## Title

# Learning from Consumers: Plug-In Hybrid Electric Vehicle (PHEV) Demonstration and Consumer Education, Outreach, and Market Research Program



## Authors

Kurani, Kenneth S
Axsen, Jonn
Caperello, Nicolette
et al.

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# Plug-In Hybrid Electric Vehicle (PHEV) Demonstration and Consumer Education, Outread, and Market Research Program

Principal Investigator: Kenneth S. Kurani
Project Management: Kevin Nesbitt, Marilyn Kempster
Researchers: Jonn Axsen, Nicolette Caperello, Jamie Davies, Tai Stillwater
Plug-in Hybrid Electric Vehicle Research Center
Institute of Transportation Studies
University of California, Davis

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Institute of Transportation Studies ◦ University of California, Davis
One Shields Avenue ◦ Davis, California 95616
PHONE: (530) 752-6548 ◦ FAX: (530) 752-6572
WEB: http://www.its.ucdavis.edu

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We'd like to thank the thirty-four households who participated in the research reported here, especially inviting us into their homes multiple times, their willingness to complete questionnaires and interviews, and their frank evaluations.

## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

## ABSTRACT

Will people recharge a vehicle that does not have to be recharged? This, and the degree to which plug-in hybrid electric vehicle (PHEV) designs emphasize gasoline or electricity, are central to assessing the energy and environmental effects of PHEVs. Plug-in conversions of hybrid vehicles are being made available to (predominately new-car buying) households throughout the Sacramento region for four to six weeks each. The vehicles are instrumented to report travel and energy; households are interviewed and surveyed. Results from the first 34 households—all selected in part because they can recharge a vehicle at home—indicate that on average they will recharge a PHEV about once per day, but with wide variation across households. The PHEV designs created by these households emphasize increased fuel economy rather than all-electric operation—as did the designs of prior representative samples of new-car buyers (who had not driven PHEVs). This result may be due in part to 1) "anchoring" (respondents are driving a PHEV that does not practically allow all-electric operation), and 2) households not creating integrated assessments of gasoline and electricity use/cost from the in-vehicle and internet-based instrumentation. Over the PHEV trials, narratives are co-authored about the PHEVs and their place in the ongoing life-stories of the participants. The primary themes to emerge are changing driving behavior, recharging habits and etiquette, confusion about PHEVs and how they work, and the role of payback analyses and more intuitive assessments of whether PHEVs are "worth it." Tracing social interactions by the participants about the PHEVs reveals that complex translation of ideas and information about PHEVs is occurring as the PHEV drivers, in particular, use their trial period to reflexively explore lifestyle and identity possibilities of these new vehicles.

# EXECUTIVE SUMMARY

This document reports on a research project designed to address the question, "Why would consumers buy plug-in hybrid electric vehicles (PHEVs)?" With funding from the California Air Resource Board's Alternative Fuels Implementation Program (AFIP) and funding and in-kind support from other partners, the Plug-in Hybrid Electric Vehicle Research Center (PHEV Center) at the University of California, Davis implemented a PHEV Demonstration and Consumer Education, Outreach, and Market Research Project (hereafter referred to as the Project). This report describes the Project and summarizes the findings from the first thirty-four households. The Project will continue through 2009; results will be updated in subsequent reports.

## Project Design

The Project was conducted as the following three main activities: 1) vehicle conversion to plug-in operation, 2) demonstration and research, and 3) education and outreach.

### *1) HEV to PHEV Conversions*

Toyota Priuses were purchased and converted to plug-in operation using the Hymotion, (now, A123Systems) conversion package. A dozen such vehicles are regularly used in active support and conduct of the Project. The A123Systems conversion involves the installation of a 5KWh (nominal) lithium-ion battery in the spare tire well in the rear cargo area of the vehicle, as well as the necessary electrical and communications connections to incorporate the battery into the vehicle's drive system and to recharge the battery. The battery charges from a standard US three-prong, grounded, 110-volt outlet. Using the PHEV terminology in this report, the PHEV-conversions used in this Project can be described as blended PHEV-30s, in which we adopt the definition of CD range as the distance at which the vehicle switches from CD to CS operation. This characterization will be restated in the discussion of the households to reflect their on-road performance in these vehicles.

Additionally, the vehicles were equipped with onboard data collection and transmission devices. Idaho National Laboratory (INL) provided the devices and the cellular service to transmit the data. V2Green, Inc. (now, Gridpoint, Inc.) manufactured the data collection and transmission systems. They also summarize vehicle data on a website; UC Davis contracted for additional programming services to allow individual Project drivers to track their performance.

### *2) Demonstration and Research*

The PHEV-conversions have been, and continue to be, placed in households in northern California for several weeks at a time. Households are recruited with the assistance of AAA Northern California, Nevada & Utah. During the households' PHEV trial use periods, we collect data on travel, vehicle recharging and refueling, performance of the vehicle, and participants' response to the PHEV technology. Data are collected directly from the vehicle using on-board data systems, as well as from interviews, questionnaires, and fueling logs.[1]

### *3) Public Education and Outreach*

The PHEVs were also used in a public education and outreach programs. The vehicles were displayed at public events and used in educational settings. Information on PHEVs remains accessible from the PHEV Center's website.

## Research Activities within the Project

Within the overall Project there are four related research activities.

### *A. Household response to the PHEV-conversions*

In some sense the entire Project is about household response to PHEV-conversions. This specific activity focuses on the following results:

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[1] We can infer from vehicle data when it has been refueled with gasoline, but the only way to know how much was paid for gasoline is to have drivers record this information.

1. What are the PHEV designs created by Project households and how do these designs compare to those created by survey respondents who have no experience driving PHEVs?

2. What are the recharging behaviors of the Project households, and how do driving behaviors influence recharging behaviors?

3. Given that Project participants are driving one specific incarnation of what a PHEV can be, what are the effects on their transportation energy use?

### *B. Narratives*

We employ narrative research methods in this Project both to synthesize the large amounts of disparate data we are collecting for each household and to analyze both those synthesis documents and the original textual data from the household interviews. The purpose of the synthesis narratives is to tell the best possible story about each household and their experience with PHEVs. The purpose of subjecting the interviews to analysis is to ascertain what themes emerge across the households' experiences.

### *C. Interfaces and Instrumentation*

Research on driver feedback is carried out in two phases. First, we assess the participants' use of and response to the in-vehicle energy information displays based on the stock Toyota Prius Energy Monitor and Fuel Consumption displays (as modified by the PHEV-conversion) and the website displaying summary performance data from their vehicle. Results from this first phase of interface and instrumentation research are included in this report.

The second phase of instrumentation research builds on the first, but is not scheduled to begin until summer 2009. In the second phase, a custom-made driver feedback display will be included as part of the research design for a subset of the Project households.

*D. Social Influence*

A sub-group of 10 to 15 social networks (each centered on a household driving the PHEV-conversion) will be investigated to ascertain how interpersonal interactions influence assessment of electric-drive vehicles. Analysis of four networks has been completed to date and is discussed in this report. Three research questions are addressed:

1. Do interpersonal interactions play a significant role in the assessment of electric drive vehicles?

2. If so, how can we characterize the interpersonal interactions that influence consumer perceptions of functional, symbolic, and pro-societal attributes?

3. Under what conditions might households adopt the pro-societal car?

## Participating Households

Participants are recruited through an "illustrative" sampling method (Turrentine and Kurani, 2007.) Such a sample does not attempt to be representative of a population; rather, the purpose is to illuminate the behavior of specific groups. The sampling frame for the Project is defined by 1) automotive insurance requirements, 2) geographic location, 3) vehicle ownership, 4) driving behavior, and 5) broad categories of household structure. Participants are selected for the Project with the participation of AAA Northern California, Nevada & Utah. Volunteers from the recipients of the invitation letter log-on to a website hosted on a UC Davis server, where they complete a brief questionnaire which solicits more specifics of the potential participants vehicles, home, travel, household, and contact information. UC Davis researchers review the questionnaire responses and select households based on the goal to illustrate the responses of different types of households.

In comparison to samples of the general population and of the population of California and northern California who have previously completed questionnaires for UC Davis regarding PHEVs (Axsen and Kurani, 2008), the Project households differ in that, on average, they have higher income, education, and likeliness to own their home. All three of these may be explained by a single design choice made for the Project: all participating households must have a place to recharge the vehicle at home. Still, the Project participants as a group only accentuate differences between our prior samples of new-car buying households and the general population; they do not introduce any new differences. In particular, the Project participants are similar to other recent samples of new car buyers in terms of concerns with environment and energy and knowledge about electric-drive vehicles.

### What PHEVs do Project Participants Design?

At the end of their PHEV trial period, households complete a set of PHEV design games—the same design games completed by prior samples of survey respondents (Axsen and Kurani, 2008). The overarching conclusion from the design games is that even the Project households who have had a chance to drive a PHEV (that offers blended CD operation) do not design PHEVs that offer all-electric operation. Rather, the Project participants, like the survey respondents before them, create designs that emphasize improvements in (CD and CS) fuel economy.

Project participants who had driven a (blended-operation) PHEV for a month were more likely than the previous survey respondents to 1) design a PHEV they are interested to buy rather than opt to buy a conventional vehicle, 2) design a PHEV that had better PHEV performance than the base PHEV design offered to them (the base offering took eight hours to recharge, achieved 75 mpg in blended CD operation for 10 miles, and achieved 10 mpg higher in CS operation than a conventional version of the same car), and 3) choose an HEV as the base vehicle they considered for redesign as a PHEV. The Project does appear to have a slightly greater persuasive effect in convincing participants that a PHEV is a worthwhile and desirable vehicle for their household. Still, these differences are at the margin, and the overall conclusions one draws from the Project participants are similar to those we drew from the survey.

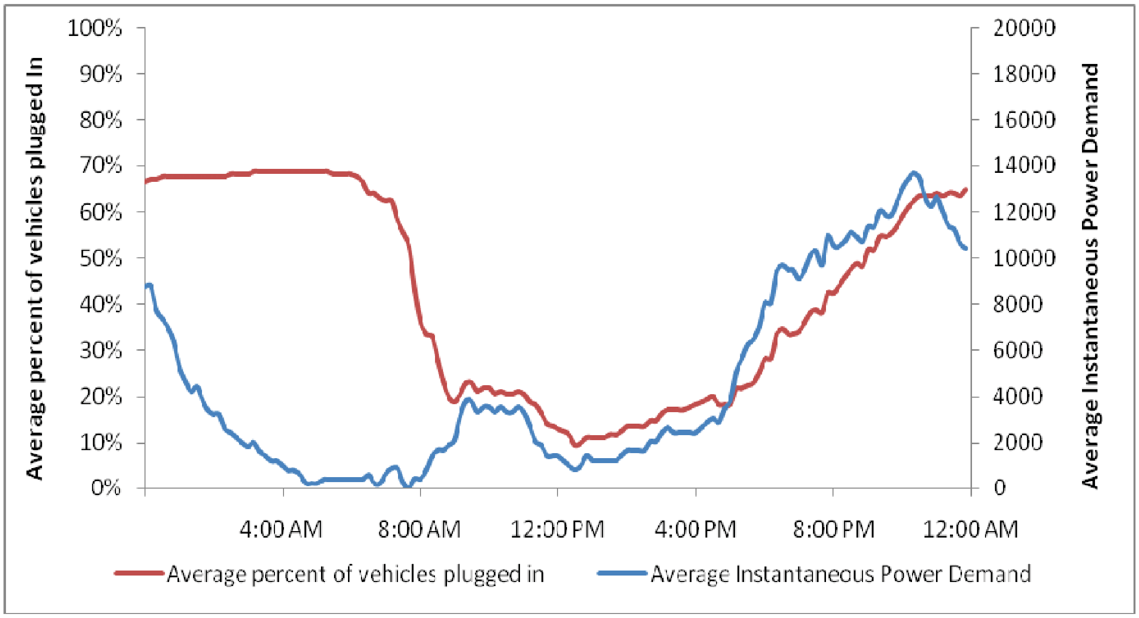
## Charging and Refueling Behaviors

There may be no more fundamental question about PHEVs than whether or not people will plug-in a vehicle that does not have to be plugged-in. The answer from the Project participants to date is, “Yes, we will.” The Project households, on average, plugged-in these PHEV-conversions about once per day, and did so more often on weekdays than weekend days. There was large variation in the mean frequency of PHEV recharging across households—from zero to 2.6 times per weekday and zero to 1.5 times per weekend day. The mean frequency of plugging-in on weekend days was lower than on weekdays because there was now workplace charging and the PHEVs were more likely to be away from home, and thus away from the households’ primary or sole recharging location. Only a few households found away-from-home recharging locations they used on a regular basis. The incidence of zero charging on weekdays is largely explained by one household who decided that recharging the PHEV-conversion made too little difference to warrant their difficulty and hassle in recharging the vehicle.

We assess the time-of-day distribution of PHEVs’ access to electricity and actual electricity demand to recharge PHEVs. The former is the distribution of times that PHEVs are plugged into the grid; the later is the distribution of times that electricity is actually being demanded by PHEVs for recharging. The weekday distributions from the last week of each of the 34 households are shown in Figure ES-1.

Across the 170 weekdays represented in Figure ES-1 (34 households times 5 weekdays), 70 percent of households had plugged in their PHEV between 10:00 pm and 6:00 am. By 9:00 am only 20 percent of households had their PHEV connected to the grid. This can be explained by the number of respondents in the Project that have full time jobs, and typically leave home in the morning to go to work. While there were two households that charged during the day while at work, the PHEVs that were plugged-in to the electrical grid during midday were mostly due to retired individuals and teleworkers. At 4:00 pm, when households start to return home from work, vehicles begin to be plugged in, until 10:00 pm by which time the percentage of households who have plugged in their PHEV stabilizes again at about 70 percent.

**Figure ES-1: Electricity Availability (Percent of PHEVs Plugged-in) and Instantaneous Power Demand by Time-of-Day (Watts), Weekday Average.**




Given driving and recharging behavior by the Project households, electricity demand to recharge their vehicles ramps up at 5:00pm and peaks just after 10:00pm. It declines steadily through the rest of the night and into the morning, reaching practically zero by 5:00am. While there were several households that charged during the day at work, most of the demand to recharge these vehicles was between 9:00am and noon.

Weekend days differ from weekdays. Fewer PHEVs are plugged in during the weekend high availability period: about 55 percent of vehicles were plugged in between 11:00pm and 6:00am on weekends as compared to 70 percent between 10:00pm and 6:00am weekdays. The weekend high availability period starts an hour later than on weekdays. Compared to weekday recharging, it appears as though some individuals, if they had access to an outlet, plugged in longer during the weekend. However, on average, not as many people plugged in their vehicles on weekend days compared to average weekdays.

As with weekday electricity demand, most actual weekend electricity demand to recharge the vehicles occurred between 5:00pm and 2:00am. There are significant differences in the total power required between weekdays and weekend days. On average, weekend electricity demand increased more slowly over the course of the evening. In general, this difference from weekdays is because during weekends the PHEVs are starting their recharging at a higher state of charge than on weekdays, and, thus, there is not as great a cumulative impact upon the power demanded. Essentially, as those vehicles plugged in later start recharging, their impact on the rate at which total power demand increases (summed across all households) is less than on weekdays, because other households' vehicles which were plugged in earlier have already finished recharging.

### Variation in Vehicle Use, Recharging, and CD-miles Across Households

The recharging results presented so far focus on the recharging behavior summed and averaged across the participants. This hides the variation in 1) the frequency with which people recharged the PHEV, 2) the distances households drive per recharging interval, i.e., the distance driven between two recharging events, and 3) the percentage of total miles each household drove in CD mode. The participants varied in their experiences with the vehicle, in their concepts and appreciation of the value of recharging, and in their access to different recharging locations. Figure ES-2 illustrates the overall variability in performance of the participants with regard to their average monthly (gasoline-only) fuel economy, the percentage of miles they drove in CD mode, and the overall distance they drove in the PHEV during their respective vehicle trials.[2]

In Figure ES-2, each circle represents one household. The diameters of the circles are proportional to the total miles driven by that household in the PHEV over their trial period. For scale, the largest circle ("Nancy," in the lower left) represents just over 3,000 miles of driving. That it also depicts the lowest percentage of miles in CD mode and nearly the worst gasoline-only fuel economy in the trial to date is due to several long, multi-day tours Nancy took away from home during which she drove the PHEV-conversion many miles between recharging events.

The basic conclusions to be drawn are that individuals varied greatly in their driving and recharging behaviors and, importantly, in the relationship between these two. A few households drove only 20 to 30 percent of their miles in CD mode. On the other hand, a

[2] All household names are pseudonyms.

few households drove approximately 80 percent of their miles in CD mode and achieved monthly average gasoline-only fuel economy measures of approximately 70 mpg.

**Figure ES-2: Gasoline-only Fuel Economy by Percentage of Miles Driven in CD Mode, Weighted by Total Monthly PHEV (CD+CS) Distance**

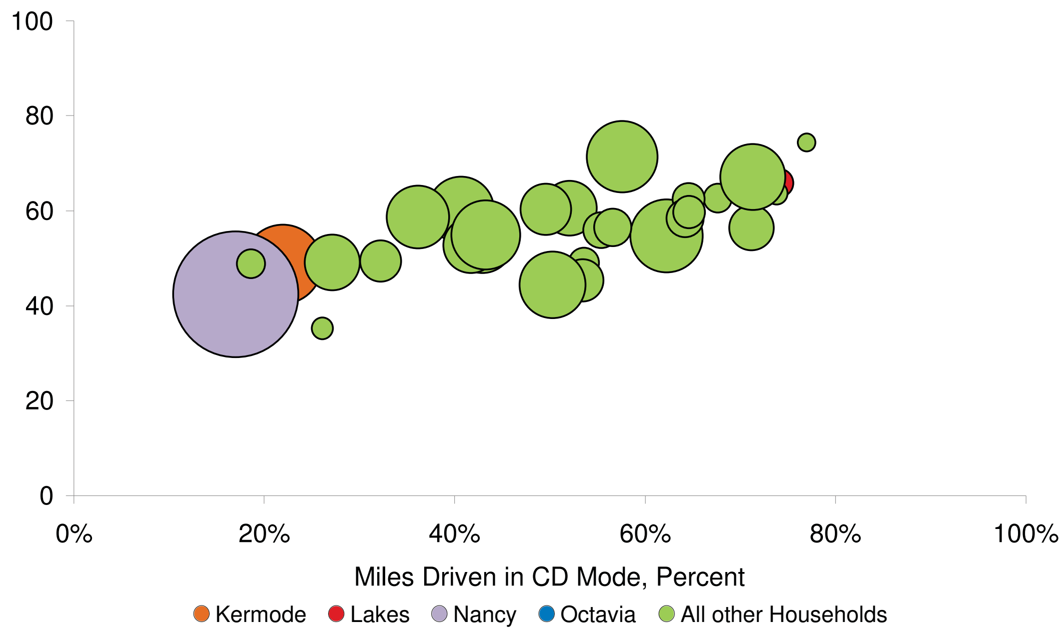



Figure ES-2 shows the potential for drivers of these particular PHEV-conversions to achieve reductions in the gasoline-intensity of their daily mobility through differences in how they drive and recharge the vehicle, e.g., driving and recharging such that the miles in a recharging interval closely match the driver's realized CD range. Still, there is tremendous variability in how closely participants' behavior matches this technically ideal pattern that is not illustrated in Figure ES-2.

### The Overall Effects of Recharging on Energy Use

First, we address changes in gasoline-only fuel economy because this was the primary metric used by households; we then turn to an analysis of the total energy effects. Across the group of households, mean CS fuel economy was 44.7mpg; mean CD fuel economy was 67.1mpg. Thus, the group mean increase in CD vs. CS is 49 percent. These group measures mask tremendous variation across households. The distribution of households' mean fuel economy improvements between CS and CD operation ranged from 21 to 101 percent. However, improvements over 70 percent were exceptions—90 percent of households had improvements less than 71 percent and the median improvement was 46 percent.

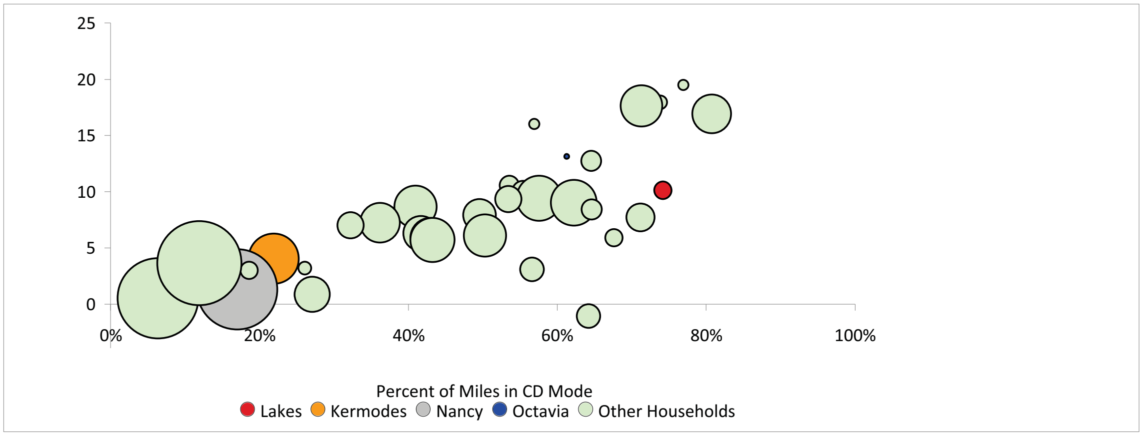
The analysis of total energy effects presented here is preliminary and partial. It is preliminary because we do not expect that the full range and variety of the relationships between travel and recharging behavior on one hand and total energy use on the other have yet been observed among the Project participants' to date. Further, this analysis is preliminary because only one particular PHEV is analyzed. The analysis is partial because it is not a life-cycle analysis; here we address only electricity out of the battery and gasoline out of the tank. Further, the analysis is partial because we address only the marginal difference that it makes that the Project households drove and recharged (to the extent each did) a PHEV instead of an HEV.

We compare their total energy use, i.e., gasoline plus electricity, during their PHEV trial to the amount of gasoline they would have used had they driven their entire PHEV trial without ever recharging. To illustrate relationships between driving, recharging, and energy use we plot the marginal percentage decrease in total gasoline (tank to wheels) plus electricity (battery to wheels) by the percent of their miles they drove in CD mode for their four-week PHEV trial in Figure ES-3. As in Figure ES-2, the size of each data point in Figure ES-3 is proportional to the total miles driven during each household's trial.

The first point is that a comparison of Figures ES-2 and ES-3 shows the households' use of the simple measure of (gasoline-only) fuel economy is not qualitatively wrong. As the percent of miles driven in CD mode increases, fuel economy and energy savings both increase. Figure ES-3 confirms that across the households, energy was being saved through the substitution of electricity for gasoline by recharging the PHEVs compared to the amount of gasoline these households would have consumed had they not recharged the PHEVs.

