivia's Salar de Uyuni desert has 5.4 million tons of lithium, which could be used to make lithium batteries for hybrid and electric vehicles. Other important reserves are located in Chile, China, and Brazil. (10) Regarding rare earth elements, most reserves are located in China, which controls the world market for these elements.

Figure 3 Piles of Salt - Salar de Uyuni Bolivia

Electricity sources

In order to determine the environmental performance of PHEVs, a key step is to determine the source of the electricity used to charge the battery. The projections of regional generation mixes for a target year so can help make predictions how PHEVs will perform in different markets. The type of power plants varies by region, so it is important to examine these vehicles on a regional basis in order to better understand their effects. A number of recent studies provided projections of the charging demand of PHEVs and matched the projected demand to the estimates of available generation capacities. These studies varied according to the regional scope and intent.

The issue of determining the generation mix at the time of vehicle charging is considerably difficult and uncertain as the mix is dependent on the scale the PHEVs are deployed, the current inventory of power plants and the availability of primary resources needed.

The factors that affect the electricity generation mix

The generation mix has multiple cycles depending at the lowest granularity level on the time of day, to seasons, determined by the time of year. On other dimensions, the geographical region, vehicle and charger design, load growth patterns, and the associated generation expansion in the years prior to the charging event have a considerable influence on the mix (11).

1 Time of the day

During the day, sharp peaks could be caused by air conditioning demand that would typically occur in the late afternoon and early evening. However, demand is at a minimum overnight when businesses are closed, lights are off, and air-conditioning load is at its lowest power consumption.

As the electricity demand increases, additional generating units are dispatched to meet the load. When a PHEV charger is activated and the demand is high, it causes additional load on the marginal generator (i.e., the last unit brought online). When that unit reaches full capacity, another unit is brought online as the marginal unit, and so forth. Therefore, when a large number of PHEVs would be added to a system, several additional generation units may be required to meet the charging load.

Consequently, the energy mix used as a primary resource would change and therefore also the emissions of those units is allocated to the PHEV charging load would be different. In an extensive interconnected region, transmission constraints can develop so that several geographically separated generating units must operate at part load to meet an increasing demand.

2 Time of the year

Seasonal load variations also affect the mix of units brought on-line to meet the PHEV charging demand. A typical trend is the peaks caused by the hot summer days when the electrical energy is highly consumed by the cooling devices, or in cold winters when there is a high demand for heating

2 Climates

The climate characteristics affect the energy generation mix and add up to the other characteristics that define it: in the regions with a warm climate the of air-conditioning loads, which add to the daytime peak, causing even more demand of energy in the critical period. Electric heating loads tend to increase off-peak demands and may compete with the off-peak charging of PHEVs during the winter season.

Another time-of-year effect is the variation of power plant capacity with ambient temperature. This also affects the availability of capacity for dispatching to meet PHEV charging loads.

4 Regional conditions

Climate, fuel availability, population, industrial activity, local regulation, water availability, pollution levels, and other regional characteristics have influenced the development of each region's specific power system, including the generation mix. As a result, the generation mix varies substantially from region to region.

5 Vehicle and Charger Design Factors

The vehicle design characteristic with the greatest influence on PHEV charging load is the battery capacity, which is related to the AER and weight of the vehicle. It is most commonly assumed that the charger will operate at normal household power levels, typically 110 V – 220V and no more than 20 amps. A sport utility vehicle (SUV) type of PHEV may require larger batteries than a compact or sedan type of PHEV. In order to charge these batteries in a reasonable length of time, more charging current is required. The benefit of reduced charging time comes at an additional cost of the higher demand.

6 Load Growth and Generation Expansion

Even if the expansion of PHEV industry hasn't yet expanded too much there is a constant need of innovation in this promising industry.

The planning of expansion, which optimizes changes to the generator inventory, is a complex process. Many issues need to be taken into account: load growth projections, changes in regulations, and the technical performance characteristics of current and future generator options. Therefore the final inventory in the future would likely be substantially different under carbon emission constraints than it would be in a usual case.