The relatively low percentage of CD driving of Nancy and the Kermodes—which we know was due to long, multi-day tours—yields low percentage energy savings from a large (compared to the other households) base. Octavia and the Lakes achieved much higher percent energy reductions but across much less travel, and thus a smaller energy base. They did so in part because of the much higher percentage of their travel they accomplished in CD mode—accomplished both because they recharged more often and traveled fewer miles than Nancy and the Kermodes.

**Figure ES-3: Decrease in Households' Total Energy (Gasoline plus Electricity) for their PHEV-conversion (as compared to an HEV) by Percent of Miles driven in CD Mode, percent.**




The range of percent total energy savings achieved by plugging in the PHEV-conversions in comparison to not plugging them in is from -1 to 19 percent. Higher percent savings are achieved by households who drive higher percentages of their miles in CD operation—either because they tend to drive fewer miles per day than their achieved CD range (and generally recharge everyday) or recharge multiple times per day. The household in which energy use increased was due to changes in drivers and trip distances.

### Narrative Analysis: What, why and how?

We have two purposes in employing narrative: synthesis and analysis. First, we have a tremendous amount of disparate information about each household; narrative provides a framework to organize, analyze, and report all these data. Second, narratives explain, provide coherence, and show causality.

The primary themes to emerge from the narratives are changing driving behavior (primarily through the influence of the in-vehicle instrumentation), recharging habits and etiquette, confusion about PHEVs and how they work, and the role of payback analyses or more intuitive assessments of whether PHEVs are "worth it." Some people changed how they drive the car after seeing their instantaneous fuel economy; others drove the PHEV as any other car, and specifically like they had no particular control over energy use. Some people likened plugging in the PHEV to recharging a cell phone and made it part of their daily routine, but were hesitant to recharge outside of their homes due to a lack in social etiquette and concerns for safety. Many people were confused about the state of charge of the battery; this influences how often they recharged. Some were concerned about the cost of the PHEV and payback; they saw PHEVs as helping with environmental problems but wondered how much they were paying to do so.

### Interfaces and Instrumentation

There are two main sources of vehicle information available to study participants. First, there is the stock display console screen in the 2007 and 2008 model Toyota Priuses converted to PHEVs for the Project. The two screens are 1) an Energy Monitor schematic of energy flows in the vehicle as well as the instantaneous fuel economy, and 2) a Consumption screen that provides fuel economy averaged over 5-minute intervals and over the tank (or whenever the driver resets the average).

Second, participants had access to the data they generated through driving, recharging, and refueling the vehicle via a website designed by the on-board data system provider. The website displays vehicle summary data as well as the location and status of the vehicle. Although the website provides detailed summary information—for example, driving data are summarized by trip, day, week, fortnight, and month—few participants reported being influenced by the website.

The discussion of interfaces and feedback during interviews was subjected to additional analysis. The resulting themes were limited availability of web-based interfaces, information presented in abstract contexts, confusion (either about what certain information meant or about what behaviors to enact based on given information), novelty or lack of persistence of attention to information and new behaviors, learning, goal setting, and an hypothesis about gender-specific responses to energy information. The following lessons from these themes are proposed to guide further research into the role of interfaces and instrumentation:

- The closer information is to the point of interest and action, i.e. in the car vs. on the home computer, the more likely it is that the information will be used.
- Simplicity in representation and interpretation is critical to driver understanding.
- The interface should support drivers in setting and achieving goals by providing relevant summary information.
- Instantaneous Fuel Economy can provide drivers with erroneous information, especially during braking.
- Whenever possible, information should be presented in a grounded context so that drivers can quickly understand the relative impact of their behavior.

### Social Influence on the Evaluation of, and Spread of Information about, PHEVs

PHEVs and other electric-drive vehicles are innovations because of what they can do: new battery and drivetrain technology allows users to offset gasoline use with electric-drive capabilities and to plug-in to the electrical grid, often at home. From a functional perspective, consumers may interpret the desirability of electric-drive technology according to its ability to save them money on transportation, to improve drivetrain reliability, or to simply improve the experience of driving. But PHEVs, and electric-drive vehicles more generally, may also be assigned different social meanings than conventional vehicles. For example, Heffner et al. (2007) found five symbolized meanings that motivated HEV purchases: preserve the environment, oppose war, manage personal finances, reduce support to oil producers, and embrace new technology. Further, electric drive vehicles embody another class of attribute that differentiates them from conventional vehicles: the potential to benefit society in new ways. Green (1992, p133) provides a framework to classify goods on a private/public scale, where private good are characterized by "exclusive and personal consumption and individual payment; not associated with the public welfare," whereas societal or public goods are characterized by "nonexclusive consumption and collective payment" such as "clean air" and "saving endangered species."

The first question in this social network research asks whether interpersonal influence plays a significant role in the assessment and adoption of electric-drive vehicles. The research reported here suggests that the observed social interactions are influential for primary households (those actually driving the PHEV-conversions) and secondary participants (members of primary households' social networks who have volunteered for interviews). The second research question delves deeper to explore and characterize specific processes of social interaction and influence. We describe these interactions from five perspectives: contagion, conformity, dissemination, translation, and reflexivity. The primary households and their interaction with their social network illustrate (to some degree) each of these five approaches. We find the two most insightful approaches to be translation and reflexivity.

Results to date suggest that interpersonal interactions within social networks play an important role in shaping the assessment of these PHEV conversions, and likely electric-drive vehicles more generally. Diffusion, conformity, and dissemination provide useful concepts for particular processes, but translation and reflexivity appear to best provide the language and theoretical depth required to integrate the various motives and perceptions observed among participating social networks. However, before conclusions can be drawn, more networks need to be explored and further analysis is required.

# 1. A Research Agenda to Address How Consumers Drive, Recharge, and Value Plug-in Hybrid Electric Vehicles

This document reports on a research project designed to address the question, "Why would consumers buy plug-in hybrid electric vehicles (PHEVs)?" An integrated set of demonstration, research, education, and outreach activities was deployed to accomplish the following:

- Provide California households with the requisite knowledge and experience to provide informed responses to PHEVs, thus overcoming one primary impediment to commercialization—a lack of understanding by consumers, vehicle designers, fuels providers, and regulators of consumers response to the following:
    - Driving, recharging, and refueling patterns of PHEVs, that is, to what extent will drivers of PHEVs recharge from the grid or refuel the ICE, and where and when will recharging occur;
    - Different symbols of the meaningful and motivational features and capabilities of PHEVs, e.g., all-electric range, high fuel economy, electric-drive, ability to use renewable fuels, etc.;
- Inform the California Air Resources Board of the potential effect of consumer driving and recharging/refueling behavior on the potential for PHEVs to reduce greenhouse gas and other vehicle emissions.
- Inform the California Air Resources Board as well as the California Energy Commission, electric utilities, CalISO, and other parties of consumer response to PHEVs on the potential benefits, markets and impacts of PHEV technologies, including the following:
    - The potential for PHEVs to reduce petroleum consumption;
    - The effects of PHEVs on operation of the electrical grid;

With substantial funding from the California Air Resource Board's Alternative Fuels Implementation Program (AFIP) and additional support from the California Energy

Commission's Public Interest Energy Research (PIER) Program, the Plug-in Hybrid Electric Vehicle Research Center (PHEV Center) at the University of California, Davis implemented a PHEV Demonstration and Consumer Education, Outreach, and Market Research Project (hereafter referred to as the Project). Other Project contributors include the AAA Northern California, Nevada & Utah, and Idaho National Laboratory (United States Department of Energy).

This report describes the Project and summarizes the findings from the first thirty-four households. The Project will continue through 2009; final results will be updated in subsequent reports.

## The Project in Context

The Project is the third research activity in a multi-year, integrated research agenda. In brief, the agenda is as follows:

1. PHEV "pioneers"—interviews of early converters of HEVs to PHEVs and drivers of these first conversions
2. Internet-based survey of new car buyers' baseline knowledge and priorities regarding PHEVs—samples representative nationally, with over-samples to represent new car buyers in California and northern California.
3. Household PHEV Demonstration and Market Research
    a. Add improved in-vehicle energy feedback displays of cost, integrated feedback on electricity and gasoline use, emissions etc.
4. A second large sample survey based on the prior PHEV research projects

The first two research activities in this agenda are completed, the third is described in this report as are initial findings, and the fourth is forthcoming pending funding. As appropriate, the description and reporting of the design and results of the Project will be put into context of this larger agenda. For examples, some of the questionnaires completed by Project participants are the same as those completed by the participants in the prior national survey and the Project participants are compared to the northern California over-sample.

## Reasons for this Project

This Project addressed the following questions: how will drivers use PHEVs—drive, recharge, and refuel them—and what kinds of PHEVs will buyers want? The defining feature of PHEVs—the ability to plug the vehicle into the electrical grid and refuel it from another network of liquid (or gaseous) fuels—is the source of both their potential benefits and the uncertainty over whether their potential can be realized. Much of the appeal of PHEVs is based on the flexibility afforded by two energy systems. This flexibility offers new choices for consumers, from a range of vehicle designs, e.g., size of battery and motor, as well as flexibility around the way the vehicle is used, e.g., how often the battery is recharged vs. how often the liquid (or gaseous) fuel is refueled. To achieve and optimize the potential of PHEVs to reduce vehicle emissions and gasoline consumption, i.e., to accomplish their societal benefits, PHEV owners will need to use electricity from the grid.

Consumers will be faced with a previously unknown set of capabilities and thus unfamiliar choices. For example, the larger the battery chosen by buyers, the greater the percentage of their driving can be accomplished using electricity from the grid. On the other hand, the larger the battery the higher the initial price of the vehicle. As the initial vehicle price will be readily apparent, but the new and largely unfamiliar benefits only unfold in the future, sound policy and market actions depend on assessing potential consumers' response to these distributions of costs and benefits. Moreover, PHEVs can be engineered to suit different consumers or regulators; PHEVs can be designed to minimize $CO_2$ reduction, provide high torque and acceleration, maximize battery life, or maximize consumer control over the choice between electricity and gasoline.

### *Are Consumers Impediments to PHEV Commercialization and Benefits?*

Are PHEVs to be encouraged because they represent a rich set of consumer and social values or discouraged as inviting unwelcome, unproductive tradeoffs between the here-to-fore largely separate gasoline and electrical energy systems? One key variable in PHEV commercialization and in the attainment of any environmental and social benefits is the "locus of control," that is, who has control over vehicle operations—drivers, vehicle engineers, or regulators?

The fear of regulators, vehicle manufacturers, and energy suppliers is that drivers-in-control could be deleterious to goals for the environment, air quality, energy consumption, energy systems operation, and the ability to warrant vehicles for emissions, fuel consumption, and reliability. In this worldview consumers are seen as at best disinterested and non-compliant, and at worst as anti-compliant. This bias is old and persistent; we believe it may be contradicted by a number of real world experiences. Writing a review of consumer energy research nearly three decades ago, McDougall *et al* (1981) reveal such bias: "…recognize that *probable* energy savings represents a net impact based on *potential* savings in a technical sense, reduced to allow for imperfect behavioral response." [Emphasis in the original.] More recently, Friedland et al. (2003) observe the continued absence of people in energy policy: "Especially lacking is policy or guidance that incorporates personal choices in energy–use reduction decision-making."

What this pessimistic view of people ignores is that at least some people if provided with control, information, incentive, and opportunity—such as can be provided with a PHEV—will exceed the "technical potential" possibilities. In interviews with buyers of non-plug-in HEVs, we have heard several accounts that suggest their drivers were saving more energy than technical analysts would calculate (Kurani and Turrentine, 2004; Heffner, Kurani, and Turrentine, 2005). This occurred by several means that illustrate the potential effects of driver control, information (feedback), incentive (symbolic and/or financial), and opportunity. In some cases, the HEV prompted further thinking by the owner about energy reductions in other areas of their life. Most directly (and in contradiction to economists' assumptions of a rebound effect, i.e., increased driving because of reduced operating costs), some HEV drivers actively attempted to drive their HEV less than the vehicle it displaced. In gaming interviews with non-BEV owners we observed that when provided with an incentive in the form of a cost savings through the use of electricity rather than gasoline, these households appeared to quickly learn to adjust their travel between the use of a (hypothetical) BEV and their actual vehicles (Kurani and Turrentine; 1996, 2002).

## Project Design Summary Description

This discussion points to two facts that guide the design of this Project. First, consumers are unaware of the potential advantages, disadvantages, new capabilities, and costs of PHEVs. Second, how consumers form their awareness, how they assimilate and process new knowledge about PHEVs, how they turn this awareness, knowledge, belief, and motivation into demand for PHEVs, and thus whether consumers will buy PHEVs, which type of PHEVs they would like to buy, and how they might drive, recharge and refuel those PHEVs are all largely unknown.

The Project was conducted as the following three main activities.

### *1) HEV to PHEV Conversions*

With funding from the California Air Resources Board, Toyota Priuses were purchased and converted to plug-in operation using the Hymotion, (now, A123Systems) conversion package. While such vehicle conversions are clearly only an interim step, they offer a test-bed for real world research with car-buyers. A dozen such vehicles are regularly used in active support and conduct of the Project. Another Prius (purchased with funding from the California Energy Commission) was converted, adorned with large signs identifying it as a PHEV and as a vehicle of UC Davis' PHEV Research Center; this vehicle is reserved for education and outreach activities and support of the Project.

The A123Systems conversion involves the installation of a 5KWh (nominal) lithium-ion battery in the spare tire well in the rear cargo area of the vehicle, as well as the necessary electrical and communications connections to incorporate the battery into the vehicle's drive system and to recharge the battery. The battery charges from a standard US three-prong, grounded, 110-volt outlet. The recharging point is in the left-rear bumper of the vehicle. A fully discharged battery can be recharged in approximately five hours.

It is important to understand that the converted vehicle remains subject to the underlying control strategy of the OEM vehicle. Specifically, these PHEV-conversions are best described as operating in a manner that more or less continuously blends electricity and gasoline—though it is the case that while the conversion, or supplemental, battery is discharging, far more electricity is being used than in a conventional Prius and it is easier, though by no means easy, to drive so that the ICE remains off. Still, even while the supplemental battery is contributing to the propulsion of the vehicle, aggressive accelerations, speeds higher than 35mpg, and upward grades are likely to cause the ICE to start to meet the additional load.

Additionally, the vehicles were equipped with onboard data collection and transmission devices. The devices and the cellular service to transmit the data were provided to the Project by INL. V2Green, Inc. (now, Gridpoint, Inc.) manufactured the data collection and transmission systems. They also port the data to a website that summarizes vehicle performance. UC Davis contracted for additional programming services to allow individual Project drivers to track their performance. These information systems and modifications will be described further in section 3D: Instrumentation and Interfaces.

### *2) Demonstration and Research*

The PHEV-conversions have been, and continue to be, placed in households in northern California for several weeks at a time. Households are recruited with the assistance of AAA Northern California, Nevada & Utah. The households are selected because they represent important markets segments and use patterns for PHEVs. The realized sample of Project participants to date will be described in detail in the next section. During the households' PHEV trial use periods, we collect data on travel, vehicle recharging and refueling, performance of the vehicle, and participants' response to the PHEV technology. Data are collected directly from the vehicle using on-board data systems, as well as from interviews, questionnaires, and fueling logs.[3]

[3] The demonstration vehicles are instrumented to record travel and recharging/refueling behavior. Additionally, drivers complete a refueling log: we can infer from vehicle data when it has been refueled

*3) Public Education and Outreach*

The PHEVs were also used in a public education and outreach programs. The vehicles were displayed at public events and used in educational settings. Information on PHEVs was accessible from the PHEV Center's website. Education and outreach events included UC Davis' Picnic Day and Whole Earth Festival, Earth Day activities, and other public events, school events, and vehicle displays.

### Research Questions to be addressed in this Project

The Research and Education and Outreach activities address the following questions.

- **Purchase choices:**
  - What sorts of PHEV designs will buyers want?
- **Charging and refueling behaviors:**
  - When, where and how much will PHEV owners choose to recharge from the electrical grid rather than refuel with liquid (or gaseous) fuels?
- **Driving behaviors:**
  - When, where and how much of their driving will PHEV users accomplish by electricity vs. gasoline?
  - How does energy use and cost information affect driving and recharging behavior?
- **Broader impacts:**
  - How will overall social and environmental benefits affect individual choices?
  - What information about PHEVs is spread through the social networks of participants and how do those exchanges affect the formation of drivers' values regarding PHEVs?

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with gasoline, but the only way to know how much was paid for gasoline is to have drivers record this information.

## Research Activities within the Project

Within the overall Project there are four related research activities, these are briefly described here and more fully discussed in the following major sections of this report.

### *Household response to the PHEV-conversions*

In some sense the entire Project is about household response to PHEV-conversions. This specific activity focuses on the following results:

1. What are the PHEV designs created by Project households and how do these designs compare to those created by survey respondents who have no experience driving PHEVs?

2. What are the recharging behaviors of the Project households, and how do driving behaviors influence recharging behaviors?

3. Given that Project participants are driving one specific incarnation of what a PHEV can be, what are the effects on their transportation energy use?

The other activities described next explore why the responses above are as they are, how they are formed, and how they might be influenced by information.

### *Narratives*

We employ narrative research methods in this Project both to synthesize the large amounts of disparate data we are collecting for each household and to analyze both those synthesis documents and the original textual data from the household interviews. Each household completes three on-line questionnaires including two sets of complex PHEV design games. Each household completes three to five semi-structured interviews, resulting in two to six hours of recorded and transcribed conversations. Each vehicle is equipped with on-board data collection systems, resulting in 500,000 to 700,000 records on the household's driving, recharging, and refueling of the vehicle. Synthesis narratives are written by incorporating data from all these sources. Narratives have beginnings and ends, but are more than simple chronologies of events; they have plots to give meaning and coherence to events. The starting point for synthesizing the data into a narrative begins with the interviews. Additional data are brought in from the questionnaires, e.g., the PHEV designs created in the on-line questionnaires. The interviews explain why the households designed the PHEV they did, supported (or contradicted, if that is the case) by the data from the vehicle.

The purpose of the synthesis narratives is to tell the best possible story about each household and their experience with PHEVs. The purpose of subjecting the interviews to analysis is to ascertain whether themes emerge across the households. That is, what can we say about the groups' experience? For example, across the group how do households talk about similar things, e.g., recharging?

Both the synthesis narratives and the interview analyses are somewhat contrived since, in general, the entire Project is an intrusion into the participants' ongoing lives (narratives) and specifically, the interviews are semi-directed and therefore not entirely of the households' own telling. For example, knowing that recharging behavior is central to the research goals of the Project, all households are asked to talk about recharging. We neither simply wait to listen to whether they talk about recharging, nor allow them to complete their interview without at least addressing questions about recharging.

### *Interfaces and Instrumentation*

Research on the effect of driver feedback is carried out in two phases. The first is integral to the design of the vehicles, PHEV-conversions, and on-board data systems deployed in this Project. The PHEV-conversion process adds a color change to the battery icon on the stock Prius Energy Monitor to tell the driver when the vehicle has switched from CD to CS operation.[4] The on-board data systems transmit data to the service provider, who displays summaries of the data on a website. As part of the household interviews, we assess the participants' use of and response to these two interfaces. Further, we examine whether the addition of the website information makes any measurable impact on the

[4] Terminology used to describe the operation of PHEVs is explained fully in the following sub-section: Defining Terms.

vehicle performance as recorded by the on-board data systems. (Most of the households included in this report were not provided access to the website displaying their vehicle's data until halfway through their trial month.) Results from this first phase of interface and instrumentation research are included in this report.

The second phase of instrumentation research builds on the first, but is not scheduled to begin until summer 2009. In the second phase, a custom-made driver feedback display will be included as part of the research design for a subset of the Project households. The display device will allow the driver to choose from a variety of information to be displayed. Evaluation will be based on additional survey and interview questions as well as data recorded by the existing V2Green data systems and the new in-vehicle device.

### *Social Influence*

Within this PHEV demonstration, a sub-group of 10 to 15 social networks (each centered on a household driving the PHEV-conversion) will be selected investigate how interpersonal interactions influence the assessment and adoption of electric-drive vehicles. Analysis of four networks has been completed to date and is discussed in this report. Three research questions are addressed:

1. Do interpersonal interactions play a significant role in the assessment and adoption of electric drive vehicles?

2. If so, how can we characterize the interpersonal interactions that influence consumer perceptions of functional, symbolic, and pro-societal attributes?

3. Under what conditions might households adopt the pro-societal car?

To explore these research questions, this project maps, measures, and stimulates the personal networks of selected households. A multi-method qualitative approach is followed, combining semi-structured interviews, internet-based questionnaires, and a social episode diary technique to track each social network. First, prior to receiving the PHEV, the participating household is asked to map their social network and invite several people from it to take part in the study. During each participant's PHEV trial, information is collected regarding their social discussions and interactions with network members—seeking to characterize how social interactions influence perceptions, expectations, and ultimately, purchase intention. Findings will help inform policymakers, researchers and industry how new technologies with pro-societal attributes could enter the market.

## Defining Terms

In this section we present the basic vocabulary that we will use throughout this report to describe PHEVs. Some of this vocabulary is intended for readers of this report, i.e., it is not the vocabulary we necessarily used when we spoke with our participants about PHEVs. Describing where and how those two vocabularies diverge is one of the developing outcomes of the overall research agenda of which this Project is a part.

A PHEV has both an electric motor and a heat engine—usually an internal combustion engine (ICE).[5] This flexibility also complicates vehicle designs and possible ways of using energy from two different systems. Figure 1 shows two simple schematics of possible PHEV architectures, i.e., the overall design of the PHEV system to supply power from two different sources. A series architecture powers the vehicle only by an electric motor using electricity from a battery. The battery is charged from an electrical outlet or by the gasoline engine via a generator. A parallel architecture adds a direct connection between the ICE and the wheels, adding the potential to power the vehicle by electricity and gasoline simultaneously and by gasoline only. As examples of each architecture, General Motors is working on a series architecture, e.g. the Chevy Volt and Toyota is developing a PHEV with a parallel architecture, e.g. a plug-in version of the Prius.

### *Basic PHEV Design Concepts*

Here we explain four fundamental PHEV concepts that will frame our questions with participants throughout all phases of the PHEV research agenda and the Project in particular. First, for any given architecture, a PHEV can operate in one of two modes: *charge sustaining* (CS) or *charge depleting* (CD). Figure 2 (adapted from Kromer and

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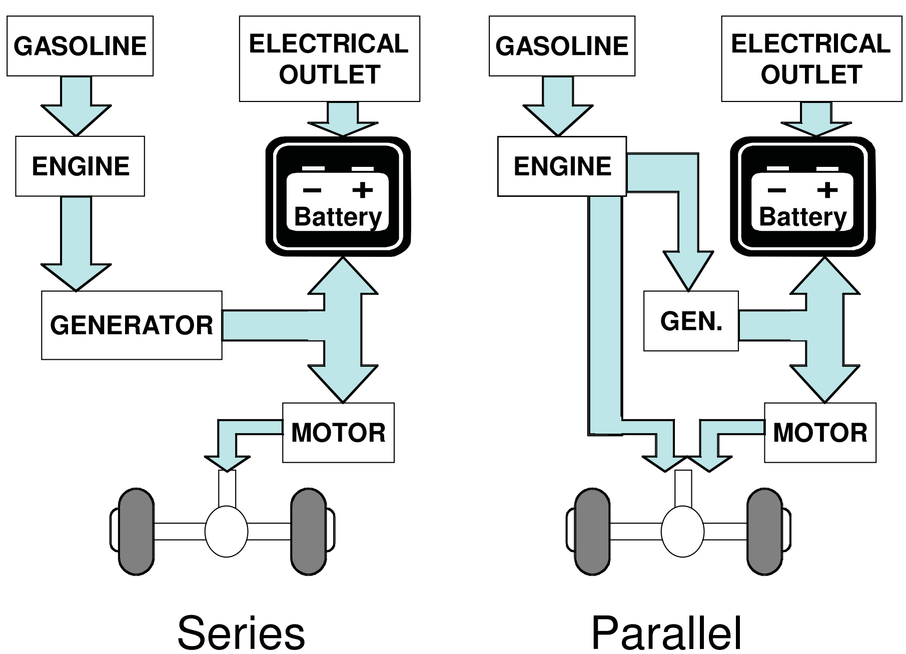
[5] As the ICEs in most conventional light-duty vehicles in the US are fueled with gasoline, we will refer to gasoline and gasoline engines without precluding the possibility of other fuels.

Heywood, 2007, p.31) illustrates these two modes. The vertical axis is the battery's state of charge (SOC); the horizontal axis is the distance traveled. In practice, the maximum SOC may be limited to less than 100 percent, and the minimum SOC higher to more than 0 percent, both to preserve battery life and improve safety. The difference between the maximum and minimum SOC is known as the usable *depth of discharge* (DOD), which varies across battery and vehicle designs.

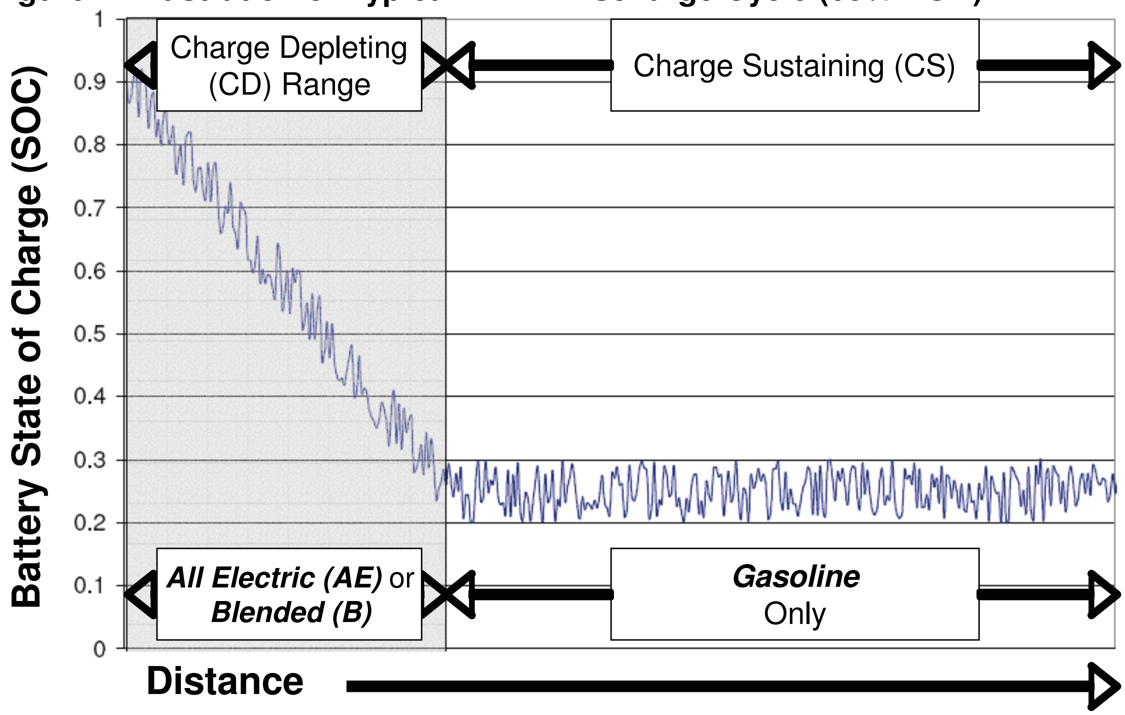
In the Figure 2 example, the battery is "fully" charged (from an electrical outlet) to 90 percent SOC. Once it starts driving, the PHEV is driven in charge-depleting (CD) mode—energy stored in the battery is used to power the vehicle, gradually *depleting* the battery's SOC. Once the battery is depleted to a minimum level, set at around 25 percent in this example, the vehicle switches to charge-sustaining (CS) mode. In CS mode the SOC is *sustained* by relying primarily on the gasoline engine to drive the vehicle, only using the battery and electric motor to increase the efficiency of the gasoline engine, as is now done in an HEV. The vehicle remains in CS mode until the battery is plugged in to the electric grid to recharge. The distance a fully charged PHEV can travel in CD mode before switching to CS mode is one definition of *CD range*.

**Figure 1: Basic PHEV Drivetrain Options—Series vs. Parallel Design**



Second, a PHEV can be designed for *all-electric* or *blended* operation in CD mode. A PHEV designed for *all-electric* operation can be driven for the CD range using only electricity from the battery, and the engine is not used at all. In contrast, a PHEV designed for *blended* operation will use electricity *and* gasoline to power the vehicle throughout the CD range—energy from the engine and the battery are "blended" together through the electro-mechanical drivetrain. Thus, a PHEV designed for *all-electric* driving will require a battery capable of delivering more power than a PHEV designed for *blended* driving because the battery (and motor and power electronics) must be capable of providing the full power of the vehicle, not just partial power.

**Figure 2: Illustration of Typical PHEV Discharge Cycle (65% DOD)**




Source: Adapted from Kromer and Heywood (2007, p31). Used with permission from authors.

Third, PHEV designs are commonly described according to CD range; the common notation is PHEV-*X*, where *X* is distance in miles. For instance, a PHEV-10 can be driven 10 miles in CD mode before switching to CS mode. However, this notation does not distinguish whether a PHEV in CD mode is operating all-electrically or by blending, nor does it specify the driving conditions that would allow CD mode for the stipulated distance. Comparisons of PHEVs, even those sharing the same PHEV-*X* designation, must reconcile assumptions regarding CD mode and driving behavior.

Kurani, Heffner, and Turrentine (2007) discuss how further confusion in PHEV notation can result from two differing concepts of PHEV-*X*. First, Gondor and Simpson (2007) argue that *X* should be defined as the equivalent number of miles of petroleum displaced by electricity from the battery. This approach makes no distinction between *all-electric* and *blended* operation; a fully charged PHEV-10 could store and use enough electricity to reduce gasoline use by the amount of gasoline required to travel 10 miles, but not necessarily during 10 continuous miles of all-electric operation. On the other hand, the California Air Resources Board (CARB, 2003) defines *X* as the total miles that can be driven before the gasoline engine turns on for the first time, also known as *all-electric* range (or *zero-emissions* range). By this definition, a fully charged PHEV-10 could be driven for the first 10 miles without using any gasoline. As of the writing of this report, CARB is considering a proposal to allow PHEVs designed for *blended* operation to receive credits under the zero emissions vehicle regulation (CARB, 2008b).

Using the language developed in this section, the PHEV conversions used in this Project could be described as blended PHEV-30s, in which we adopt the definition of the distance at which the vehicle switches from CD to CS operation as the definition of CD range. We will return to this vehicle characterization in our conclusions, modifying it in accordance with the on-road performance of our first 34 households.

## 2. PHEV DEMONSTRATION AND RESEARCH PLAN

The Project provides households with real-world experience with PHEVs prior to asking them to evaluate such vehicles and offer their preferred PHEV designs.

### Household PHEV Placements

PHEV-conversions are placed in households for periods of time that allow for the household members to learn and adapt. Starting in late-August 2008, household placements were initially scheduled for four weeks. After completing the research process with over twenty households, we judged that four weeks was not long enough for many of the households. In particular, some were still learning about recharging and its effects on energy use and cost. Further, most households were still talking about the Prius *per se*, leaving less time to discuss the added plug-in capability.[6]

Starting in February 2009, households in the Project use the vehicles for six weeks. The PHEV-conversion package allows for the conversion to be taken off-line, returning the operation of the vehicle to that of a conventional Prius.[7] Therefore, the PHEV-conversions are now delivered to the households with the conversion off-line. The conversion is placed back on-line after two weeks. This allows the households to respond to a (more-or-less) conventional Prius and then move on to experience and evaluate a particular PHEV. Further, the two-week pre-PHEV period allows us to establish a baseline of driving performance based on data from the on-board data systems.

Participants are interviewed at the start of, during, and at the end of their PHEV trial to make sure the vehicles are working properly and to explore with the household their use of and response to the vehicle. Further, the households complete a screening questionnaire (used in recruiting participants) and the first and third parts of the

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[6] Of the households included in this report, only one was a pre-existing HEV owner. Additional HEV owners are being included in the subsequent sample.

[7] Because the conversion package adds weight, the Priuses in our demonstration—with the conversions off-line—can be expected to return slightly worse fuel economy than unconverted Priuses.

questionnaire previously administered to representative samples of the US, California, and the counties along the Interstate 80 corridor from the San Francisco Bay Area to eastern suburbs of the Sacramento region. The last region was over-sampled in particular to provide a comparative population for the households participating in the Project.

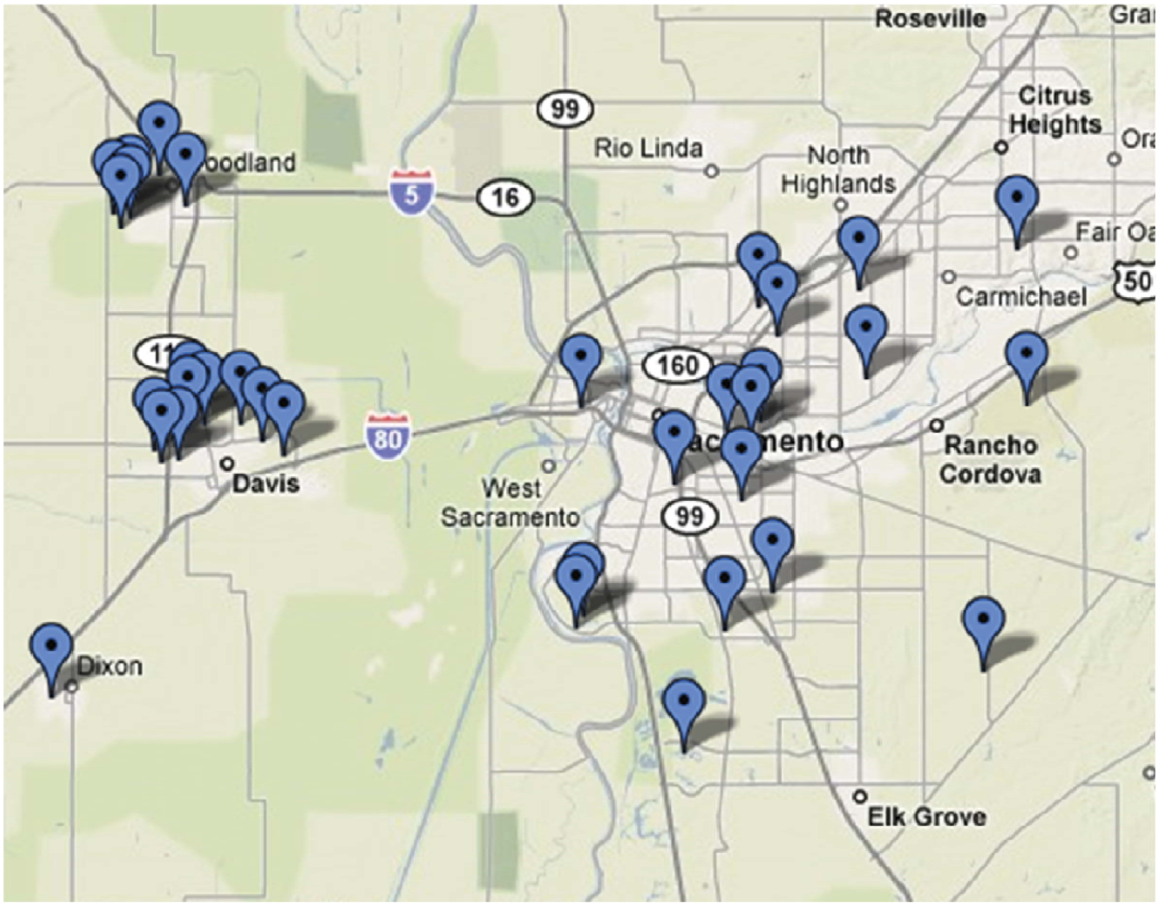
### *Sampling*

Participants are recruited through an "illustrative" sampling method (Turrentine and Kurani, 2007.) Such a sample does not attempt to be representative of a population; rather, the purpose is to illuminate the behavior of specific groups. The sampling frame for the Project is defined by 1) automotive insurance requirements, 2) geographic location, 3) vehicle ownership, 4) driving, and 5) broad categories of household structure.

Participants are selected for the Project in a three-stage process. First, AAA Northern California, Nevada & Utah issues an invitation to their automotive policyholders who 1) meet minimum requirements regarding the amount of insurance they carry and their driving records, and 2) live within the geographic region specified by researchers at UC Davis. Presently that region is roughly defined as the area within about 30 to 45 minutes driving time of Davis, CA. Second, volunteers from the recipients of the letter are instructed to log-on to a website hosted on a UC Davis server, where they complete a brief questionnaire which solicits more specifics of the potential participants vehicles, home, travel, household, and contact information. Third, researchers review the questionnaire responses and select households based on the goal to illustrate the responses of different types of households.

An illustration of the interaction between Project management and research goals is the geographic distribution of the participant households summarized in this report as shown in Figure 3. To initially simplify the logistics of vehicle delivery, pickup, and household interviews the first participants were selected from the city of Davis, CA. However, an important research goal is to incorporate households in a variety of towns, cities, and land use settings within these towns and cities. As can be seen in the figure, this goal is being achieved and will be furthered as additional participants are selected during the remainder of the Project.

**Figure 3: Geographic distribution of PHEV Project participants (n=34)**




The realized Project sample-to-date will be compared to the California and northern California survey respondents after we describe the interviews and questionnaires from which the comparative data are taken.

## The Interviews and Questionnaires

Each household was interviewed three to five times: upon vehicle delivery, every two weeks, and finally after the last week when the vehicle was retrieved. Interviews last between one and two hours. Two researchers attend the first and last interviews. All interviews are recorded; all but the first interview recordings are transcribed. The initial interviews tend to be given over to formally enrolling the household in the study—which must happen before the vehicle can be handed over and substantive interviewing can begin. During this first interview, researchers primarily listen for the questions the household has about the vehicle, offering answers that are as non-leading as possible. For example, every household asks how often the vehicle should be plugged in. Our standard response is that these cars can be driven without ever being plugged in, but that what we are hoping to learn from the household is how often they plug-in and why.

The second and third interviews follow protocols, i.e., outlines of topic areas to be covered with every household. Each topic area includes example prompts that are not used in every household, but only as needed or appropriate to each household. An example of the protocol is included in Appendix A.

In addition to the recruiting and screening questionnaire, each household in the Project also completed a two-part online survey eliciting several types of data. The survey was slightly modified from the instrument administered to over 2,200 U.S. respondents as reported in Axsen and Kurani (2008). This previous study included over-samples of California (n= 851) and Northern California (n=216) in the region along Interstate-80 from the San Francisco Bay Area to the eastern reaches of the Sacramento conurbation. In this report, responses from these two samples are compared with the responses of Project participants.

The primary survey instrument used in the PHEV Project is a set of two internet-based questionnaires, each requiring 20 to 30 minutes to complete: 1) background information, completed before the household drives the PHEV, and 2) plug-in hybrid electric vehicle (PHEV) designs, completed after the household has driven the PHEV for several weeks. Part One includes questions on vehicle ownership, knowledge of gasoline use and spending, knowledge of electricity use and spending, awareness of electric-drive vehicles, attitudes towards environmental and global issues, as well as household structure, income, education and other demographic variables. Awareness of electric-drive vehicles is assessed with questions eliciting the stated familiarity of respondents with conventional gasoline, hybrid-electric, electric, and plug-in hybrid electric vehicles. Respondents were then asked to demonstrate their understanding by choosing how each vehicle type could be fueled: with gasoline, electricity through an electrical outlet, or either. The implication of this exercise is not that consumers need to have a deep technological understanding of electric-drive vehicles in order to buy them. However, we feel that basic familiarity, i.e. whether or not the vehicle can be plugged in, may shape participants experience with the PHEV-conversion during their trial period and ultimately affect their PHEV design priorities.[8]

The Part Two questionnaire focuses on PHEV design priorities elicited in two versions of priority-evaluator games. Commonly, researchers will infer preferences for attributes of alternative fuelled vehicles by presenting participants with a description of one or several new technologies, followed with a set of hypothetical choice scenarios in which respondents make several choices from sets of vehicles of different attributes (see for example Bunch et al., 1993; Ewing and Sarigollu, 2000; Potogolou and Kanaroglou, 2007). However, Heffner et al. (2007) demonstrate that more in-depth research, such as household interviews, can reveal important information that choice experiments cannot. To improve the quality of data gathered from Project participants, prior to the PHEV design exercises, participants were provided a PHEV buyers' guide describing basic design options for PHEVs (replicated in Appendix B). Respondents then completed two PHEV design games (replicated in Appendix C). The first was a PHEV *Development Priority* game in which participants create PHEV designs over several iterations. Second was a *Purchase Design* game, similar to the first, but the design possibilities were priced in dollars and participants could reject buying a PHEV, retaining a conventional vehicle.

One key difference between the games utilized in this study and a stated choice exercise is that the games are design exercises, not choice exercises. Rather than choose their preferred vehicle design from a limited set of options (typically repeated several times) specified by the researchers, participants in the design games have a design envelope available to them, and they construct their most favored design from within that envelope subject to resource constraints. Kurani et al. (1996) discussed the basis for regarding consumer evaluations, especially of novel products such as electric-drive vehicles, as being constructed in the process of choosing (or not choosing).

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[8] As asked of the prior national, statewide, and regional samples—who will not have experience with a PHEV afforded to Project participants—the question was intended only to test whether basic familiarity with electric-drive technologies affected PHEV design priorities.

Both games focused on four PHEV design attributes: (1) hours required for complete recharge of a depleted battery, (2) gasoline use in CD mode, (3) miles of range in CD mode, and (4) gasoline use in CS mode. In each game, a base PHEV design is offered with capabilities easily achievable by current battery technology (Axsen et al., 2008): a PHEV that requires up to 8 hours to completely recharge, that can be driven for the first 10 miles in CD mode using blended operation that increases gasoline-only fuel economy to 75 mpg, and that can improve fuel economy by 10 mpg when operating in CS mode over an otherwise similar conventional internal combustion engine vehicle.[9] In both games, participants were given opportunities to improve each attribute under different resource conditions.

We chose these four attributes due to their importance in determining driving patterns as well as reflecting technological capabilities. First, the time to recharge a depleted battery in PHEVs more capable than the base design would take 6-8 hours, but technology exists to allow “fast” charging in less than one hour—allowing for significantly different recharge and driving patterns. Second, currently available PHEV conversions are designed to provide blended CD mode. We specified upgrades to account for several levels of gasoline-only fuel economy in blended operation: 75, 100, and 125 mpg. This range includes the 100 mpg “magic” number identified as important among some early PHEV conversion owners (Kurani et al., 2007). Because automakers such as General Motors have announced plans to release PHEVs designed for all-electric operation, we also include an all-electric CD upgrade option. Third, CD range depends on battery energy capacity, and proposed designs typically range from 10 to 40 miles (Pesaran et al., 2007; Kromer and Heywood, 2007). The fourth category, fuel consumption in CS mode, is comparable to the operation of today’s hybrid electric vehicles; the battery and electric motor are used to improve the efficiency of the gasoline engine, not to use grid

[9] Note that these PHEV design games are meant to represent a PHEV design space that is technologically feasible and that allows respondents to tell us which (and how much) of the four attributes are more or less important, but not necessarily to produce precise vehicle specifications. For instance, the battery required for our base PHEV design would likely require only 2 to 3 hours to fully recharge with a 110-volt circuit. However, based on pre-testing, we chose to simplify attribute levels and ignore potential interactions to create exercises that are more likely to be understood by our respondents.

electricity. Most hybridized drivetrains can increase fuel economy by 10 to 30 miles per gallon (mpg) relative to a similar size, weight, and performance vehicle.

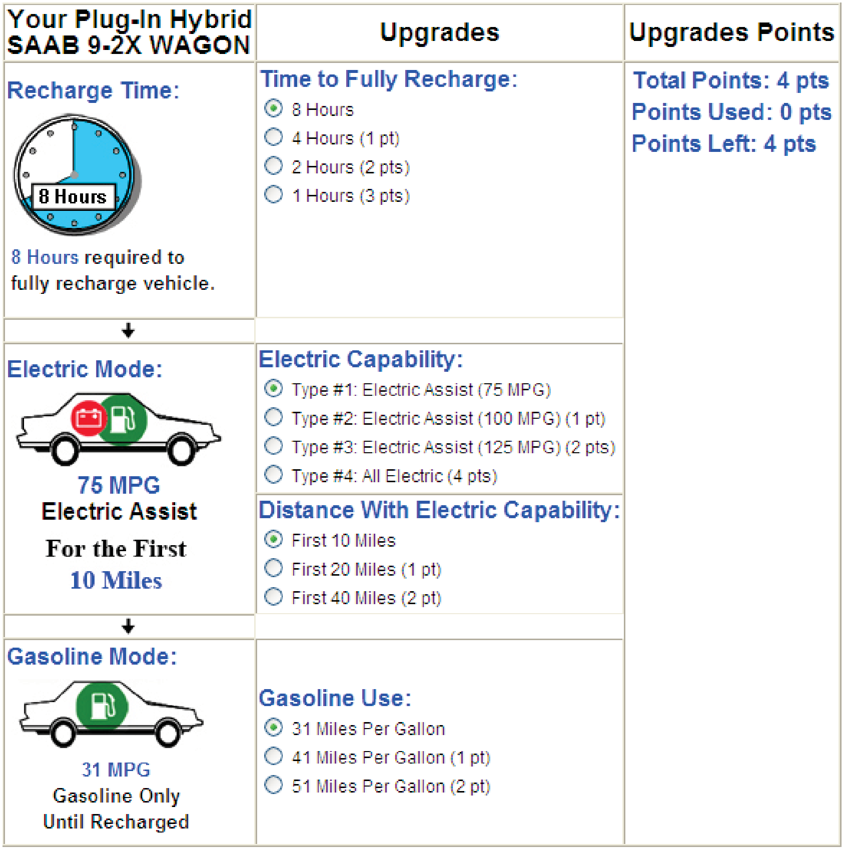
The first exercise, the *Development Priority* game, presents participants with a hypothetical scenario: an existing household vehicle is to be upgraded to a PHEV at no cost.[10] The performance and appearance of their vehicle would remain the same, except for the additional plug-in hybrid capabilities. Participants were presented with a base PHEV model and given points they must allocate among potential upgrades. Over five rounds of the *Development Priority* game, participants were provided progressively more points (Table 1). For the first three rounds of the game higher levels of upgrades of the four attributes and more combinations of upgrades were also offered, expanding the PHEV design envelope to observe participants' allocation of resources. A screenshot of the game, along with the language used for respondents, is portrayed in Figure 4.