A useful indicator of the potential capacity for PHEV charging is the current energy generation pattern. Another influence on the generation could be the PHEV charging demand itself. This charging demand is likely to increase along with a general increase in transportation energy demand. The reduction in the rate of growth is due to higher fuel economy standards, higher fuel prices, and slower economic growth, all of which lead to efficiency improvements.

7 Vehicle fuel economy

A key factor in the analysis of the PHEV performance is the amount of electricity used by the vehicle compared with the amount of fuel used by the engine. The higher storage capacity the battery has, the longer it could supply electrical energy previously accumulated from the power grid, and therefore the less engine power needs to be used.

The initial idea of a PHEV's operation was to charge the battery to a high state-of-charge then the vehicle would operate in a charge-depleting (CD) mode by using only the stored electricity until it reached a low state of charge (SOC) . Once the battery reached the low SOC threshold, it would operate in charge-sustaining (CS) mode (12).
In this manner the vehicle would attain a level of zero emissions during the CD operation. However the high battery costs, especially when the total AER is extensive, led to another concept of utilization. A blended CD mode, when the engine is intermittently turned on during the D operation increases the VMT range, by a more efficient management of the two resources

For example the engine could be turned on during high power demands in the CD mode; otherwise a significant amount of the battery's energy would be drained if not supplemented by the engine.
The blended mode of operation could reduce the size of the PHEV battery and therefore improve in performance and cost but it would raise concerns about the emissions generated.

The impact of the Plug-in Electric Vehicles in the grid

The bigger the number of PHEV in the vehicle fleet, the more impact they could have on the power grid. The electrically enabled cars impact also the fuel use and emissions. The existing equilibrium can be broken once a high number of vehicles would require electrical energy from the power grid and this effect is not known or estimated. The charging load depends on the PHEV market penetration and the charging characteristics of various PHEV products. The charging characteristics include the voltage (110 V or 220 V), the amperage, and the length of time required for charging.

Figure 4 Valley Filling technique

The method used for analysis is called valley filling. In valley filling, the new loads (in this study, PHEVs) are managed by demand-side management programs in order to fill the valleys (hours with low energy consumption) in load curve.

The two time frames considered in the analysis are the 24-hour time frame, where recharging is possible all-round the day and valley filling in the 6pm-6am time frame. The second scenario is relevant for the option of overnight PHEV battery recharging.

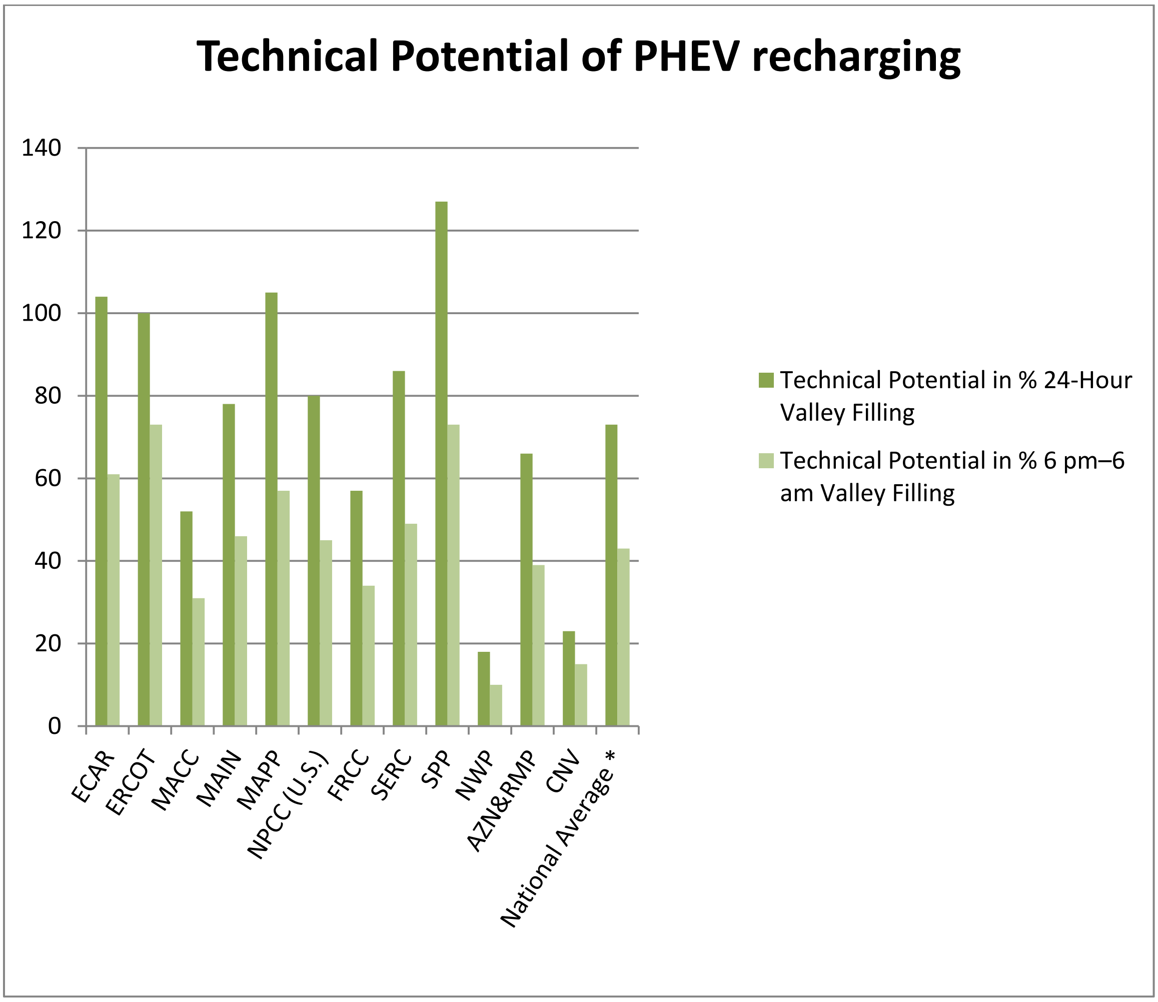

Figure 5 Technical potential of PHEV recharging

North American Electric Reliability Corporation (NERC) list of regions

1. ECAR—East Central Area Reliability Coordination Agreement
2. ERCOT — Electric Reliability Council of Texas
3. MAAC — Mid-Atlantic Area Council
4. MAIN — Mid-America Interconnected Network
5. MAPP— Mid-Continent Area Power Pool
6. NPCC –NY — Northeast Power Coordinating Council / NY
7. NPCC –NE — Northeast Power Coordinating Council / New England
8. FRCC — Florida Reliability Coordinating Council;
9. SERC — Southeastern Electric Reliability Council
10. SPP — Southwest Power Pool
11. WECC-NW — Western Electricity Coordinating Council / Northwest Power Pool Area
12. WECC-RMP/ANM — Western Electricity Coordinating Council / Rocky Mountain Power Area and Arizona-New Mexico-Southern Nevada Power Area
13. WECC-CA — Western Electricity Coordinating Council / California (11)

Figure 5 shows the available percentage of energy per each region of the 13 NERC regions listed above. The biggest amount of energy is available in the Southwest Power Pool (SPP), where the potential in 24-Hour filling is 130%. Among the regions with high available energy remarkable are also the East Central Area Reliability Coordination Agreement (ECAR), Electric Reliability Council of Texas (ERCOT) and Mid-Continent Area Power Pool (MAPP).

On average the 24-Hour Filling average is 73% and the 6 pm -6 am Valley Filling average is 43%. The statistic data gathered from the North American Electric regions shows that there is a high amount of available energy within the valleys. The electrical grid is over-sized in order to cover the peaks. Therefore the issue is not how much energy available there is but rather when that energy is available.

The data from the (NHTS) National Household Travel Survey (presented in Figure 2 Vehicle Miles of Travel Per Day Percentage) shows that 23% of vehicles were driven 10 miles or less, 44% were driven 20 miles or less, 60% were driven 30 miles or less, 71% were driven 40 miles or less, and 84% were driven 60 miles or less.
In terms of VMT (Vehicle Miles of Travel Per Day), 3% were contributed by vehicles driven 10 miles or less, 11% by those driven 20 miles or less, 21% by those driven 30 miles or less, 31% by those driven 40 miles or less, and 47% by those driven 60 miles or less.