**Table 1: Upgrades for PHEV Development Priority game**

| Attribute (base value) | Round One: (1 point) | Round Two: (2 points) | Rounds Three, Four and Five: (4, 6 and 8 points) |
|---|---|---|---|
| Recharge time: (8 hours) | 4 hours (1pt) | 4 hours (1pt)<br>2 hours (2pt) | 4 hours (1pt)<br>2 hours (2pt)<br>1 hour (3pt) |
| Charge depleting (CD) mpg and type: (75 mpg) | 100 mpg (1pt) | 100 mpg (1pt)<br>125 mpg (2pt) | 100 mpg (1pt)<br>125 mpg (2pt)<br>All-electric (4pt) |
| CD range: (10 miles) | 20 miles (1pt) | 20 miles (1pt)<br>40 miles (2pt) | 20 miles (1pt)<br>40 miles (2pt) |
| Charge sustaining (CS) mpg: (Current mpg* +10) | Current mpg +20 (1pt) | Current mpg +20 (1pt)<br>Current mpg +30 (2pt) | Current mpg +20 (1pt)<br>Current mpg +30 (2pt) |

[10] Which household vehicle was to be "upgraded" was determined in Part One of the survey as either the vehicle that the household most recently purchased, or, the newer vehicle that is most frequently driven (see the full survey in Appendix C).

**Figure 4: Screenshot of Development Priority game (Round Four)**



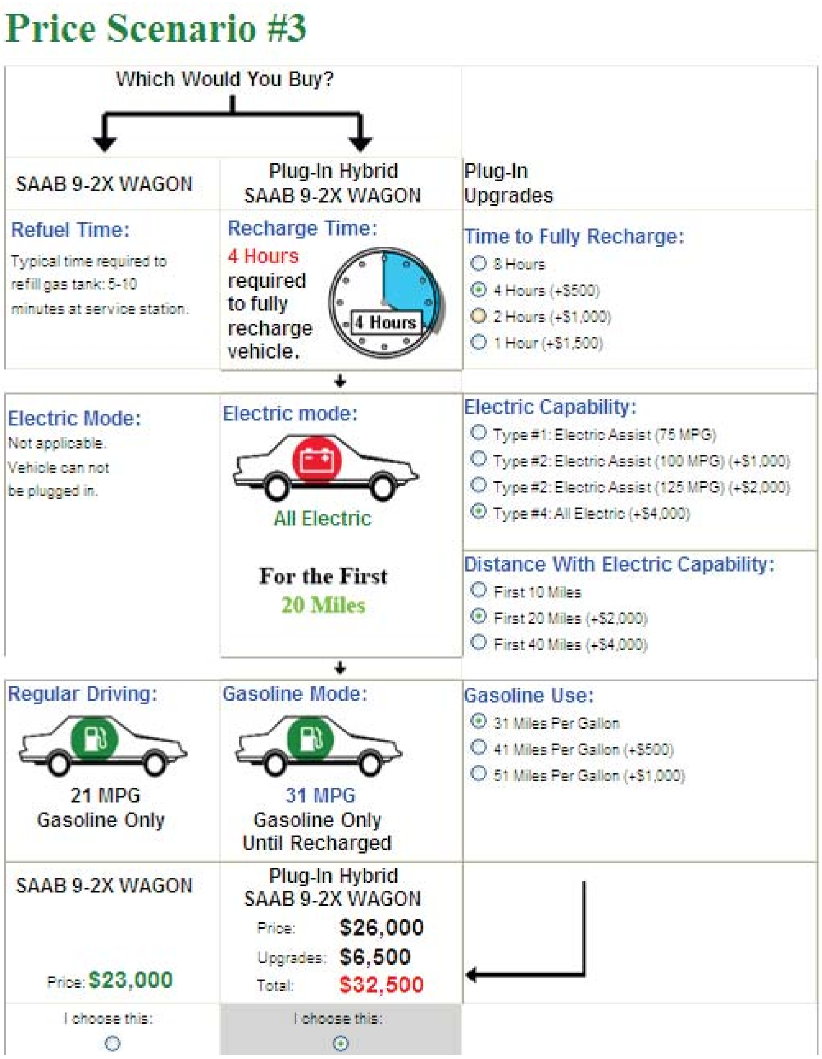

The second exercise, the *Purchase Design* game, framed the PHEV design exercise in the context of a future vehicle purchase. The questionnaire first elicited information about the anticipated price, make, and model of the next new vehicle the respondent's household would likely buy. The respondent then completed two PHEV purchase exercises, each comparing their anticipated conventional vehicle with a PHEV version of the same. Participants were presented with a "higher" price and "lower" price PHEV purchase conditions, where prices in both conditions also depended on whether the vehicle was a car or truck (Table 2). As in the *Development Priority* game, each exercise started with the same base PHEV model, with additional upgrades available for added price. The participant could choose either their anticipated conventional vehicle, the offered (base) PHEV, or to upgrade the PHEV. Figure 5 is a screenshot of this exercise.

**Table 2: Price of upgrades for Purchase Design game**

| Attributes | Attribute level | "Higher" price Car | "Higher" price Truck | "Lower" price Car | "Lower" price Truck |
|---|---|---|---|---|---|
| Base premium over conventional | | $3,000 | $4,000 | $2,000 | $3,000 |
| Added premiums: | | | | | |
| Recharge time | 8 hours | 0 | 0 | 0 | 0 |
| | 4 hours | +$500 | +$1,000 | +$250 | +$500 |
| | 2 hours | +$1,000 | +$2,000 | +$500 | +$1,000 |
| | 1 hour | +$1,500 | +$3,000 | +$750 | +$1,500 |
| CD mpg and type | Blended | | | | |
| | 75 mpg | 0 | 0 | 0 | 0 |
| | 100 mpg | +$1,000 | +$2,000 | +$500 | +$1,000 |
| | 125 mpg | +$2,000 | +$4,000 | +$1,000 | +$2,000 |
| | All-electric | +$4,000 | +$8,000 | +$2,000 | +$4,000 |
| CD range | 10 miles | 0 | 0 | 0 | 0 |
| | 20 miles | +$2,000 | +$4,000 | +$1,000 | +$2,000 |
| | 40 miles | +$4,000 | +$8,000 | +$2,000 | +$4,000 |
| CS mpg | Conventional mpg +10 | 0 | 0 | 0 | 0 |
| | Conventional mpg +20 | +$500 | +$1,000 | +$250 | +$500 |
| | Conventional mpg +30 | +$1,000 | +$2,000 | +$500 | +$1,000 |

Because battery and drivetrain costs are uncertain, upgrade prices in Table 2 are hypothetical. We are less concerned whether the prices we now present to participants will be right in a future (if and) when PHEVs are marketed, and more concerned with how participants respond in the PHEV design space within different price contexts. Still, the price contexts we present are not wholly imaginary. Overall, prices are based on short term (high price) and long term (low price) estimates from previous studies: Markel (2006) estimates incremental costs for PHEVs with all-electric capabilities (7 to 19 kWh) at $6,000 to $22,000, while Kalhammer et al. (2007) provide cost estimates for PHEVs with slightly lower capacity batteries (4 to 14 kWh) in the range of $2,000 to $8,000. Price premiums for PHEV designs in our survey ranged from $3,000 to $13,500 for cars in the "high" price condition, and from $2,000 to $7,250 in the "low" price condition. For trucks, base model PHEV prices are increased and upgrades doubled based on Duvall et al.'s (2002) estimates of a full size SUV PHEV requiring 75 percent more energy capacity and 190 percent more battery power to achieve the same CD performance as a compact car PHEV.

**Figure 5: Screenshot of Purchase Design game ("high" price, vehicle model customized for respondent)**




## Who are the Project Participants?

To explore whether findings from the Project can be generalized to other people, we describe briefly who the Project respondents are and how they compare to other larger samples. These include the California and northern California over-samples we surveyed during our nationally representative survey of new car buying households. Other comparisons are made to the 2001 Nationwide Household Travel Survey, the 2005-07 American Community Survey, and the 2000 United States Census.

Descriptions of the samples on the following attributes are presented in Table 3: household hybrid vehicle ownership, respondents' gender, education, age, household income, and housing type. One important difference between the Project participants and all other samples is that Project participants are chosen, in part, because they have a place at home to recharge the PHEV—we judged it to be of little value to give a vehicle to a household who could not routinely and easily recharge the vehicle, if they chose to. This choice on our part will introduce some differences in income and housing type as seen in Table 3. Finally, the description of the Project households is highly provisional and will change by design over the remainder of the Project.

Our sample contains about the same proportion of HEV owners as do our survey over-samples for northern California and California—but still, this is one HEV owner (to date). Though we cannot report hybrid vehicle ownership rates for the ACS or Census samples, it seems clear that all our survey and Project samples contain a higher proportion of hybrid owners than exist in the general population. Still, the over-representation is not so large as to skew overall responses. We expect that the percentage of hybrid owners in the Project sample will ultimately be higher than it is now.

The gender balance of the present Project participants represents that of the general population and California over-sample; the northern California over-sample is skewed toward male respondents. The Project participants are skewed toward people with graduate educations—even compared to our survey over-samples, which are skewed toward higher education compared to the general population samples. Respondents in all three of our samples are much more likely to be between the ages of 35 and 54 than the general population; the skew toward this age group is even stronger in the present Project sample than in the survey over-samples. As with education and age, the present sample of Project participants amplifies the distinctions from the general population of the survey over-samples: the over-samples of new car buyers in California and northern California are more likely to have higher household incomes than the general population and the Project participants are even more likely to have higher incomes. As noted above, by design (or rather, because of known correlations between housing type and ability to recharge at home) our survey respondents are far more like to live in detached homes.

## Table 3: Comparing Project participants, survey respondents, and the general population

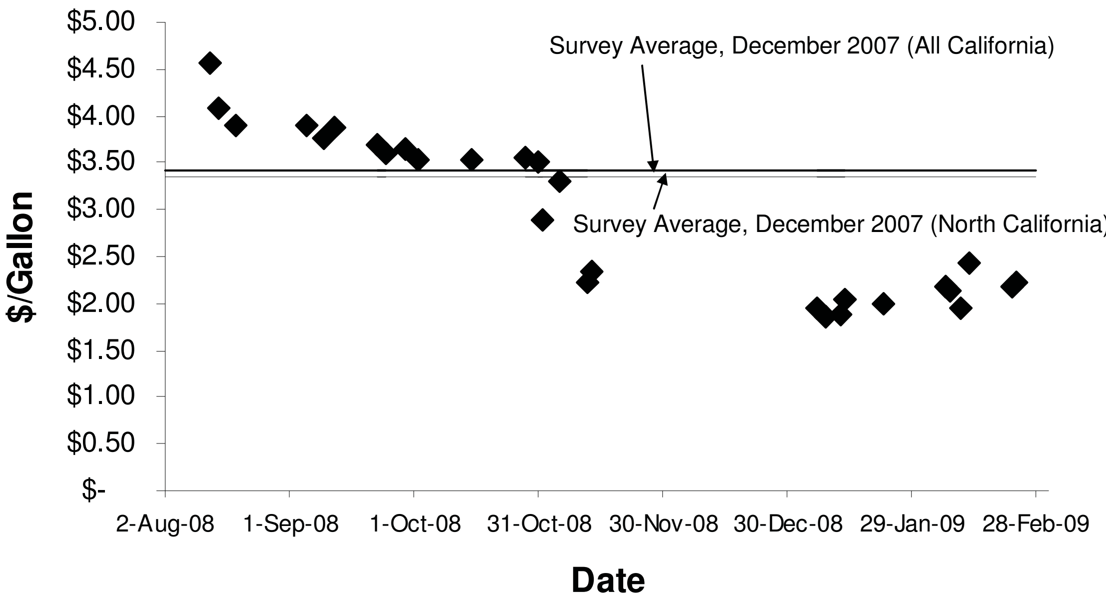
| Target | | AAA members | New vehicle buyers | | | General population | |
|---|---|---|---|---|---|---|---|
| Year | | 2008-9 | 2007 | 2007 | 2001 | 2005-7 | 2000 |
| Data source | | PHEV Demo | PHEV Survey (Nor. Cal.)[a] | PHEV Survey (Cal.)[a] | NHTS[b] (Cal.) | ACS[f] (Cal.) | Census[g] (Cal.) |
| Sample size | | 34 | 216 | 851 | 389 | | |
| Hybrid owner? | Yes | 11.8% | 8.9% | 10.6% | - | - | - |
| Gender[c] | Male | 49.2% | 59.7% | 48.5% | 44.5% | 50.0% | 49.7% |
| | Female | 50.8% | 40.3% | 51.5% | 55.5% | 50.0% | 50.3% |
| Education[d] | High school or lower | 9.1% | 2.6% | 8.8% | 22.1% | 43.0% | 43.3% |
| | Some college | 21.2% | 34.9% | 33.9% | 22.1% | 20.4% | 22.9% |
| | College degree | 30.3% | 32.8% | 39.5% | 39.9% | 26.3% | 24.2% |
| | Graduate degree | 39.4% | 29.7% | 17.8% | 15.9% | 10.4% | 9.5% |
| Age[c] | 15 to 24 | 3.2% | 4.6% | 3.3% | 6.5% | 19.0% | 18.3% |
| | 25 to 34 | 8.1% | 21.1% | 20.5% | 18.0% | 18.3% | 19.8% |
| | 35 to 44 | 25.8% | 27.3% | 29.0% | 23.5% | 19.3% | 21.6% |
| | 45 to 54 | 27.4% | 29.4% | 23.7% | 24.8% | 17.6% | 16.5% |
| | 55 to 64 | 29.0% | 10.8% | 15.1% | 13.3% | 12.1% | 9.9% |
| | >64 | 6.5% | 6.7% | 8.3% | 13.8% | 13.8% | 13.8% |
| Household income | < 30 k | 3.1% | 1.8% | 2.0% | 6.3% | 25.3% | 31.2% |
| | 30 k to 60 k | 15.6% | 11.9% | 17.6% | 23.4% | 25.8% | 29.5% |
| | > 60k to 100k | 15.6% | 35.1% | 27.7% | 32.3% | 23.0% | 22.1% |
| | > 100k | 65.6% | 51.2% | 52.7% | 38.0% | 25.8% | 17.3% |
| | Mean income[e] | $117,734 | $106,949 | $104,814 | $84,416 | $73,944 | $61,441 |
| | Ratio of mean incomes (new vehicle buyer/gen. pop.) | 1.59 | 1.45 | 1.42 | 1.37 | | |
| Housing type[d] | Detached house | 94.1% | 71.3% | 68.1% | 79.4% | 58.0% | |
| | Attached house | 5.9% | 10.3% | 11.9% | 4.4% | 7.0% | |
| | Apartment | 0% | 17.9% | 16.7% | 13.6% | 30.7% | |
| | Mobile home | 0% | 0.5% | 3.4% | 2.6% | 4.2% | |

[a] U.S. weights provided by Harris Interactive.
[b] NHTS sample limited to responding California households that had purchased a vehicle of model year 2001 or 2002.
[c] For PHEV Project: data reported for all participants; for PHEV survey: data only reported for responding member of household.
[d] For PHEV Project and PHEV survey: data only reported for responding member of household.
[e] Mean approximated from the product of middle values assigned to each income category and the proportion of the sample in that category.
[f] 2005-2007 American Community Survey 3-year estimates, California.
[g] 2000 Census by the U.S. Census Bureau.

### Gasoline Prices Faced by Survey Respondents and Project Participants

One question we are repeatedly asked regarding the national study is, "When was it done in comparison to the run-up of gasoline prices to past $4.00 per gallon during the summer of 2008?" The answer is that the national survey was conducted in December 2007 and precedes the rise of gasoline prices past $4.00 per gallon by several months. The average price last paid for gasoline by the California and northern California samples were both about $3.40 per gallon as shown by the horizontal lines in Figure 6.

**Figure 6: Comparing gasoline prices from survey respondents (lines) and Project participants (diamonds)**




In contrast, the first Project participants were paying well in excess of $4.00 per gallon for gasoline in August 2008. But these are a small minority of Project participants, as prices quickly declined through September and October 2008 to, and then below, the average of the price faced by the national survey respondents. Still, whether they faced higher gasoline prices during their PHEV trial period or whether they simply recall such higher prices from last summer, we expect that our Project participants may be more sensitive to the uncertainty of gasoline prices than the national survey respondents were at that time. This may make Project participants less like our survey respondents, but makes them more like their peers, i.e., all car-buying households, who have now lived through this same price history.

### Motivations and Knowledge regarding Electric-drive

The invitation sent by AAA Northern California, Nevada & Utah did not emphasize motivations to volunteer; still, one might speculate that the households volunteering for a PHEV demonstration project have stronger motivations and knowledge regarding electric-drive vehicles than households in general. Responses to three questions regarding motivations are summarized in Figure 7: global warming, air pollution, and energy (in)dependence. The Project sample contains a slightly higher percentage of people who state that each of these three issues is “a serious problem, and immediate action is necessary” than in the California and northern California survey samples. Still the differences are small. We judge the differences to be unlikely to make a substantive difference in any conclusions we may draw between the samples on their PHEV designs.

On the issue of knowledge regarding electric-drive vehicles, a question in the first part of the questionnaire completed by both the survey sample and Project participants asked respondents to rate their familiarity with conventional, electric, hybrid-electric, and plug-in hybrid vehicles. This was followed up by a question asking how each of these four types of vehicles are fueled and/or recharged. Responses to this second question are summarized in Figure 8. In general, there is little to distinguish the knowledge of electric drive vehicles among the Project participants from the survey respondents—except on the specific issue of plug-in hybrids. Across all samples, very high percentages of respondents know that a plug-in hybrid can be both fueled and plugged-in; the highest percentage is among our Project participants. There are a few opportunities for “information leaks” to the project households about PHEVs—the recruiting phone call and the information provided to households when the PHEV is first delivered.

**Figure 7: Comparing environmental beliefs among survey respondents ("CA" and "NCA") and Project participants ("Demo")**

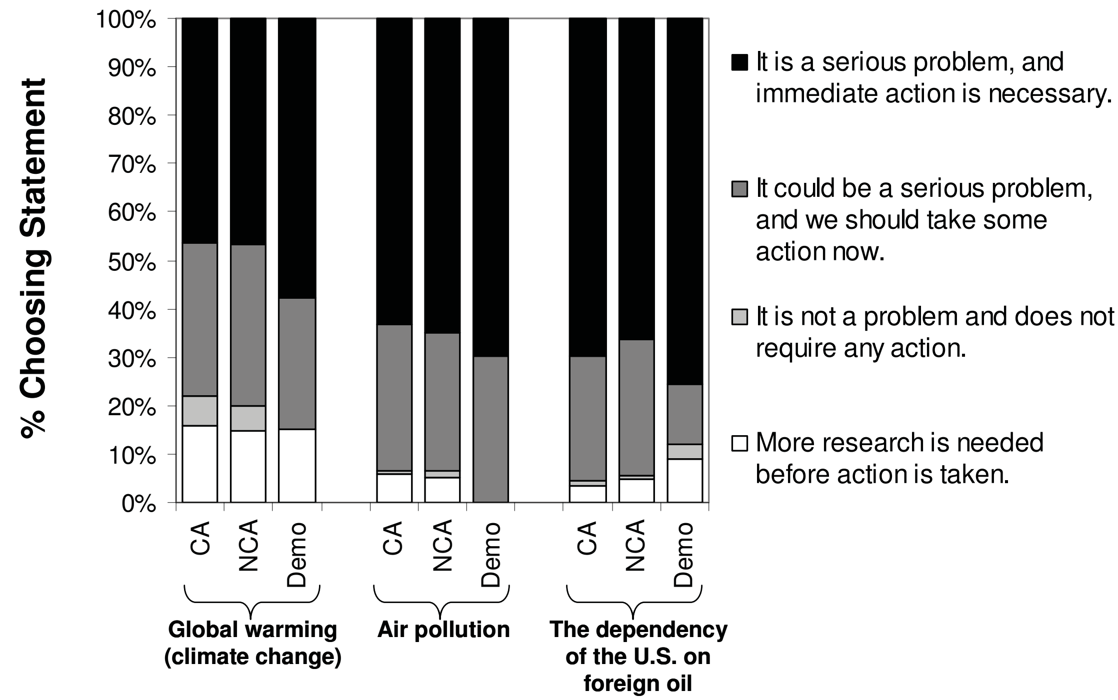
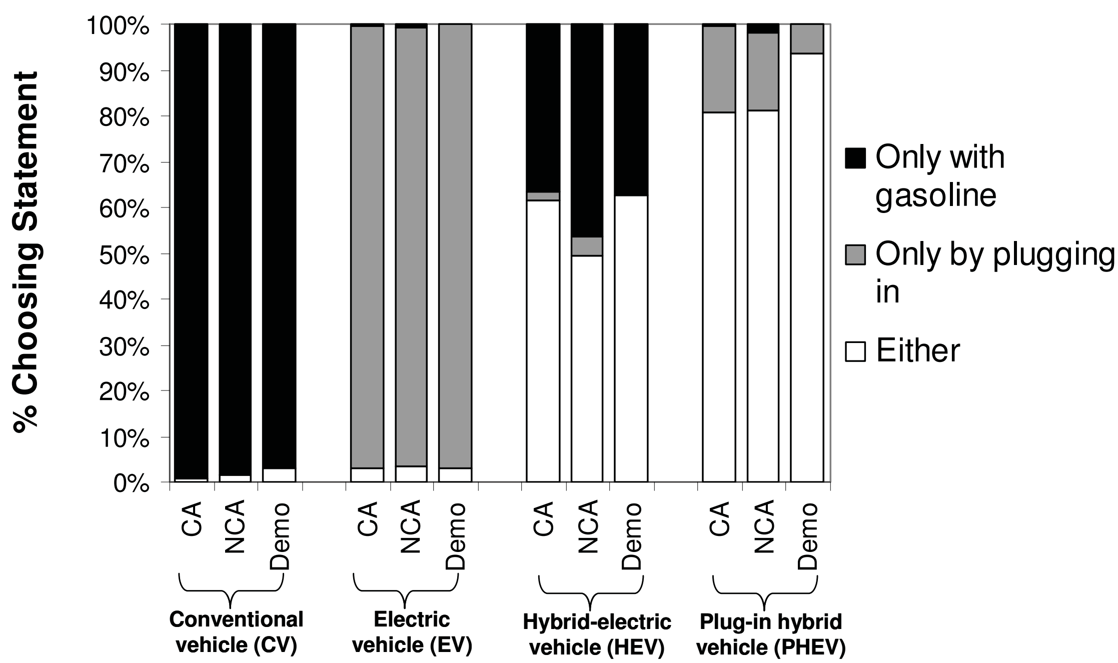



**Figure 8: Comparing electric-drive knowledge among survey respondents (CA and NCA) and Project participants ("Demo"): "From what you understand of these vehicle technologies, which can use fuel, and which can be plugged in?"**



## 3A. PROJECT RESULTS: PHEV DESIGNS

All participants in the Project and in the prior survey research created PHEV designs. We use these designs as measures of what is interesting and valuable to respondents about PHEVs. In addition to our inherent interest in the PHEV designs created by the Project participants, we are interested in whether and how the Project participants' designs differ from those created by the prior survey respondents.