DailyTravel Range of Vehicle	VMT Share in NHTS 2001	One Charge/Day – % "Electric" VMT by PHEV Type				
		10 EV mi	20 EV mi	30 EV mi	40 EV mi	60 EV mi
Up to 10 mi	3.3	3.3	3.3	3.3	3.3	3.3
10-20 mi	8.1	5.3	8.1	8.1	8.1	8.1
20-30 mi	10	3.9	7.9	10	10	10
30-40 mi	10	2.8	5.7	8.5	10	10
40-60 mi	16.8	3.4	6.7	10.1	13.5	16.8
Over 60 mi	51.8	4.5	8.9	13.4	17.9	26.7
PHEV sum	100	23.2	40.6	53.4	62.8	74.9

Table 1 Share of National VMT Available for Substitution by a PHEV Using 100% Grid Electricity until depletion

PHEVs can travel beyond of their CD (charge depleting) range, but for their specified CD range they can electrify the first miles of their daily travels.

PHEVs can drive well beyond their CD range, they can increase the maximum electrified VMT by utilizing their entire CD range with electrical propulsion power and then continue in CS mode using gasoline. This is illustrated in Table 1, where five PHEVs with different ranges are shown. PHEVs with a 10-mile CD range and operating in 100% CD mode can electrify the same VMT as EVs up to that CD range (3.3%). However, far more importantly, they can electrify the first 10 miles for all vehicles traveling beyond 10 miles, thereby electrifying an additional 23.2% of all VMT on a typical day.
Column "PHEV sum" assumes 100% market share by specified PHEV, one charge per day, and PHEV operation in 100% CD mode until the battery is depleted. The solid line divides the upper limit of the proportion of VMT in each column that could be served by fully electrically propulsion means. The entire column can theoretically be served by PHEVs in the CS mode.

Data in Table 1 shows the maximum potential transfer of VMT to electricity when all vehicles in the nation are full PHEVs with a certain range capability, charged once, and completely charge depleted once per day.
In reality, market penetration will be affected by the PHEV cost and perceived return. In light of the expense of batteries, sales of PHEVs to those who cannot fully utilize the battery pack is far less probable than for those who can effectively utilize the pack each day.

Prediction model for the electricity demand

In order to predict the electricity demand for a future time-frame, the factors that influence the future demand need to be analyzed. One of the most relevant ones is the number of PHEVs that would be in the vehicle fleet in the next years. Paper (13) *Prediction of Electricity Demand Due to PHEVs Distribution in Korea Using Difusion Model* shows a possible model for the electricity demand prediction.

In the subchapter "PHEV as an efficient transportation mean", it is presented the analysis of the necessary distance traveled by an average driver per day. The results show that PHEVs in their actual technological state are able to fulfill the average needs. So even if we would ignore the technical advancement that would probably take place in the next years regarding the PHEV technology, the all-electrical range satisfy the user's requests. Secondly the energy needed in average by a PHEV to serve the user in a similar way as the engine cars do now.

The method used for determining the PHEVs sale predictions is the Bass Diffusion model. The model is presented by the formula:

$$TCN_i = m \int_i^{i+1} \frac{p(p+q)^2 e^{(p+q)t}}{(p+q*e^{-(p+q)t})^2}\, dt$$

Where TCN_i represents the total cumulative number of PHEVs sold in year *i*, *m* represents the potential maximum number of items sold. The coefficient of innovation is *p* and *q* represents the coefficient of imitation.
In order to use the model, coefficients *m*, *p* and *q* are found using statistical analysis on the historical data. The maximum potential sales number, *m* is inferred to be $125*10^5$. The yearly car sales number is $7*10^5$ in 2008. The coefficients p and q are extracted from the sales data presented in the following figure:

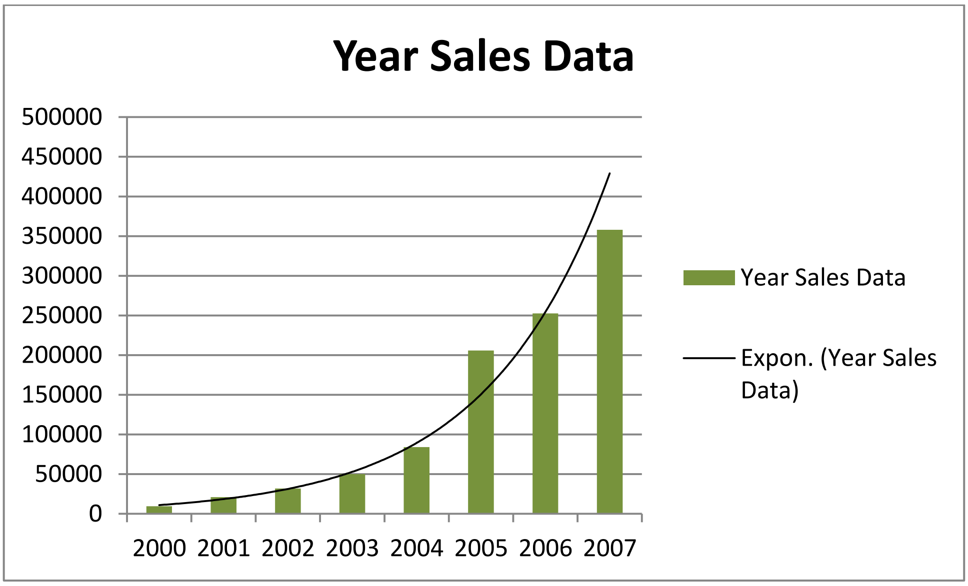

Figure 6 U.S. Historical PHEV Sales Data

The values for the two coefficients are p=0.000000365 and q=0.447. Based on Bass' Diffusion model the prediction data presented in Figure 7 and Figure 8 for the years 2012 – 2036.

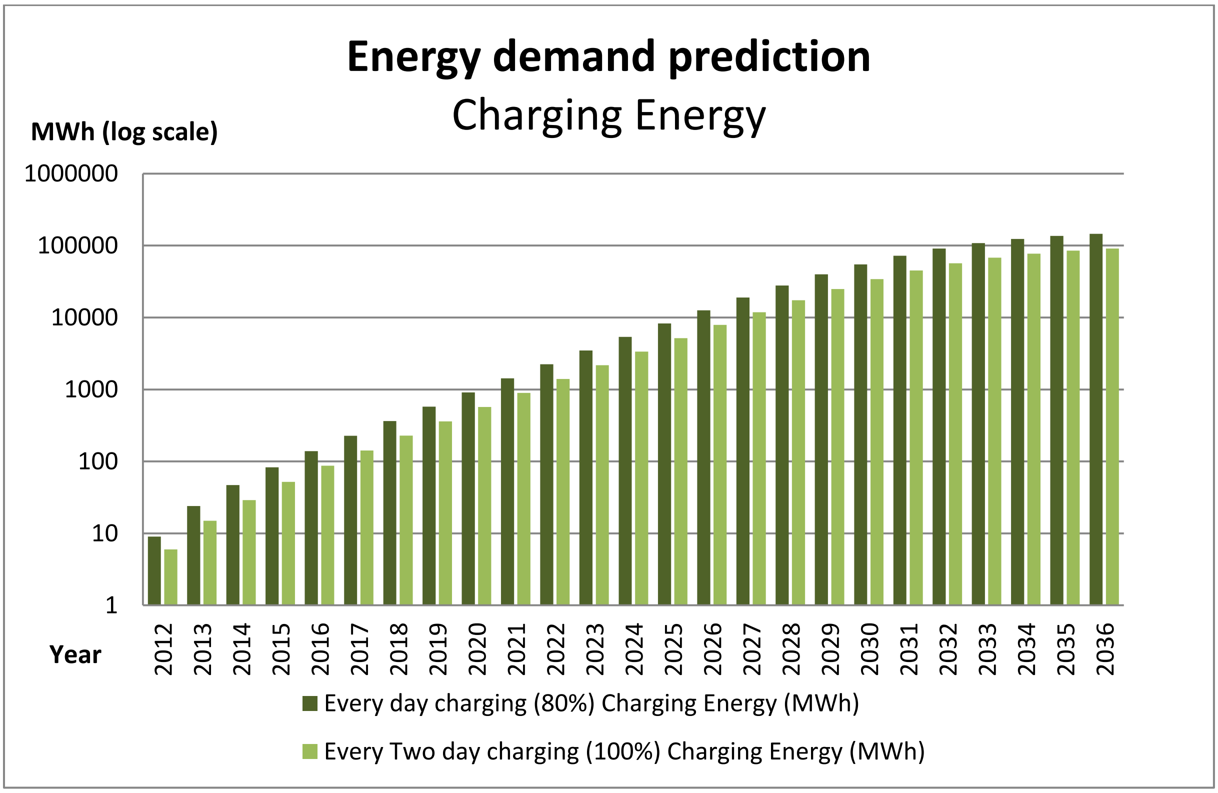

Figure 7 Energy Demand Prediction - Charging Energy

In Figure 7, the Charging Energy demand is presented on a logarithmical scale. In 2033 the necessary charging energy demanded would be 10^5 MWh for the Every Day charging scenario. In the alternative 2 day charging, the 10^5 MWh energy demand would be reached in year 2036.

Figure 8 presents the Charging Capacity demand on a logarithmical scale. In 2030 the necessary charging capacity demanded would be 10^4 MW for the Every Day charging scenario. In the alternative 2 day charging, the 10^4 MW energy demand would be reached in year 2032.