### Whose PHEVs? Plausible early markets

This section compares the PHEV designs elicited from the 34 households who completed their Project participation between August 2008 and April 2009 with those elicited from respondents in the California (CA) and northern California (NCA) over-samples of the national survey in December 2007. The PHEV design games were described in the previous section, and reproduced in Appendices B and C. In this section, PHEV design priorities are reported only for respondents classified as *plausible early market* PHEV buyers by satisfying two requirements: 1) they demonstrate access to sufficient recharge infrastructure, defined here as home access to an electrical outlet for their vehicle, and 2) interest in PHEVs as indicated by a reported purchase intention in the "higher" price condition of the *Purchase Design* game. Based on these conditions, Axsen and Kurani (2008) described 33.5 percent of responding U.S. new car buyers as *plausible early market respondents*. In the California over-sample, 45.8 percent of respondents park their vehicle within 25 feet of an electrical outlet at home, and of these, 73.5 percent indicate PHEV purchase intention in the "higher" price scenario, and thus 33.7 percent of the total California sample are classified as the *plausible early market respondents* (n=286). In the northern California over-sample, 45.6 percent have home recharge access, 71.3 percent of which indicate a PHEV purchase intention, and thus 32.5 percent of the total sample is classified as *plausible early market respondents* (n=63).[11] Among the PHEV Project

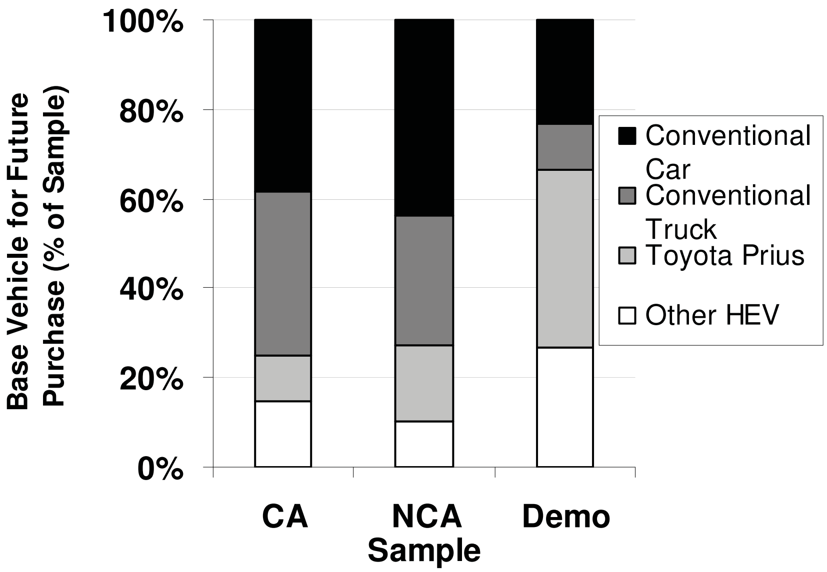
[11] Because of the small samples for the households who completed their Project participation by April 2009 and for the plausible early market respondents in northern California, the comparisons made here are descriptive and exploratory rather than (necessarily) representative.

participants, all have access to home recharging because it is a requirement for participation. Among these 34 households, 30 (88 percent) indicate a PHEV purchase intention in the higher price scenario and thus these 88 percent are included as the *plausible early market* Project participants. Clearly nothing about the likeliness to design a PHEV as their plausible next new vehicle purchase distinguishes the California and Northern California survey samples from the national sample; equally clearly, Project participants are more likely to design their next new car as a PHEV. Given they are more likely to design a PHEV, are our Project households designing *different* PHEVs than did our survey respondents?

### What PHEVs do they Design?

The PHEV *Purchase Design* game first asks households to select a vehicle they were most likely to buy next. Figure 9 compares these base vehicles selected by survey respondents with those selected Project participants. Notably, 67 percent of Project participants selected some variety of HEV and 40 percent selected a Toyota Prius. These percentages are 2 to 3.5 times higher than those of the CA and NCA samples, indicating a much more frequent interest in hybrid vehicles among Project participants (after their PHEV trial) than was elicited from a broader samples of CA and NCA car buyers (who lacked direct experience with a PHEV). This difference may not be due to a predisposition and/or self-selection of Project participants. Recall from their previous description that Project participants: are not substantially more likely to own a hybrid, do not possess more knowledge about electric drive vehicles, and do not have more concern for environmental or global issues—at least not to such a degree as to warrant a 2 to 3.5 fold increase in hybrid interest in these design games. One explanation supported by the household interviews that because Project participants completed the PHEV *Purchase Design* game after driving the PHEV-conversion for several weeks, participants had become more interested in hybrids in general, and in the Toyota Prius in particular.

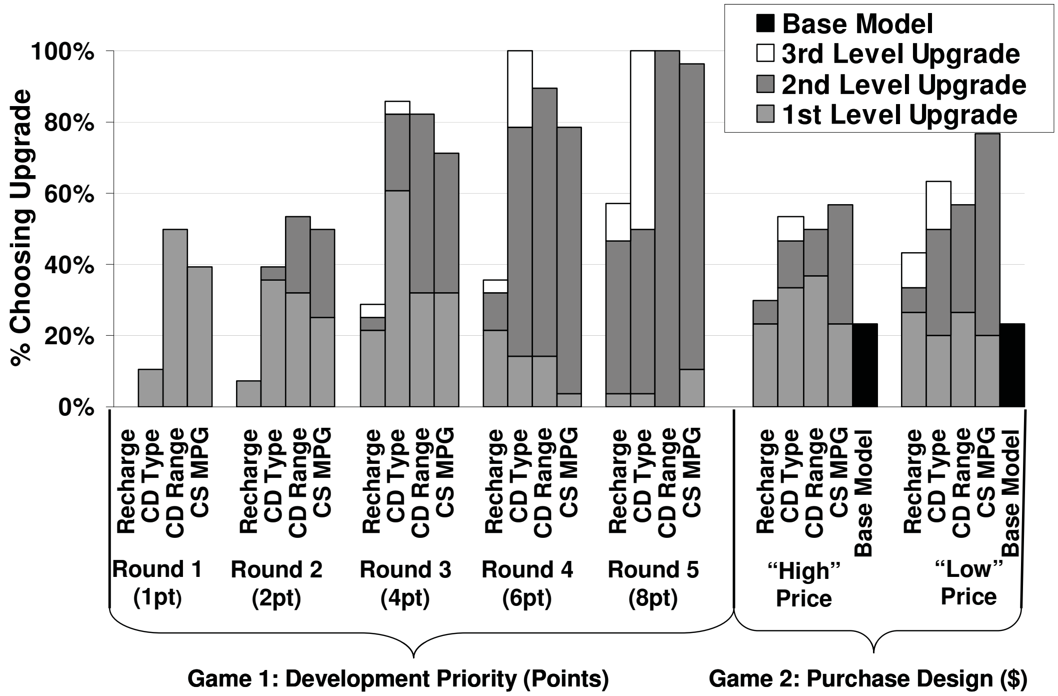
**Figure 9: Comparing base vehicles chosen for PHEV Purchase Design Game (*plausible early market* only: CA, n=286; NCA, n=63; Project, n=30)**




Focusing on the interests of these *plausible early market* Project participants, results of the two PHEV design games are summarized in Figure 10. In Round One of the *Development Priority* game, respondents were given one point to allocate towards one upgrade to the base PHEV model. As described previously, four upgrades were available: recharge time (from 8 to 4 hours), gasoline-fuel economy during CD mode (from 75 to 100 mpg), CD range (from 10 to 20 miles), or CS gasoline-fuel economy (from 10 to 20 mpg over the conventional version of the vehicle). Improving the CD range was the most frequently chosen upgrade (50.0 percent), while improving CS fuel economy was a close second place (39.3 percent).[12] The general ranking of attribute upgrades in Round One continues through later rounds: a higher percentage of potential early market respondents designed PHEVs with CD range upgrades and CS fuel economy upgrades, as well as CD type in later rounds, and few respondents designed PHEVs with faster recharge times.

[12] Although the percentages add up to 100 across the columns in Round One, they do not in further Rounds because respondents have enough points to choose multiple upgrades.

**Figure 10: Upgrades selected in PHEV design games by Project participants (*plausible early market* Project participants only, n=28)**

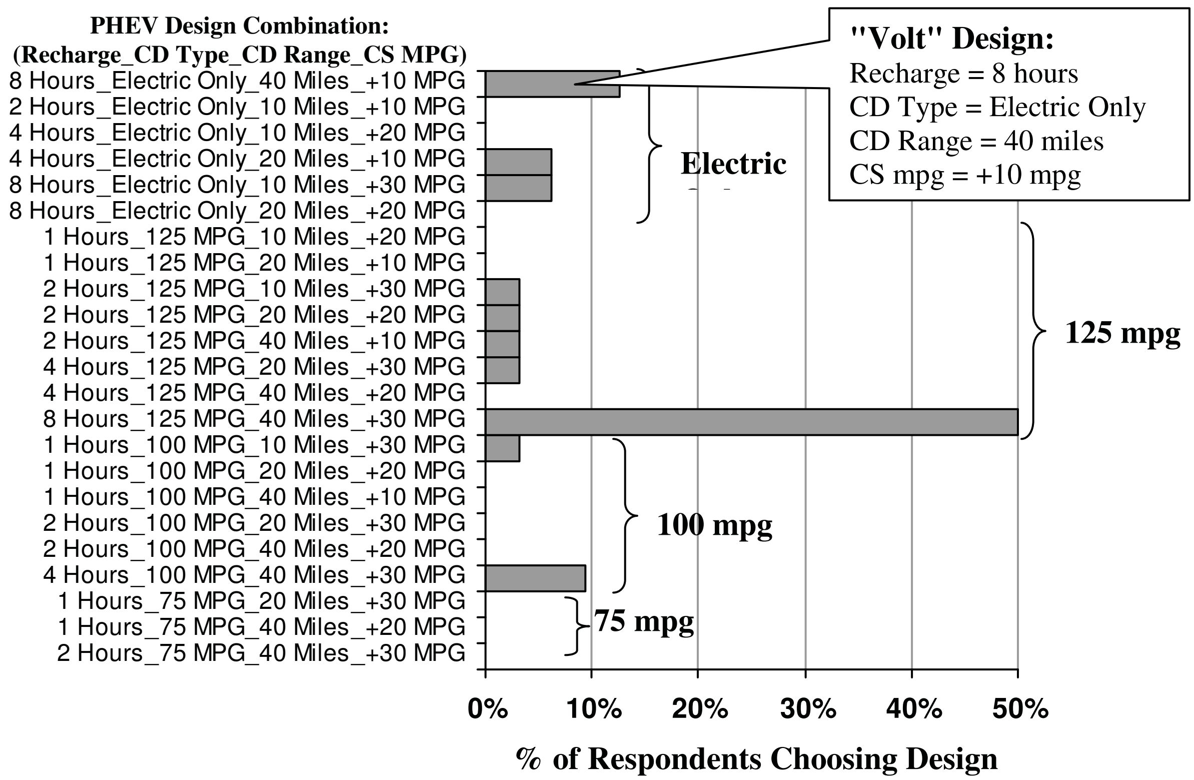



All-electric operation (in CD mode) was first offered to respondents in Round Three of the *Development Priority* game; only one of the 28 households (3.6 percent) incorporated this upgrade into their PHEV, which came at the expense of any other upgrades available in prior rounds.[13] In Round Four, the number of *plausible early market* Project participants designing a PHEV with all-electric operation rose to six (21.4 percent). Figure 11 portrays the 23 different possible PHEV designs possible in Round Four. This is the first round in which the design envelope allows a PHEV with 40 miles of all-electric range—a vehicle performance (at least as measured by CD mode and range) similar to GM's Volt concept. Only three of *plausible early market* Project participants (10.7 percent) created this specific design. Overall, all-electric operation was not a chosen frequently when points were relatively scarce and alternative design possibilities were available, i.e. in Rounds Three and Four of the *Design Priority* game. PHEV

[13] Although 30 households were previously identified earlier as the *plausible early market PHEV demo* participants, data from the development priority game (game 1) are only reported for 28 households due to missing data (Figure 10, Figure 11, and Figure 13).

performance priorities varied substantially; no single PHEV design emerged as a majority favorite. Still, the Project sample to date is the most heavily skewed toward a single design, i.e., 8 hours recharging, 125mpg for 40 miles in CD operation, and +30 mpg in CS operation (compare to Figures 14 and 15).

**Figure 11: Distribution of selected PHEV designs in Round Four of Development game (*plausible early market* only: Project, n=28)**




As previously noted, results of the *Purchase Design* game suggest that the majority of Project participants would value PHEV capabilities in their next vehicle. Figure 10 also depicts the proportion of upgrades chosen in the price conditions for this second version of a PHEV design game. Seven of *plausible early market* Project participants (25 percent) chose the base PHEV models with no upgrade in both price conditions. Among those who created higher cost designs, overall patterns of these designs are similar to those created in the *Development Priority* game; CS fuel economy upgrades were chosen more often than other upgrades, and there is no evidence of the strong interest in all-electric operation observed among some pioneer PHEV conversion drivers (Kurani et al., 2007). All-electric upgrades were chosen by two households (seven percent) and four households (13 percent) in the higher and lower price conditions, respectively.

Figure 12 depicts the proportion of CD type and CD range designs selected by Project participants. Note that 11 households (37 percent) designed a PHEV capable of 75 mpg for the first 10 miles, and that 24 households (86 percent) designed a blended CD design (as opposed to all-electric) with a range of 20 miles or less. Such designs have far lower battery requirements than the all-electric, longer-range designs assumed by various battery experts (Axsen et al., 2008).

Figure 13 compares Round 4 of the Development Priority game results from *plausible early market* Project participants with those respondents from the CA and NCA samples. Results are fairly similar across samples, though Project participants selected recharge upgrades less frequently, and selected 100 CD mpg and +30 CS mpg more frequently. Figures 14 and 15 show the distribution of PHEV designs in Round Four in the CA and NCA samples, respectively for comparison to Figure 10.

All figures indicate a wide variety of PHEV design interests among households, without any particular draw to the all-electric 40-mile "Volt" concept. Figure 16 compares the same samples in terms of the higher price scenario of the PHEV Purchase Design game, where a substantially higher proportion of Project participants selected some level of CD type and range upgrades. Several differences among samples could contribute to this trend; Project participants have: higher household income (as portrayed in Table 3) and more experience with PHEV driving (having actually driven a PHEV for several weeks), as well as other potential differences in driving patterns, commute patterns or other factors that were not measured in all three samples.

**Figure 12: Distribution of selected PHEV designs in high price scenario of Purchase Design Game (*plausible early market* Project participants only, n=30)**

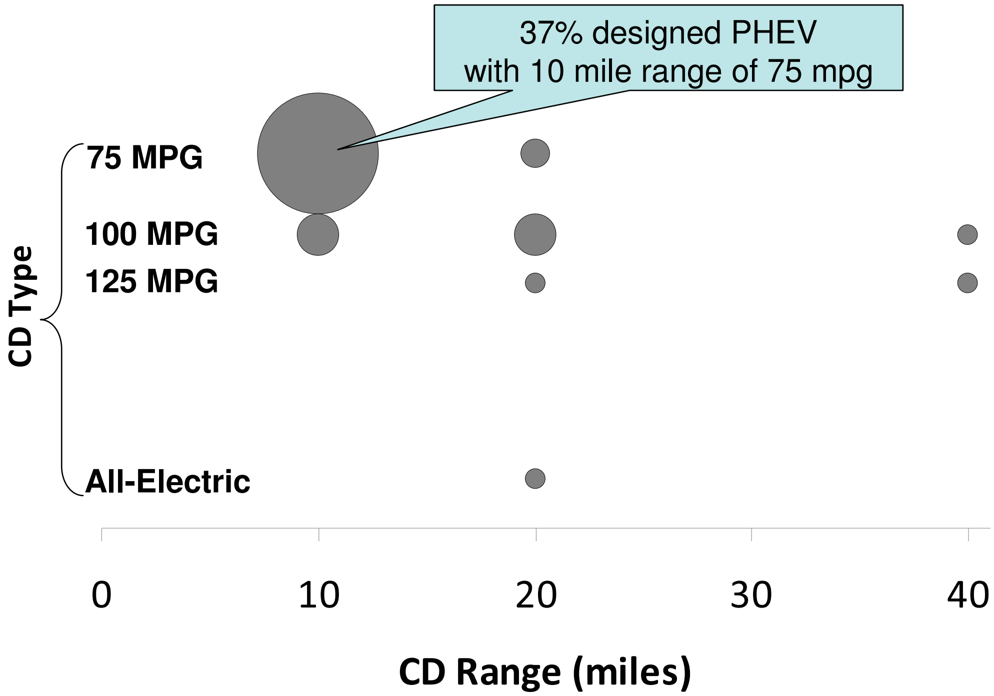



**Figure 13: Comparing upgrades selected in Round 4 of Development Priority game, (*plausible early market* only: CA, n=286; NCA, n=63; Project, n=28**

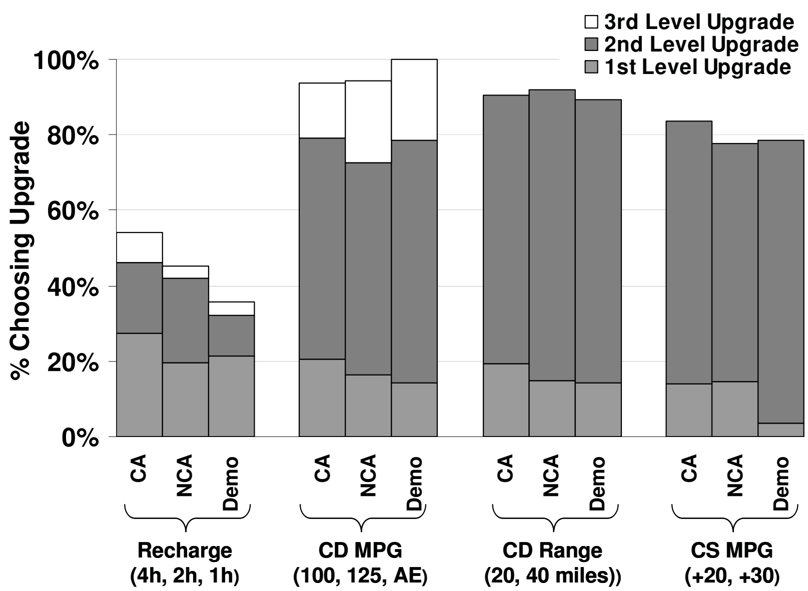


**Figure 14: California Distribution of selected PHEV designs in Round Four of Development game (*plausible early market* only: CA, n=286)**

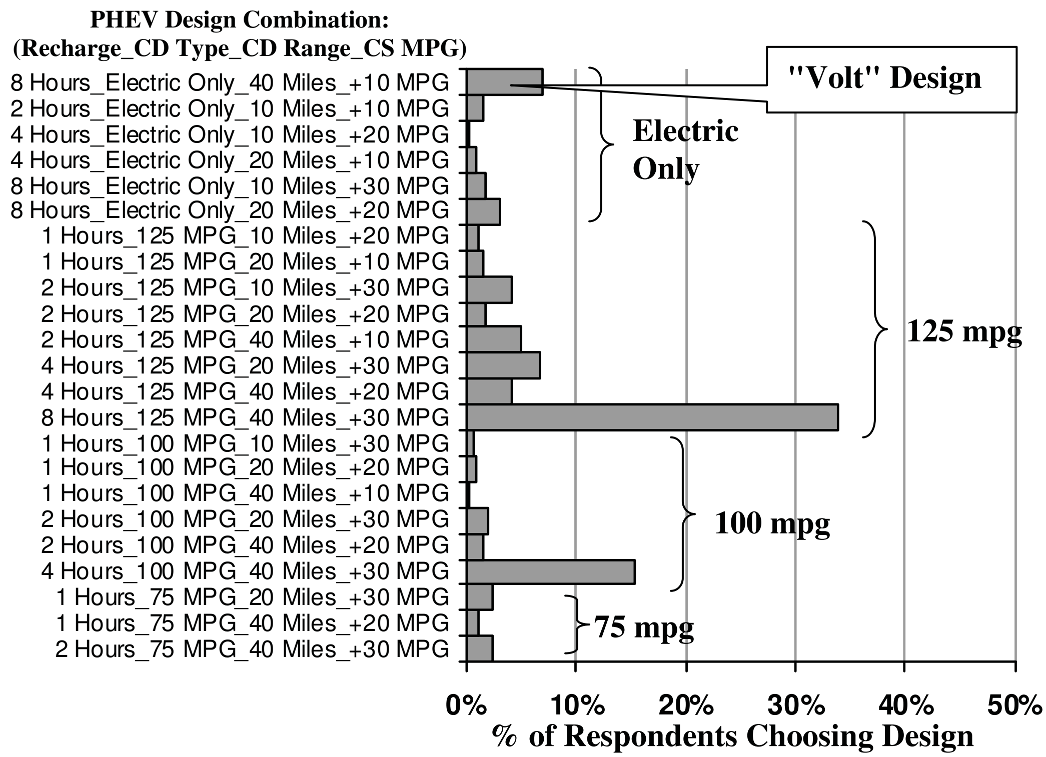


**Figure 15: Northern California Distribution of selected PHEV designs in Round Four of Development game (*plausible early market* only: NCA, n=63)**