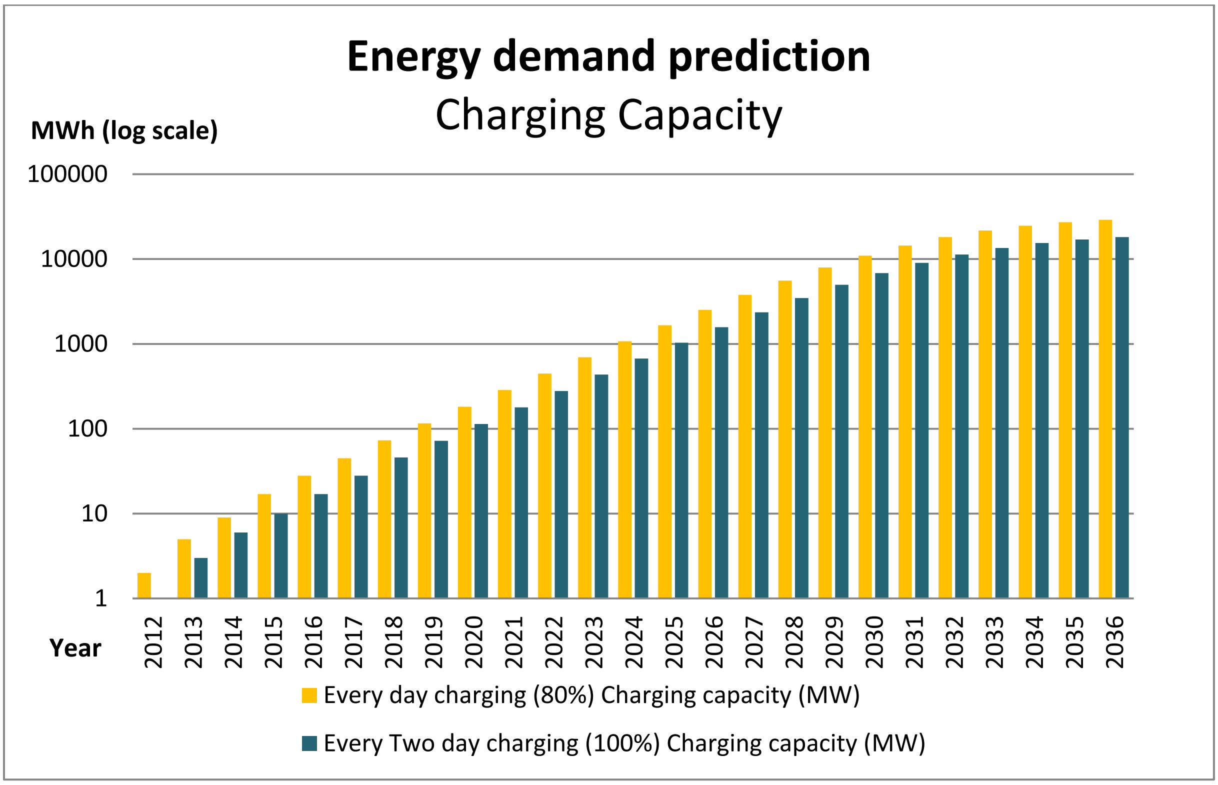

Figure 8 Energy Demand Prediction - Charging Capacity

Conclusions

The energy demands predicted for the future are pretty high, but if the energy management is done in a Valley Filling mode, the available energy should still be enough for decades. Exploring alternative paths in the existing technology or even developing further technology for an efficient utilization and energy service offerings would compensate for the increased price for PHEVs and batteries.

The potential for PHEVs to reduce per-vehicle petroleum consumption is clearly very high. Without knowing the future costs of petroleum, it is impossible to determine the future economics of PHEVs. However, an assessment of the rate of fuel use should consider driving habits (distances but also styles of driving) in order to obtain an accurate estimate of the oil-savings potential of PHEVs in actual use. The more efficient way of employing the battery utilization, the blended mode PHEV CD operation complicates estimation difficulties, but could represent a good compromise option. It is likely that it will be quite a challenge to justify the PHEV capital cost premium on the basis of reduced lifetime energy costs alone. Other incentives and business models may be required to create an attractive value proposition for PHEV motorists and increase the sensibility regarding the pollution issues.

There is a real potential for electric drive vehicles to create value while they are stationary and plugged in to the power grid. By deploying the vehicle's power systems to perform ancillary services for the power grid operator, there is the potential for economic value to be created. This would invert the cost vs. emissions benefit tradeoff; there could be a cost benefit together with the emissions benefit. Vehicle based grid services may prove to be instrumental in overcoming market and cost barriers in the adoption of electric and other advanced technology vehicles.

Bibliography

1. Internal Combustion Engine. *Wikipedia.* [Online] http://en.wikipedia.org/wiki/Internal_combustion_engine.
2. *Where Is the Early Market for PHEVs?* **Danilo J. Santini*, Gerben Passier°, Francois Badin**, Arie Brouwer°°,.** 4, s.l. : The World Electric Vehicle Journal, Vol. 2.
3. **Survey, National Household Travel.** NHTS Data Center. [Online] nhts.ornl.gov.
4. *Integration of Electric Drive Vehicles with the Electric Power Grid -- a New Value Stream.* **Alec Brooks, Tom Gage.**
5. United States National Research Council. *Wikipedia.* [Online] http://en.wikipedia.org/wiki/United_States_National_Research_Council.
6. Plug-in hybrid. *Wikipedia.* [Online] http://en.wikipedia.org/wiki/Plug-in_hybrid.
7. *"Environmental Assessment of Plug-In Hybrid Electric Vehicles : United States Air Quality Analysis Based on AEO-2006 Assumptions for 2030.* **Knipping, E. and Duvall, M.** Vol. Volume 2.
8. **Clayton, M.** A reality check on plug-in hybrids. *The Christian Science Monitor.*
9. **Kanellos, M.** Plug in your hybrid, pollute less? [Online] cNet News.com.
10. Página sobre el Salar (Spanish). [Online] Evaporiticosbolivia.org.
11. *Well-to-Wheels Energy Use and Greenhouse Gas Emissions Analysis of Plug-in Hybrid Electric Vehicles.* **A. Elgowainy, A. Burnham, M. Wang, J. Molburg, and A. Rousseau.** s.l. : Argonne National Laboratory.
12. *Impacts Assessment of Plug-in Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids.* **Grids, Vehicles on Electric Utilities and Regional U.S. Power.**
13. *Prediction of Electricity Demand Due to PHEVs Distribution in Korea Using Difusion Model.* **Jong-Ryul Won, Yong-Berum Yoon, Kyung-Jin Lee.**
14. **LECG.** *Plugin Hybrid Databook.*
15. **Pike Research.** Plug-in Hybrid Electric Vehicles. *www.pikeresearch.com.* [Online] http://www.pikeresearch.com/research/plug-in-hybrid-electric-vehicles.