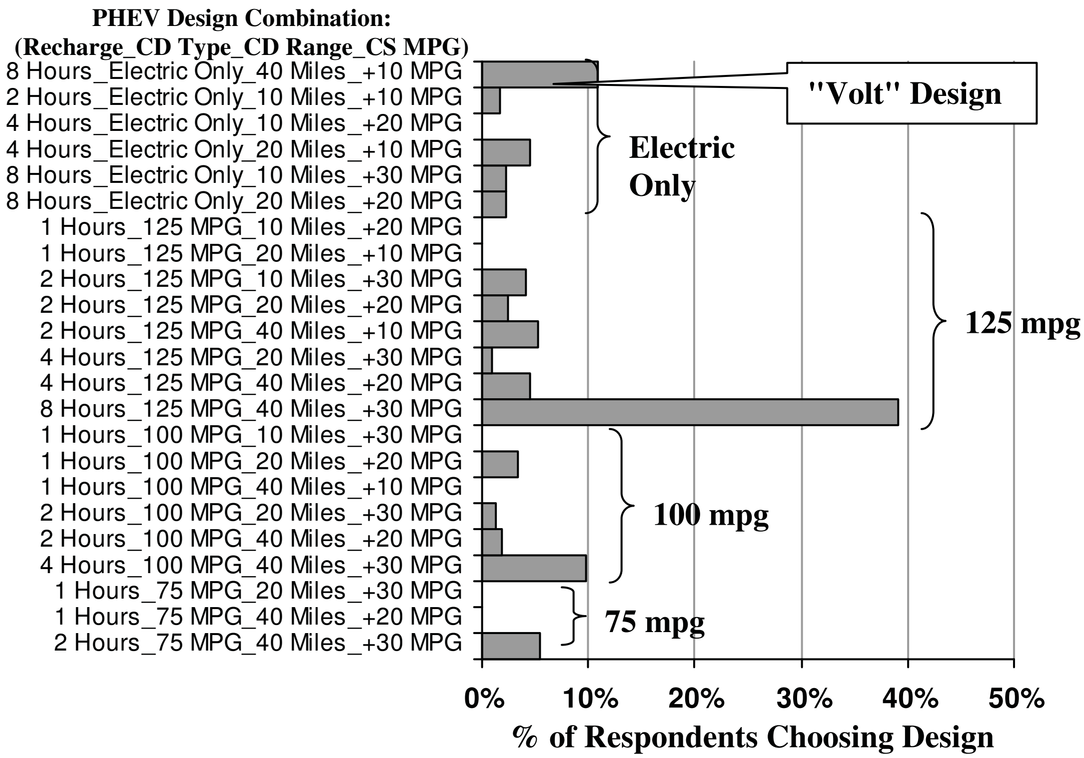
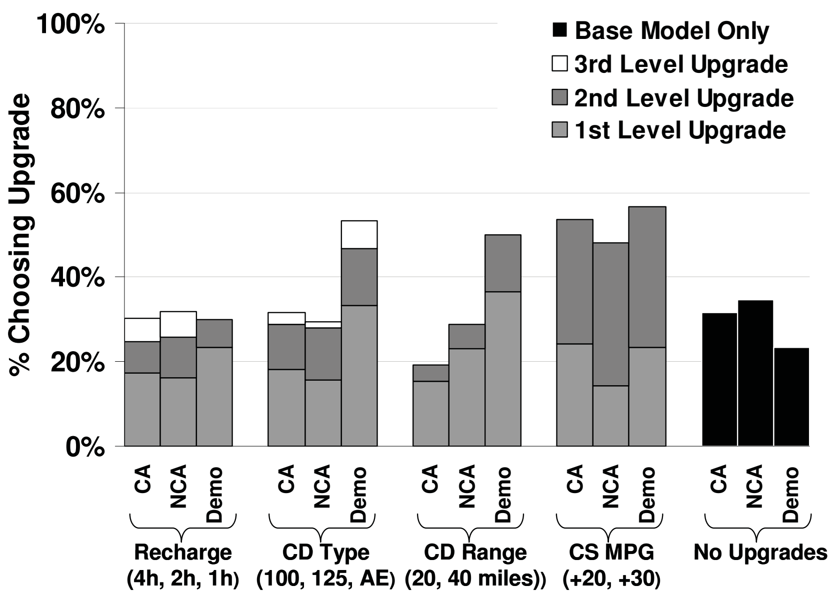



**Figure 16: Three-Sample Comparison of upgrades selected in higher price scenario of Purchase Design game (*plausible early market* only: CA, n=286; NCA, n=63; Project, n=30)**



## PHEV Design Conclusions

In summary, the variety of PHEV designs created by survey respondents and Project participants suggests there is still opportunity for automakers to explore and develop different PHEV designs. We found little evidence of inherent demand for all-electric operation in CD mode, even among Project participants who had experience driving a (CD blended-operation) PHEV for a month—though our Project cannot presently exclude the possibility of participants anchoring on what we have now made familiar to them, i.e., blended rather than all-electric CD operation. An even smaller subset was interested in creating a vehicle with performance attributes combining 40 miles of CD range with all-electric CD operation. These patterns contrast with the findings of Kurani et al.'s (2007) interviews with "pioneer" PHEV conversion drivers who exhibited strong interest in maximizing CD range and moving toward all-electric operation—effectively to approach the capabilities of pure electric vehicles. This difference suggests that while all-electric CD operation may be particularly attractive to a small subset of consumers, including those who already have extensive knowledge and experience with electric vehicles, at this point in time most households who buy new vehicles are more interested in high fuel economy, even after completing a multi-week trial with one PHEV incarnation.

Participation in the Project appears to have decreased the importance of improvements in recharging rates compared to prior survey respondents, but keep in mind Project participants are selected in part because they are able to recharge at home. Project participants are somewhat more likely to design a PHEV for their next new vehicle—rather than revert to a conventional vehicle—than are the survey respondents. Project participants are also more likely to choose a HEV as their base new vehicle from which to consider the design of a PHEV.

The wide variety of PHEV designs created by survey respondents and Project participants support the notion of a "blank slate" early PHEV market, where early buyers may have little in the way of PHEV performance expectations. That is, not only is there room for a variety of technical pathways, but also there is room for multiple meanings of PHEVs. Desired PHEV designs and capabilities may be subject to change. Project participants and survey respondents had little pre-existing understanding of PHEVs and the responses we elicited are sensitive to the PHEV information and experience we did provide. As information about PHEV technology, costs, benefits, and meanings are transmitted throughout the population, interest in particular PHEV attributes and performances could shift too. For example, all-electric CD operation could become more meaningful to, and valued by, car buyers as they gain experience with all-electric driving and as they participate in the process of identifying just what all-electric operation means to people.

Our respondents PHEV designs suggest the possibility of a trajectory over time of PHEV and electric-drive market development. Our respondents are designing PHEVs that are far more technologically and financially feasible than “experts” assume. In particular, most of those designs provide some all-electric driving, as even PHEVs that use blended operation in CD mode afford some all-electric driving. If we start with these less aggressively electric designs, then over subsequent market and vehicle generations, the electric capabilities of PHEVs can be increased as costs come down—due to learning by doing, technology development, and improved designs—at the same time that more consumers have learned to value increased electric-drive capabilities.

## 3B. PROJECT RESULTS: RECHARGING

PHEVs provide some degree of fuel flexibility to consumers, giving them the option of using gasoline and grid-generated electricity. Given that the effects of PHEVs on energy use, the environment, and the electricity grid depend on driving and recharging behaviors, there is particular interest in how often PHEV owners will recharge a vehicle that does not have to be recharged and when PHEV owners will recharge their vehicles. The "fuel" mix and the carbon content of the electricity used to recharge electric-drive vehicles will vary according to how often, when, and where vehicles are recharged. Furthermore, in examining future "smart grid" scenarios in which vehicles may act as mobile power sources (or sinks), it is important to begin to replace analysts' assumptions with measures of PHEV owners' driving and recharging behaviors. From the 34 households-to-date, we have obtained detailed information about their driving and recharging behaviors. In this section, we summarize how participants, with minimum input from researchers, acted with regards to the frequency, time of day, and location of recharging.

Drivers in this Project have the option of recharging a vehicle to decrease gasoline use and increase electricity consumption for the duration of the supplemental battery's charge. Recall, the PHEV-conversions used in this Project provide blended operation in CD mode: the cars are still subject to the underlying HEV hardware and software. During CD mode these PHEV-conversions will blend in more electricity than does a conventional Prius (which operates only in CS operation). Like a conventional Prius, it is practically difficult to achieve sustained all-electric driving in real-world conditions.

All figures presented in this section are based on the last week of each household's trial with the PHEV conversion. This provides a common period over which we can compare the same number of days and days of the week from each household. Also, the last week represents the highest degree of uniformity of understanding about recharging behavior across the households. Finally, since we judge that the households had developed their recharging habits by this last week (or had developed their habits as much as they were going to in the course of their PHEV trial), we view their final week with the PHEV as most representative of how these vehicles would be recharged by the households in the future. This judgment is generally confirmed by the household interviews.

Perhaps more than any other information presented in this report, readers are cautioned against generalizing our observations here to all PHEVs and users. Daily life provides rhythms and routines that might shape behavior, for example the PHEV recharging frequency discussed next. Still, we believe that PHEV recharging behavior may also be shaped by the relationship between personal and household travel on the one hand and PHEV designs, especially all-electric vs. blended CD operation and CD range, on the other. For example, while the weight of evidence gathered so far in this Project suggests that households owning PHEVs will, on average, plug-in the PHEV more than once per day in an unconstrained world (as will be detailed next), we are not yet prepared to dismiss the argument that if these households had been given PHEVs with a different CD range, the frequency of households plugging in different PHEVs to the electric grid may be different than we observed.[14]

### How often do People Plug-in their PHEV-conversions?

The frequency with which people plug-in PHEVs to the electrical grid is perhaps the central daily behavior affecting the energy, environmental, and social benefits of PHEVs. Other important behaviors include the purchase of a PHEV whose CD range allows the household to accomplish the greatest proportion of miles driven in CD mode (constrained by the expense of buying too much CD driving range) before their next recharge opportunity and driving behaviors affecting overall efficiency, notably accelerations, top speeds, and routes. The context for interpreting the PHEV recharging behavior observed to-date in this Project is as follows. First, the only participants in this Project are people who can recharge a PHEV at their home. Second, as most households lacked a sense of the etiquette that would shape recharging at away-from-home locations, less away-from-

[14] We use the phrase "plugging-in" to refer to all acts of connecting the vehicle to the electrical grid, regardless of the final state of charge of the battery when the vehicle is unplugged. We do this to create a more general category that contains both "recharging," with its connotations of returning the battery to 100 percent SOC, and partial recharging, in which the vehicle is unplugged and driven before the battery reaches 100 percent SOC.

home recharging was observed than may otherwise occur in a world where the rules and conventions are known. Households who noticed "EV" parking and recharging spaces often asked us whether they could park and charge their PHEVs in such spaces. The few bolder individual who tried discovered that such spaces presently lack 110-volt outlets suitable for the PHEVs they were driving. Many people said they were uncertain of the propriety of asking friends, acquaintances, and business-owners to recharge. (See the discussion of recharging etiquette in the later section on narratives.) Third, no household was provided with time-of-day electricity tariffs. The second and third are related in that some away-from-home recharging opportunities such as workplaces would most often be used during the day (when electricity rates would presumably be higher, especially during afternoons and early evenings, under time-of-day electricity tariffs). PHEV drivers would then face countervailing signals—maximizing their PHEV benefits by plugging in more, but having to pay a higher price than nighttime electricity in order to do so. In short, the recharging frequency data reported here is from households who can recharge at home, whose recharging frequency is constrained by a general lack of away-from-home recharging opportunities created by the lack of both physical infrastructure and social norms, but unconstrained by differential electricity prices.

We calculate the mean number of times per day each household plugged-in their PHEV on weekdays and weekend days and plot the resulting frequency distributions in Figure 17. As explained above, the figures are based on only the final week of each household's experience with the PHEV-conversion. The weekday distribution ranges from zero to 2.6 instances of plugging-in per day. (The zero-value for weekdays is from one household who determined that recharging made too little difference (compared to the substitution of an HEV into their household fleet) to make it worthwhile.) The mean of the weekday distribution is slightly more than one plug-in event per day (1.05), 14 households (41 percent) were plugging in their PHEV more than once per day, on average across weekdays.[15]

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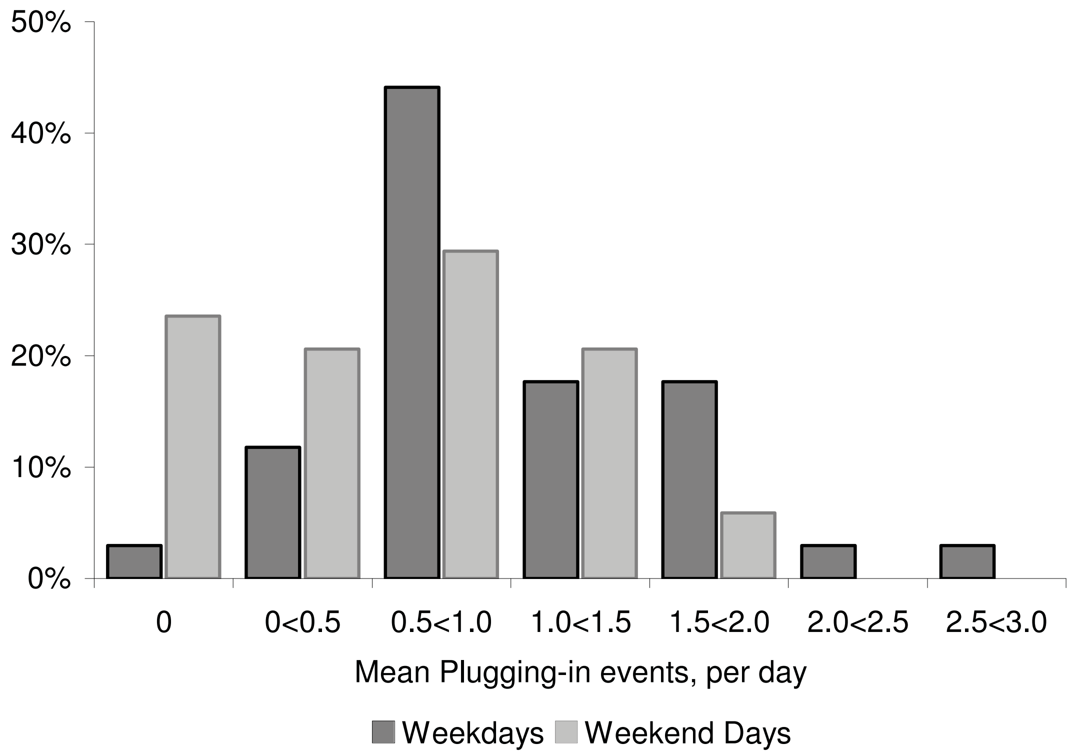
[15] We observed a difference in mean recharging frequency across weekdays from a high of 1.24 recharges per household on Wednesday to a low of 0.88 on Thursday. However, we presently regard this fine a level of analysis to be provisional and hypothetical

**Figure 17: Mean Daily Household Recharging Frequency Distributions, Weekdays and Weekend Days, Percent**




Plugging-in occurs less frequently on weekend days than on weekdays. Notably, one-fourth the sample did not plug-in their PHEV on either weekend day; the high-end of the range was 1.5 times per weekend day. The mean number of times a PHEV was plugged-in per household was 0.82 per weekend day; nine households (27 percent) did so more than once per day. The two biggest causes of the lower mean weekend frequency were 1) the absence of recharging at work by two households, i.e., two households who plugged in at least twice a day on weekdays because they were plugging-in at home and work recharged less frequently on weekend days because work was not available to them as an alternative recharging location, and the higher likeliness in several households of not recharging at home on weekends because the PHEV was not at home at least one weekend evening. The PHEVs were often taken on out-of-town trips on weekends, but were rarely if ever charged during these long, and often overnight, trips.[16]

### Electricity Availability And Instantaneous Power Demand

To describe recharging behavior observed during each household's demonstration, we have summarized information in two additional measures: electricity availability and instantaneous power demand. We define electricity availability as the time of day during which the vehicle was plugged into an electrical outlet. Conceptually, this means that the vehicle could be at any stage in its recharging cycle, available battery capacity, or at any location—so long as it is connected to the grid, electricity is available to the vehicle. We define instantaneous power demand as the power drawn from the grid to recharge the supplemental PHEV battery. The observed average recharging rates for these PHEV-conversions were observed to vary across households—generally falling between 900 and 1200 watts. In order to compare and summarize across households, instantaneous power demand is standardized (by assumption) to be the nominal average recharging rate of 1000 watts. Additional parasitic loads from the battery cooling system, in the range of 30 to 50 Watts, and brief periods of higher demand during the initial phases of battery charging and longer periods of lower demand during trickle charge at end of the charging cycle respectively have been ignored.[17]

The electricity availability and instantaneous power demand are represented as the percentage of vehicle users plugged in and the average instantaneous power demand (summed across households) at a specific time of day respectively, between 12:00 AM to 12:00 PM across all weekdays and weekend days. Average electricity availability and summed instantaneous power demand for every day of the week are in the Appendix E.

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[16] The latter reason is supported by the fact that the average number of recharging events per household was higher on Sundays (0.94) than Saturdays (0.71)—consistent with a PHEV returning on Sunday from an overnight trip that started on Saturday. As in the prior footnote though, such differences between days are provisional, and in this case must be regarded as supportive, but not conclusive evidence.

[17] When we have ascertained whether the differences in the observed average recharging rates are due to differences across electrical outlets, vehicles, or both, we will provide a more refined analysis of power demand. Still, the broad behaviors described here have greater import for other analytical work than do the precise specifications of power demand for the specific combination of battery and recharger employed in these particular vehicles.

### *Electricity Availability & Instantaneous Power Demand: All Weekdays*

Treating all households' last week of driving the PHEV as if it had occurred during the same calendar week and all weekdays as if they were equivalent, Figure 18 displays the percentage of vehicles plugged in at a given time of day for all weekdays (in red, and on the left axis) and the instantaneous power demand summed over the households and averaged over weekdays (in blue, and on the right axis). As the red line shows, across the 170 weekdays represented in Figure 18 (34 households times 5 weekdays), 70 percent of households had plugged in their PHEV between 10:00 pm and 6:00 am. By 9:00 am only 20 percent of households had their PHEV connected to the grid. This can be explained by the number of respondents in the Project that have full time jobs, and typically leave home in the morning to go to work. While two households charged during the day while at work, the other PHEVs plugged-in to the electrical grid during midday were due to retired individuals and teleworkers who typically were at home during the day. At 4:00 pm, when households start to return home from work, vehicles begin to be plugged in, until 10:00 pm by which time the percentage of households who have plugged in their PHEV stabilizes again at about 70 percent.

As Figure 18 represents an average from all participants' weekdays during their last week, it is not a representation of actual daily behavior. Daily electricity availability varied within each household from day to day. Figure 19 represents the observed variability in when households plug in their PHEVs on weekdays, showing the low and high values for the percentage of vehicles plugged in for all weekdays by time of day. The bottom edge of the red area represents the low values observed at each point in time, and the top edge, the high value. For the time period between midnight and 6:00am, the lower values are predominantly due to the recharging behavior on Monday nights.

The greatest difference—in excess of 30 percentage points—between low and high percentages of households plugging in their PHEV occurs during the early evening, and reflects the variability both 1) within and across households in when they plug in the vehicle in the evening, and 2) variation across different days of the week. The lower boundary of the electricity availability during the evening is largely defined by Friday when more people tended to plug in the PHEV later in the evening.