List of abbreviations

BEV - Battery alimented vehicle
HEV - Hybrid Electrical vehicle
PHEV - Plug-in Hybrid Electrical Vehicle
NHTS - National Household Travel Survey
VMT - Vehicle Miles of Travel
CD - Charge-depleting
CS – Charge-sustaining
SOC - State of charge
AER – All Electric Range

North American Electric Reliability Corporation (NERC) list of regions
1. ECAR—East Central Area Reliability Coordination Agreement
2. ERCOT — Electric Reliability Council of Texas
3. MAAC — Mid-Atlantic Area Council
4. MAIN — Mid-America Interconnected Network
5. MAPP— Mid-Continent Area Power Pool
6. NPCC –NY — Northeast Power Coordinating Council / NY
7. NPCC –NE — Northeast Power Coordinating Council / New England
8. FRCC — Florida Reliability Coordinating Council;
9. SERC — Southeastern Electric Reliability Council
10. SPP — Southwest Power Pool
11. WECC-NW — Western Electricity Coordinating Council / Northwest Power Pool Area
12. WECC-RMP/ANM — Western Electricity Coordinating Council / Rocky Mountain Power Area and Arizona-New Mexico-Southern Nevada Power Area
13. WECC-CA — Western Electricity Coordinating Council / California

Annex

Energy demand prediction

Year	Cumulative	Every day charging (80%)		Every Two day charging (100%)	
		Charging capacity (MW)	Charging Energy (MWh)	Charging capacity (MW)	Charging Energy (MWh)
2012	713	2	9	1	6
2013	1829	5	24	3	15
2014	3572	9	47	6	29
2015	6298	17	83	10	52
2016	10557	28	139	17	87
2017	17211	45	227	28	142
2018	27603	73	364	46	228
2019	43817	116	578	72	361
2020	69089	182	912	114	570
2021	108403	286	1431	179	894
2022	169390	447	2236	279	1397
2023	263578	696	3479	435	2175
2024	408051	1077	5386	673	3366
2025	627344	1656	8281	1035	5176
2026	954961	2521	12605	1576	7878
2027	1432954	3783	18915	2364	11822
2028	2106724	5562	27809	3476	17380
2029	3011579	7951	39753	4969	24846
2030	4150596	10958	54788	6848	34242
2031	5472603	14448	72238	9030	45149
2032	6869484	18135	90677	11335	56673
2033	8206243	21664	108322	13540	67702
2034	9369628	24736	123679	15460	77299
2035	10301613	27196	135981	16998	84988
2036	11000084	29040	145201	18150	90751

U.S. Historical PHEV Sales Data

Year	Year Sales Data	Yearly Share (%)
2000	9500	0.06
2001	21000	0.13
2002	32000	0.2
2003	50000	0.31
2004	84199	0.52
2005	205828	1.26
2006	252636	1.55
2007	358000	2.2

Technical Potential for Fueling the Regional Vehicle fleet with available electricity

Region	Technical Potential in %		Total Number of Vehicles in Mill.
	24-Hour Valley Filling	6 pm–6 am Valley Filling	
ECAR	104	61	27.7
ERCOT	100	73	15.5
MACC	52	31	20
MAIN	78	46	16.7
MAPP	105	57	5.8
NPCC (U.S.)	80	45	19.6
FRCC	57	34	11.5
SERC	86	49	37.8
SPP	127	73	11.9
NWP	18	10	15.7
AZN&RMP	66	39	8.8
CNV	23	15	25.8
National Average *	73	43	216.9