**Figure 18: Electricity Availability (Percent of PHEVs Plugged-in) and Instantaneous Power Demand by Time-of-Day (Watts), Weekday Average.**

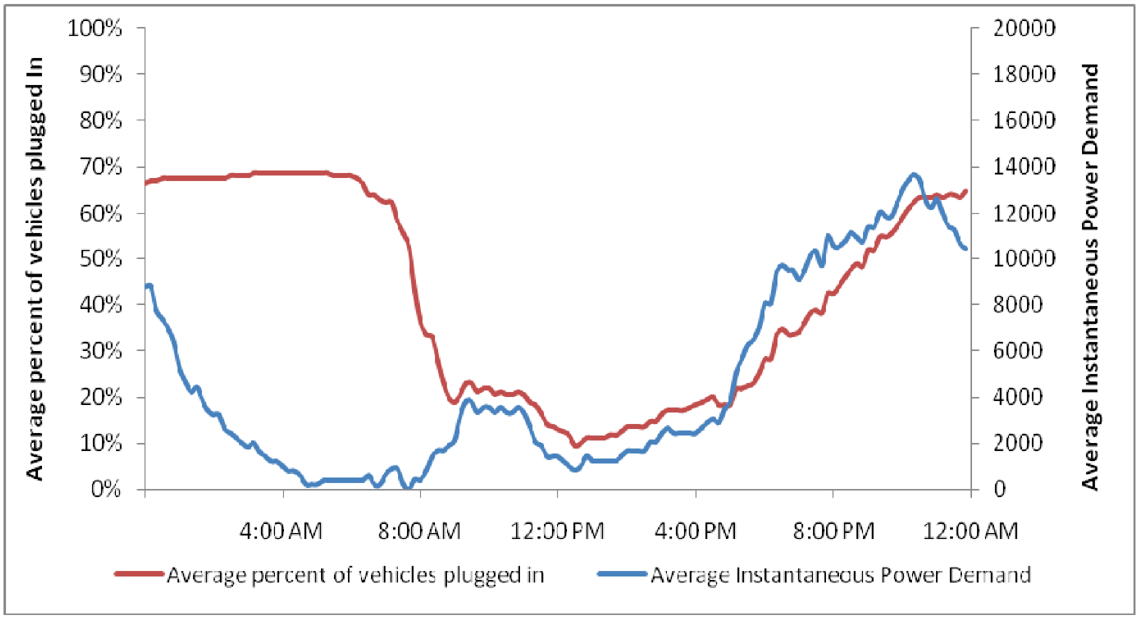
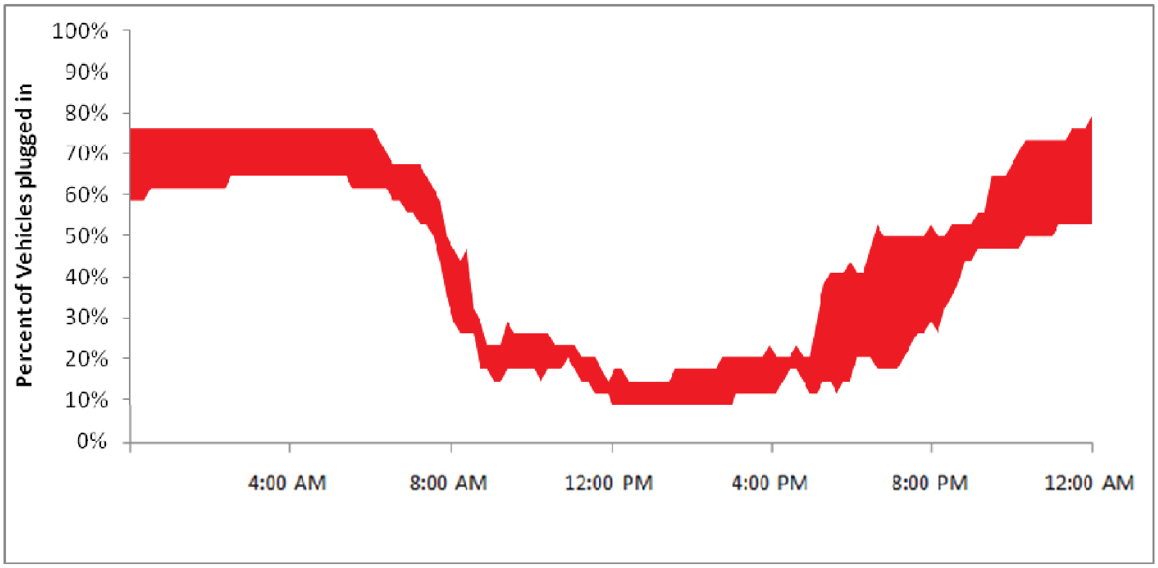



**Figure 19: Variability of Weekday Electricity Availability by Time of Day, Percent**

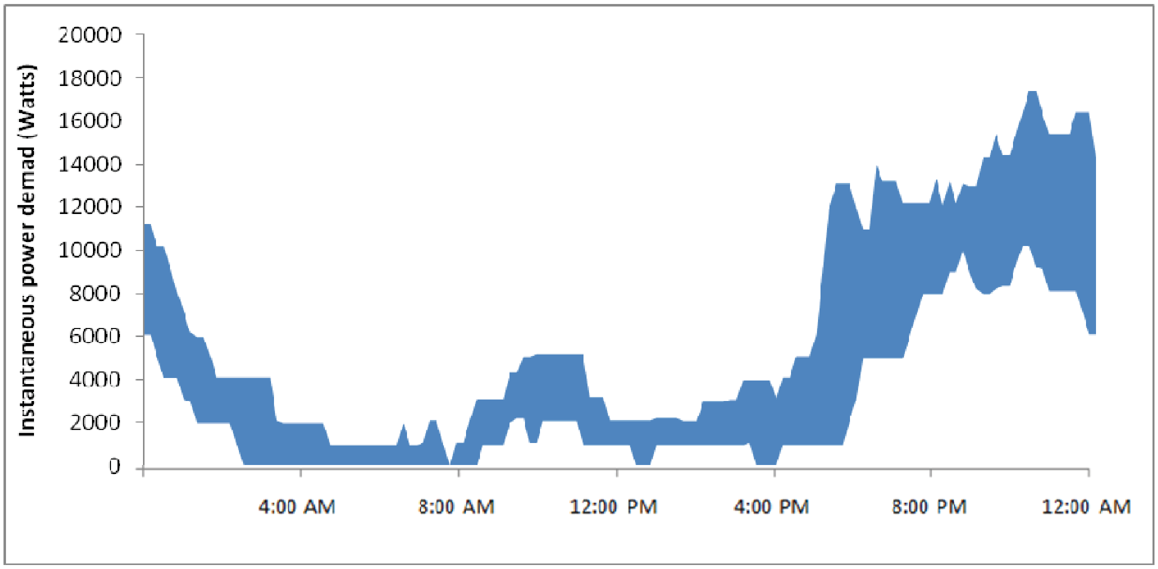


While the electricity availability tells us when the vehicles were connected to the grid and could recharge from the electric grid or discharge to the grid, it does not differentiate between the two. We discuss electricity demand for recharging next. The blue line in Figure 18 shows the average weekday instantaneous power demand by time of day for all 34 Project households-to-date. Instantaneous power demand is derived by summing the power demand created for every day of the week by time of day for all participants' last week, and averaging across all five weekdays to create an "average weekday." Given driving and recharging behavior by the Project households, electricity demand to recharge their vehicles ramps up at 5:00pm and peaks just after 10:00pm. It declines steadily through the rest of the night and into the morning, reaching practically zero by 5:00am. While there were several households that charged during the day at work, most of the demand to recharge these vehicles was between 9:00am and noon.

As we did with electricity availability, we show the day-to-day variability in instantaneous power demand for a given time of day, i.e., we start to disaggregate the average to show the range of demand across weekdays. As Figure 20 shows, the most variability in time of day power demand occurs in the evenings between 5:00pm and midnight. The lower boundary of the power demand between 4:00pm and 8:00pm is a primarily a result of the increased probability of households plugging in the PHEV later in the evening on Fridays. The upper boundary is shaped by a higher percentage of people recharging earlier on Wednesday nights. Regardless of the absolute power level at 5:00pm, there is a rapid increase in the instantaneous power demanded between 5:00pm and 6:00pm.

By comparing electricity availability and instantaneous power demand in Figure 18, we see a picture of aggregate recharging behavior and, consequently, of grid impacts. In the absence of any signals, e.g., prices, or supporting systems, e.g., timers, on weekdays households tended to plug in their PHEVs in the early evening, usually upon arriving home, and to unplug them when they left home in the morning. This means that the period between 5:00pm one day and 9:00am the next morning on weekdays is the period with the highest average likeliness of a PHEV being plugged in. Instantaneous power demand increases rapidly starting at 5:00pm as more vehicles are plugged to the grid, especially if those vehicles plugged in earlier have not yet finished recharging.

**Figure 20: High and Low Weekday Instantaneous Power Demand, Watts**




While the prospect of rapid increases in electricity demand during peak hours is frightening to electricity providers as well as to energy and environmental analysts, it is clear from our observations that there is potential to shift electricity demand for these PHEVs from the early evenings, i.e., 5:00pm to 8:00pm, until after 10:00pm, since instantaneous power demand to recharge these vehicles declines rapidly after 10:00pm and all recharging is completed by 5:00am the following morning.

*Electricity Availability & Instantaneous Power Demand: Weekend Days*

Weekdays may provide routines to daily life, including vehicle travel: a daily commute, trips to school or daycare, or the stop at the grocery store before heading home. Weekends may lack these routines or have their own. Hence, driving and recharging behavior, access to a plug during the day and the time of day instantaneous power demand, may differ from weekdays. To track and account for these differences, we provide next an analysis of weekend days that parallels the analysis above for weekdays.

Figure 21 shows the average percent of vehicles plugged in at a given time of day during weekends (in red, on the left axis) and instantaneous power summed across households and averaged across weekdays (in blue, on the right). Fewer PHEVs are plugged in during the weekend high availability period than during the weekday high availability period: about 55 percent of vehicles were plugged in between 11:00pm and 6:00am on weekends as compared to 70 percent between 10:00pm and 6:00am weekdays. Note also that the high availability period starts an hour later on weekend days than on weekdays. While electricity availability decreases toward and into the morning, it does so gradually and does not decline below 15 percent. The incidence of vehicles being plugged in again between 2:00pm and midnight increases less rapidly than on weekdays. Compared to weekday recharging, it appears as though some individuals, if they had access to an outlet, plugged in longer during the weekend. However, on average, not as many people plugged in their vehicles on weekend days compared to average weekdays.

Figure 22 shows the low and high values for the percentage of vehicles plugged in during weekend days. While there appears to be little variability in the percentage of vehicles plugged in during the morning and afternoon, there is a greater difference between 7:00pm and 12:00pm. The lower boundary is made up of those recharging events that occurred on a Saturday, with people tending to plug in later in the evening. Sunday recharging makes up the upper bound of the evening in the figure, where most vehicles had been plugged in by 8:00pm. The blank areas signify no difference between the high and low values.

Figure 21 also shows the average instantaneous power demand incurred on all weekend days. As with weekday electricity demand, most actual electricity demand to recharge the vehicles occurred between 5:00pm and 2:00am during weekend days. However, it should be noted that there are significant differences in the total power required. On average, weekend electricity demand increased more slowly over the course of the evening. In general, this difference from weekdays is because during weekends the PHEVs are starting their recharging at a higher state of charge than on weekdays, and, thus, there is not as great a cumulative impact upon the power demanded. Essentially, as those vehicles plugged in later start recharging, their impact on the rate at which total power demand increases (summed across all households) is less than on weekdays, because other households' vehicles which were plugged in earlier have already finished recharging.

**Figure 21: Electricity Availability (Percent of PHEVs Plugged-in) and Instantaneous Power Demand by Time-of-Day (Watts), Weekend Day Average.**

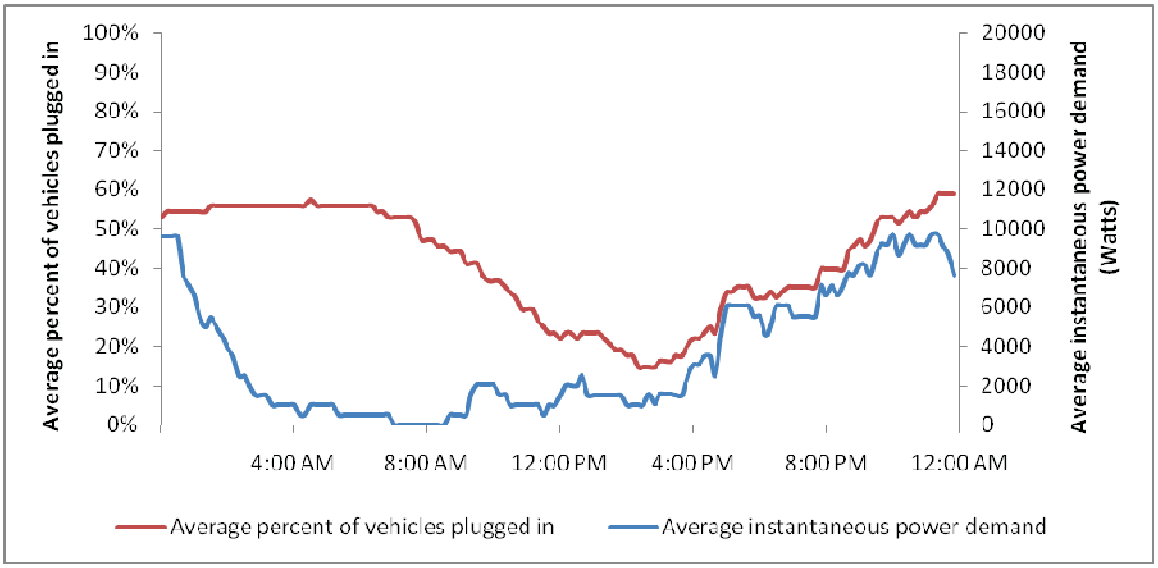



**Figure 22: High and Low Electricity Availability by Time of Day: All Weekend Days**

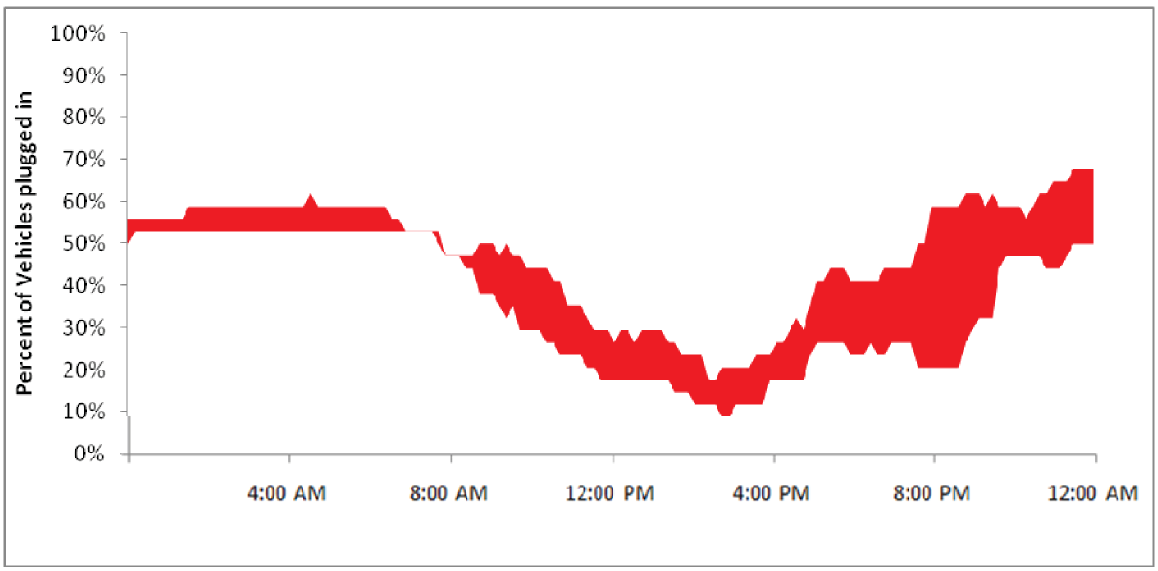
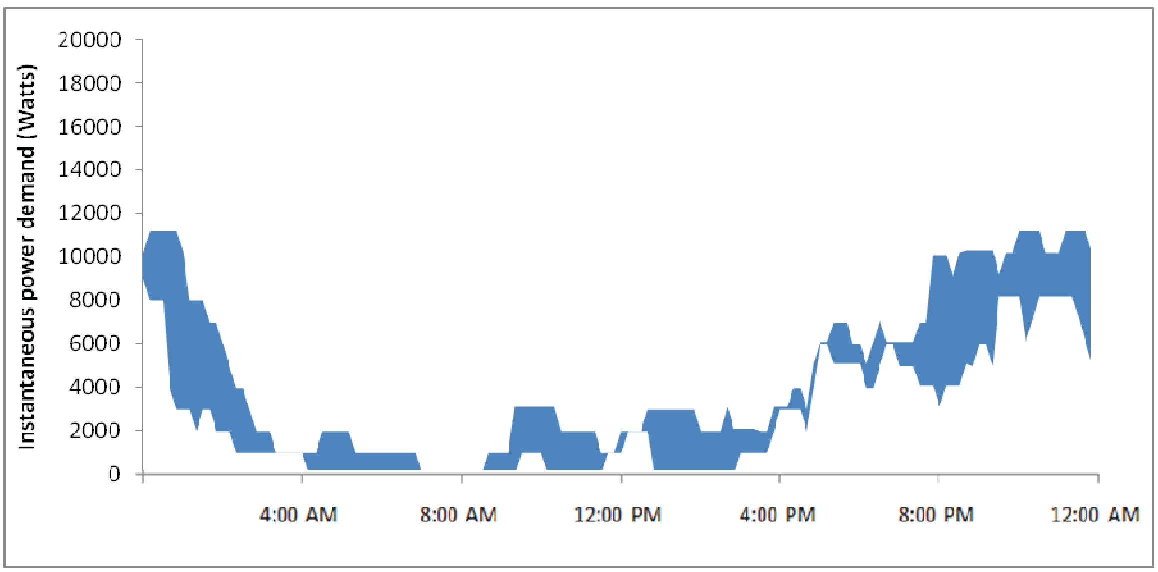


Figure 23 shows the low and high instantaneous electricity demand for all weekend days. Unlike weekdays, the greatest difference is in the very early morning. The upper boundary for the evening electricity demand is due to the demand observed on Saturdays, when people generally charged later than on Sunday. During weekends, the PHEVs were, on average, plugged in until later in the morning, and recharging took place over a longer time period and at lower total energy demand during the evening. Since the PHEVs started recharging at a higher state of charge and the vehicles were plugged in over a longer period of time, instantaneous electricity demand increases more slowly over the course of the evening than was the case for weekdays. As with the case of weekday instantaneous power demand, it appears as though there is an opportunity to shift recharging of these PHEV-conversions by these households to present off-peak electricity demand periods.

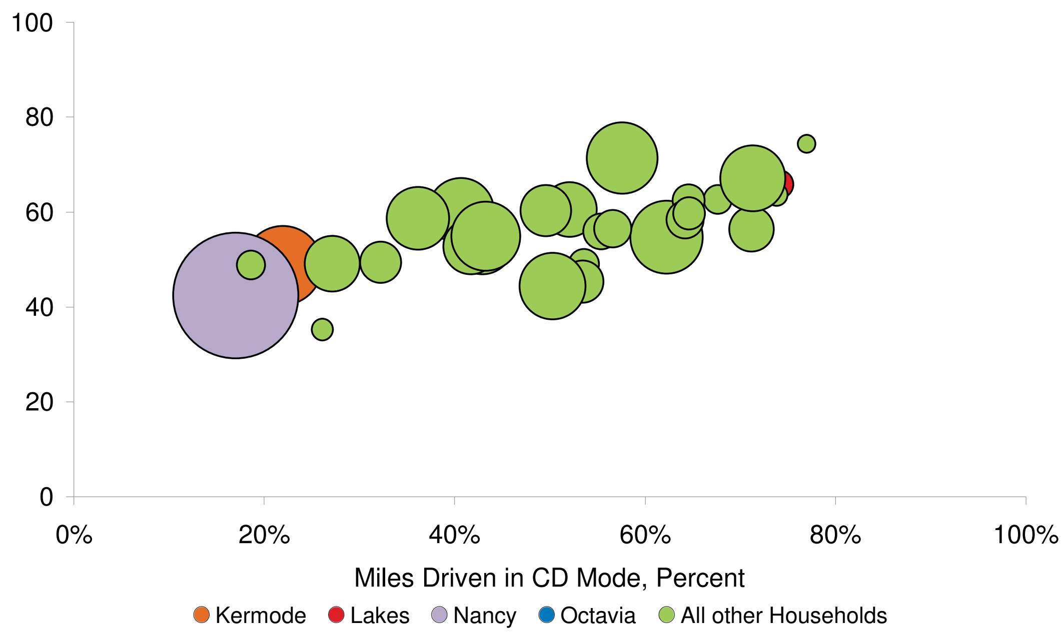
**Figure 23: High and Low Weekend Days Instantaneous Power Demand, Watts**




## Variation in Vehicle Use, Recharging, and CD-miles Across Households

The recharging results presented so far focus on the recharging behavior summed and averaged across the participants. This hides the variation in 1) the frequency with which people recharged the PHEV, 2) the distances households drive per recharging interval, i.e., the distance driven between two recharging events, and 3) the percentage of total miles each household drove in CD mode. The participants varied in their experiences with the vehicle, in their concepts and appreciation of the value of recharging, and in their access to different recharging locations. These differences will be discussed in a following section on narratives in which we relay the households' stories about their PHEV trials. For now, Figure 24 illustrates the overall variability in performance of the participants with regard to their average monthly (gasoline-only) fuel economy, the percentage of miles they drove in CD mode, and the overall distance they drove in the PHEV during their respective vehicle trials.[18]

**Figure 24: Gasoline-only Fuel Economy by Percentage of Miles Driven in CD Mode, Weighted by Total Monthly PHEV (CD+CS) Distance**




[18] The individual households identified in Figure 23 will be discussed in further detail throughout this and following sections.

In Figure 24, each circle represents one household. The diameters of the circles are proportional to the total miles driven by that household in the PHEV over their trial period. The largest circle ("Nancy," in the lower left) represents just over 3,000 miles of driving. That it also depicts the lowest percentage of miles in CD mode and nearly the worst gasoline-only fuel economy in the trial to date is indicative of several long, multi-day tours away from home during which Nancy rarely recharged the PHEV-conversion.

The basic conclusions to be drawn are that individuals varied greatly in their driving and recharging behaviors and, importantly, in the relationship between these two. A few households drove only 20 to 30 percent of their miles in CD mode—and for their additional use of electricity from the grid achieved overall gasoline-only fuel economy that is barely equal to the EPA fuel economy ratings of a conventional Prius (though, on average, they always outperformed their own driving of the PHEV-conversion in CS operation). On the other hand, a few households drove approximately 80 percent of their miles in CD mode and achieved monthly average gasoline-only fuel economy measures of approximately 70 mpg. A simple linear regression fit to the (distance-weighted) data is statistically better than simply fitting the mean of the mean average fuel economies (at $\alpha < 0.01$), but returns a modest adjusted $R^2 = 0.55$. The parameter estimated for the change in monthly mean mpg for a one-percentage point increase in the percent of miles driven in CD mode is 0.346: each percentage point increase in miles driven in CD mode leads to, on average, an increase of just over one-third mile per gallon in the monthly average fuel economy. While, as expected, a larger percentage of driving in CD mode is correlated with higher monthly mean fuel economy, there is much about the variation across households which is not accounted for by this simple model.

Figure 24 shows the potential for drivers of these particular PHEV-conversions to achieve reductions in the gasoline-intensity of their daily mobility through changes in how they drive and recharge the vehicle, e.g., driving and recharging such that the miles in a recharging interval closely match the driver-vehicle's CD range. Still, there is tremendous variability in how closely our participants' behavior matches this technically ideal pattern that is not illustrated in Figure 24. We explore next the potential for differences in travel and recharging behavior to influence measures of gasoline and electricity use, both next through the more detailed examination of one household's fuel economy and CD-mode data, and in an elaboration of three other households' overall experience in the following section on narratives.

### *The Kermodes*[19]

Here we disaggregate the PHEV driving and recharging of one of our households into their PHEV recharging intervals. We choose this particular household not because we judge them to be representative of the all the Project households or generalizable to all households: we choose them because they illustrate the large effects that differences in travel and recharging behavior can make—even within one household. The Kermodes' aggregate gasoline-only fuel economy and CD miles are shown in Figure 24 by the relatively large bubble centered on (22 percent CD miles, 49mpg). This makes them one of the "worst" performing households on one metric that is obvious and important to the Project households: (gasoline-only) fuel economy. We will show however that their aggregate performance masks a wide range of driving and recharging behaviors, signals to which the Kermodes responded, and possible summary measures to evaluate what difference it makes to the Kermodes to drive a PHEV vs. some other vehicle.

We disaggregate their six-week experience with the PHEV-conversion in Figure 25. While also a bubble chart in which the sizes of most of the bubbles are proportional to miles driven, the bubbles for their existing mid-size sedan and compact SUV are not proportional to distance traveled but are sized only to make them easily perceptible in the figure. The Kermodes' PHEV trial period lasted six weeks. For the first two weeks they drove the car with the PHEV conversion switched off, that is, they drove a slightly overweight but otherwise conventional Prius. During this time, they drove the vehicle 480 miles, averaging 44.2 miles per gallon, and—by definition—their percentage of miles driven in CD mode was zero. The green circle labeled "HEV" centered at (0 percent, 44.2mpg) in Figure 25 illustrates this performance.

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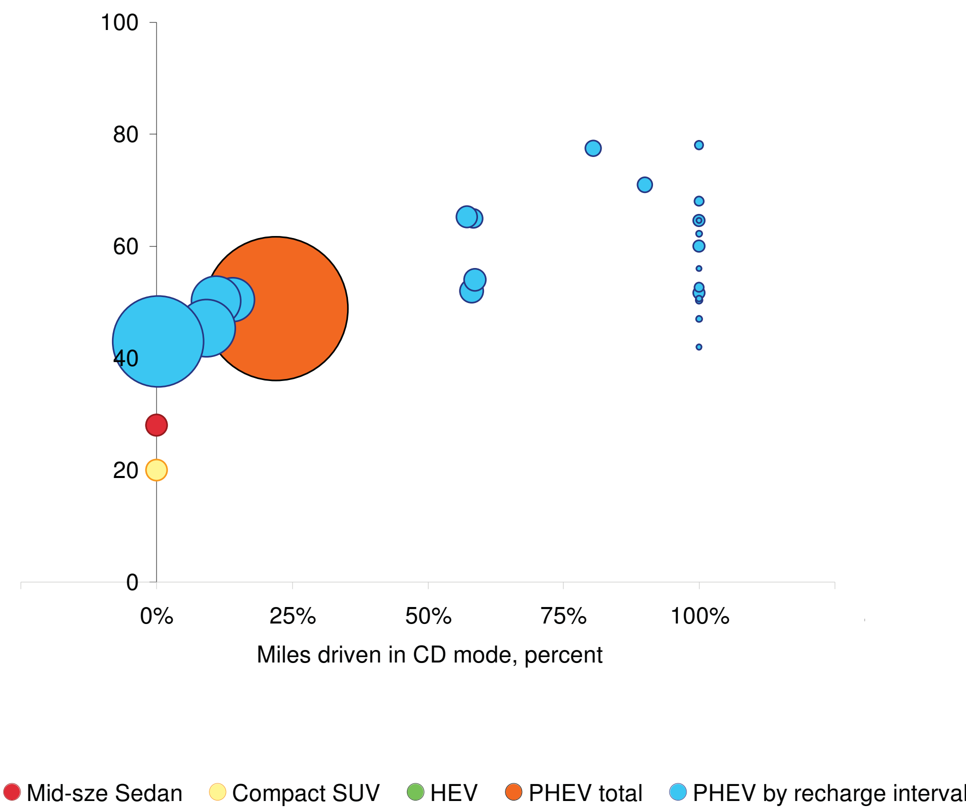
[19] All names used throughout this report to refer to Project participants are pseudonyms.

After two weeks, the PHEV conversion was switched in-line and the Kermodes drove the PHEV for four weeks. The aggregate measure of their four weeks driving the PHEV is shown by the large circle labeled "PHEV total" centered at (22 percent, 49mpg). This large circle is then disaggregated into the small circles (labeled "PHEV by recharge interval) representing each of the recharging intervals that make up their aggregate performance. Each blue bubble identifies a "recharging interval," i.e., a new bubble is formed each time the car is plugged in. For each, we plot the gasoline-only fuel economy and the percentage of miles driven in CD mode, sized in proportion to the number of miles driven in that interval. We see that the variety of performances per recharging interval within this single household is greater than the variety of the monthly average performance across all the households shown in Figure 24.

**Figure 25: The Kermodes' Distance-weighted Gasoline-only Fuel Economy by Percentage of Miles Driven in CD Mode per Recharging Interval**



For their six-week PHEV trial, the Kermodes most often substituted the PHEV-conversion—whether driven as an HEV or PHEV—for the mid-size sedan Ursula drives on a day-to-day basis. They recharged the vehicle at home every evening when they were in-town; when traveling out-of-town on multi-day tours, the vehicle was not recharged until their return home.

Differences in their vehicle use and the relationship between their travel and recharging behavior explain the three groups of PHEV recharging interval bubbles in Figure 25. From left to right, the first group is made up of the four largest bubbles, all representing multi-day tours away from home during which the vehicle was not recharged. The only place the Kermodes charged was at home, with a single exception of a brief effort to recharge at a family member's home during one of these long tours. For these tours, the PHEV substituted for the household's luxury compact SUV rather than Ursula's sedan. Second is a group of six recharge intervals that each represents a single day of driving around the Kermode's home city that exceeds their achieved CD range: the Kermodes were able to drive up to 35 miles in CD mode in their around-town driving. Third is the group of several days during which 100 percent of miles were driven in CD mode—these were all days that Ursula drove the vehicle for her daily commute and errands, as well as for some occasional evening trips.

Clearly the Kermodes' driving and recharging behaviors and the resulting fuel economy measures differed widely throughout their four weeks of PHEV use. The questions thus arise: how representative are any of the three groups of recharging intervals? Or, for that matter how representative is their PHEV trial month as a whole? The long trips the Kermodes took during which they accumulated hundreds of miles without recharging are normal trips for them: the Kermodes did not simply set off on several road trips because we had given them a free car. In that sense, the entire month is representative of a month of the Kermodes' travel—but not of every month. The Kermodes report the longest trips in their PHEV trial month are made typically twice a year. Based on the measures from the vehicle and the interviews of the Kermodes, an alternative month can be constructed in which the longest trips are replaced by other weekend travel days when the Kermodes stayed home. This constructed month yields new aggregate measures of 885 miles of

PHEV travel, of which 48 percent of mile were traveled in CD mode, resulting in an aggregate, gasoline-only fuel economy average of 55 mpg.

These two months of PHEV use—one as lived by the Kermodes and recorded by the on-board data systems and the other as constructed from that month based on the Kermodes' interviews—are summarized in Table 4. The Kermodes' lives over the course of a year can be represented by some combination of months like those shown in the table. The majority of months will be closer to the constructed month. But a couple of months a year will look similar to their actual PHEV trial month. The energy and environmental effects further depend on vehicle substitution within their household. In their actual PHEV trial month, the PHEV-conversion substituted for both their compact SUV for long trips and for their mid-size sedan for daily commutes.

**Table 4: Aggregate Measures of the Kermodes' Actual and Constructed Months of PHEV Driving and Recharging**

| Month | Actual PHEV | Constructed[1] |
|---|---|---|
| Miles | 1,932 | 983 |
| Percent miles in CD | 22 | 48 |
| Mean Monthly Gasoline-only Fuel Economy, mpg | 49 | 56 |
| Percent Difference from Kermodes' mid-size sedan[2] | 74 | 100 |
| Percent Difference from Kermodes' compact SUV[3] | 144 | 180 |
| Percent Difference from Kermodes' non-PHEV Prius[4] | 10 | 27 |

1. The constructed month is based on the actual month, but substitutes measures of the Kermodes' travel for weekends they remained home for a multi-day tour they made over one long weekend.

2. The Kermodes estimated the fuel economy of their mid-size sedan to be 28mpg.

3. The Kermodes estimated the fuel economy of their compact SUV to be 20mpg.

4. Driving the PHEV-conversion for two weeks in CS operation, i.e., with the PHEV conversion taken off-line, the Kermodes achieved an average of 44mpg. This period included one weekend trip out of town.

It seems plausible then that, at the expense of the additional electricity consumed from the grid, the Kermodes would improve their gasoline-only fuel economy by as little as ten percent and as much as 180 percent depending on what is chosen as the comparative vehicle and travel.[20] Compared to their own vehicles, driving this particular PHEV likely would achieve the claim of PHEV advocates to "double your fuel economy." Unfortunately for their claim, advocates have been arguing that the doubling occurs relative to CS operation of a conventional Prius. The Kermodes are achieving nowhere near this increase: across the two months shown in Table 1 they achieve a 10 or 25 percent improvement; even their best single recharge interval fuel economy (78mpg) approaches only an 80 percent increase in their CS fuel economy. (During one short all-CD recharging interval, they had worse fuel economy than they achieved in CS driving, perhaps illustrating the sensitivity of this specific vehicle-conversion to the effects of cold starts and the operation of the emissions system for the ICE.)

The point here is not that advocates are wrong or that PHEVs under perform (or over promise). Clearly, there is some PHEV in which the Kermodes could double their CS fuel economy while in CD mode. The point is that the efficacy of PHEVs is sensitive to not only technical design, but also driving and recharging behaviors and reference cases.

### The Overall Effects of Recharging on Energy Use

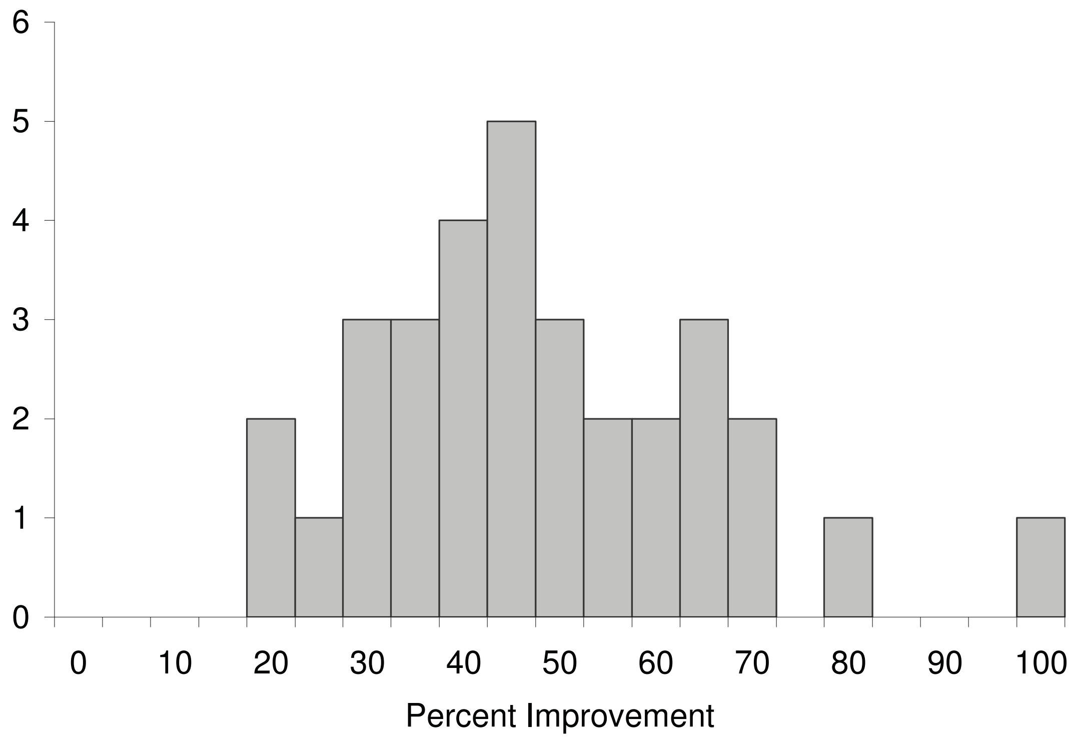
One measure of the effects of recharging is the difference in (gasoline-only) fuel economy. We describe these results first as it is the measure used by most participants. Across the group, the mean CS fuel economy was 44.7mpg; the mean CD fuel economy was 67.1mpg. Thus, the group mean increase in CD vs. CS is 49 percent. These group measures mask tremendous variation across households. The distribution of households' mean fuel economy improvements between CS and CD operation is shown in Figure 26 the range is from 21 to 101 percent. However, improvements over 70 percent are

[20] As Ursula Kermode approaches retiring, they have already discussed reducing their vehicle holdings to one car. It is our judgment based on the interviews, that it is most likely they would keep the newer, more luxurious, but less fuel-economical, compact SUV.

exceptions—90 percent of households had improvements less than 71 percent and the median improvement was 46 percent.

Another measure that begins to integrate vehicle performance capabilities with owners' driving and recharging behaviors is the percent of miles driven in CD mode. As the vehicle is fixed in this Project, differences across households are due to driving and recharging behaviors.

**Figure 26: Improvement in Gasoline-only Fuel Economy from CS to CD operation, percent**



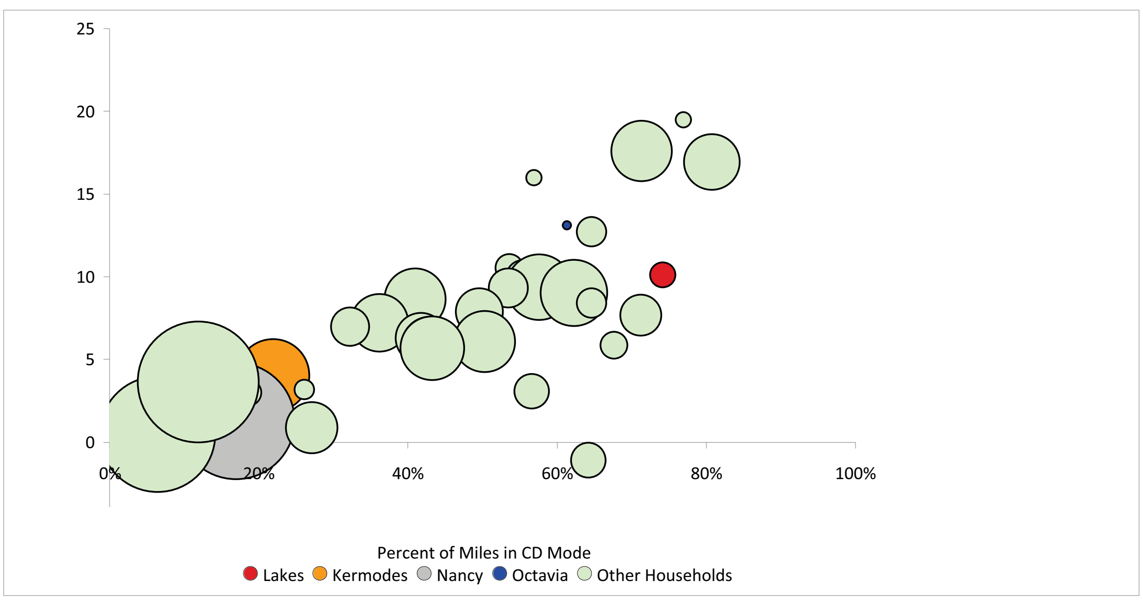

The discussion above of (gasoline-only) miles per gallon reflects the use of this measure by most households as the goal and measure of their experience with the vehicle (though fuel economy was translated into other goals by different households, e.g., cost reduction and environmental benefit). A few households used other measures related to gasoline use, e.g., distance, cost per tank, or frequency of gasoline refueling. No household created for themselves an integrated assessment of both their gasoline and electricity use.

However, such an integrated analysis is essential to the question of whether PHEVs deserve societal sanctions. The analysis presented here is preliminary and partial. It is preliminary because we do not expect that the full range and variety of the relationships between travel and recharging behavior on one hand and total energy use on the other have yet been observed among the Project participants' to date. Further, this analysis is preliminary because only one particular PHEV is analyzed. The analysis is partial because it is not a life-cycle analysis; here we address only electricity out of the battery and gasoline out of the tank. Further, the analysis is partial because we address only the marginal difference that it makes that the Project households drove (and recharged, to the extent each did) a PHEV instead of an HEV. That is we compare their actual total energy use, i.e., gasoline plus electricity, during their PHEV trial to the amount of gasoline they would have used had they driven their entire PHEV trial without every recharging, i.e., entirely in CS operation. To illustrate relationships between driving, recharging, and energy use we plot the marginal percentage decrease in total gasoline (tank to wheels) plus electricity (battery to wheels) by the percent of their miles they drove in CD mode for their four-week PHEV trial in Figure 27. As in Figure 24, the size of each data point in Figure 27 is proportional to the total miles driven during each household's trial (as an index of total energy use).

The first point is that a comparison of Figures 24 and 27 shows that the households' use of the simple measure of (gasoline-only) fuel economy is not qualitatively wrong. As the percent of miles driven in CD mode increases, fuel economy and total energy savings both increase. Whatever additional (dis)motivation, travel, or recharging would have resulted if households had created integrated representations of gasoline plus electricity use, cost, and emissions, the use of a simple measure of gasoline-intensity of their travel did not produce counter-productive outcomes. Figure 27 confirms that across the households, energy was being saved through the substitution of electricity for gasoline by recharging the PHEVs compared to what these households would have consumed had they not recharged the PHEVs—a conclusion that cannot be reached from Figure 24.[21]

The four households we've discussed in more detail are situated similarly in both figures. The relatively low percentage of CD driving of Nancy and the Kermodes—which we know was due to long, multi-day tours during which they did not recharge the PHEV—yields low percentage energy savings from a large (compared to the other households) base. Octavia and the Lakes achieved much higher percent energy reductions but across much less travel, and thus a smaller energy base. They did so in part because of the much higher percentage of their travel they accomplished in CD mode—accomplished both because they recharged more often traveled fewer miles than Nancy and the Kermodes.

**Figure 27: Decrease in Households' Total Energy (Gasoline plus Electricity) for their PHEV-conversion (as compared to an HEV) by Percent of Miles driven in CD Mode, percent.**




[21] The household that shows an actual increase in energy use, i.e., a negative percentage decrease, despite a high percentage of miles driven in CD, had drivers with different driving styles and distances per trip. That is, one driver's average CS fuel economy was as good or better than the other driver's CD fuel economy.

The four households in the furthest upper-right of Figure 27 provide interesting contrasts illustrating that driving fewer miles isn't the only strategy to high percentage energy savings. The data for these four households are provided in the first four rows of Table 5. Two of the households drove only 500 to 600 miles during their four-weeks driving the PHEV—about three-fourths of these miles in CD mode. They achieved total energy savings of 19 and 18 percent compared to what they would have achieved had they never recharged. Because they traveled short total distances, they each displaced three to four gallons of gasoline, in part by consuming 56 to 64 KWh of electricity (out the battery).

In contrast, the other two households who achieved the highest percentage energy savings—17 and 18 percent—drove over 1,500 miles during their PHEV trials. Their proportion of miles driven in CD mode is high: 71 to 81 percent. These two households each displaced nine to ten gallons of gasoline, in part by consuming about 141 KWh of electricity. How did these two households achieve similar percentage energy savings over many more miles than the previous two? The households that traveled longer distances achieved high percentages of CD mode by recharging multiple times per day. Both these households had one-way commutes that were about the distance of their realized CD range and both recharged at both home and work. In a sense, these two households achieved double (or more) their effective CD range daily; the households who traveled shorter distances but achieved similar percent savings did so because so many of their travel days were shorter than their realized CD range.

The effects of the adaptations to a PHEV within a household can again be illustrated by the case of the Kermodes. Substituting the month we have constructed to simulate a month during which they do not take their long trips to southern California, but stay in-town, their percent total energy displaced increases from the four percent calculated for their actual month to 14 percent.

In aggregate across all the first households to participate in the Project, each driving the same version of a PHEV for four weeks, they drove over 33,000 miles. In doing so, and in recharging the PHEVs, they displaced 110 gallons of gasoline, at the expense of 2,066 KWh of electricity. Each of the households displaced as little as one gallon of gasoline to as much as (almost) ten, at the cost of 19 to 141KWh respectively. A simple regression across all households returns an adjusted $R^2 = 0.86$ and an estimate that for each kilowatt-hour (out of the battery), on average, these households driving and recharging these PHEV-conversions displaced 0.065 gallons of gasoline (out of the tank) compared to the amount of gasoline they would have consumed had they not recharged.

**Table 5: Energy Use and Savings, sorted by Percent Decrease in Total PHEV Energy Use**

| "Name" | Total VMT | Percent Miles in CD | Gasoline Displaced (Gallons) | Electricity (KWh) | Δ Total Energy (KWh) | Percent decrease in Total |
|---|---|---|---|---|---|---|
| | 471 | 77% | 3.43 | 55.85 | 69.60 | 19% |
| | 587 | 74% | 4.13 | 63.60 | 87.65 | 18% |
| | 1,598 | 71% | 9.76 | 141.08 | 216.20 | 18% |
| | 1,505 | 81% | 8.93 | 141.30 | 185.92 | 17% |
| Octavia | 286 | 61% | 1.58 | 25.16 | 32.62 | 13% |
| | 830 | 65% | 4.35 | 77.10 | 82.14 | 13% |
| Lake | 716 | 74% | 3.64 | 79.68 | 53.64 | 10% |
| | 902 | 55% | 3.78 | 65.73 | 72.83 | 10% |
| | 1,739 | 58% | 6.81 | 91.58 | 157.71 | 9% |
| | 1,772 | 62% | 6.37 | 105.41 | 127.91 | 9% |
| | 824 | 65% | 3.41 | 71.87 | 52.87 | 8% |
| | 1,275 | 50% | 4.27 | 83.04 | 73.23 | 8% |
| | 1,111 | 71% | 4.37 | 92.61 | 67.61 | 8% |
| | 1,538 | 36% | 4.56 | 85.76 | 81.36 | 7% |
| | 1,043 | 32% | 3.06 | 50.40 | 61.66 | 7% |
| | 1,369 | 42% | 3.56 | 62.61 | 67.82 | 6% |
| | 1,639 | 50% | 4.52 | 89.22 | 76.36 | 6% |
| | 743 | 68% | 3.17 | 83.90 | 32.23 | 6% |
| | 1,526 | 43% | 4.06 | 78.66 | 70.05 | 6% |
| | 1,687 | 43% | 4.20 | 73.70 | 80.26 | 6% |
| Kermode | 1,932 | 22% | 3.33 | 58.57 | 63.32 | 4% |
| | 568 | 26% | 1.21 | 24.08 | 20.18 | 3% |
| | 944 | 57% | 2.54 | 71.38 | 21.58 | 3% |
| | 738 | 19% | 1.09 | 18.79 | 21.18 | 3% |
| Nancy | 3,040 | 17% | 2.77 | 67.08 | 34.55 | 1% |
| | 1,372 | 27% | 1.38 | 41.20 | 9.17 | 1% |
| Total | **33,422** | 49% | **110.10** | **2,066.40** | **1,965.91** | |

## Recharging Conclusions

The households in this Project were selected in part because of their capability to recharge a PHEV at home. Further, they are all driving one specific incarnation of what a PHEV can be. For these reasons, and because of the probable correlations between PHEV performance capabilities and driving and recharging behaviors, the specific numerical results of this section should be interpreted with appropriate caution.

That said, the households participating in this Project are, on average, plugging-in these PHEV conversions about once per day, and do so more often on weekdays than weekend days. There is large variation though even in the means across households—from zero to 2.6 times per weekday and zero to 1.5 times per weekend day. The higher frequency of plugging-in on weekdays is associated with 1) some incidence of recharging at work on weekdays, and 2) recharging at home during the day by retired households. Overall frequency of plugging-in on weekend days is lower not only because there is no workplace recharging taking place, but because the PHEVs are more likely to be away from home, and thus the primary or sole recharging location.

Comparing electricity availability and instantaneous power demand provides a picture of aggregate recharging behavior and potential for electricity grid impacts for weekdays and weekend days, illustrating both when these vehicles could have been recharged and when recharging actually occurred. In general, most households plugged in their vehicles after 4:00pm on weekdays and left them plugged in until 6:00am. While the electricity demand from vehicles being plugged in between 5:00 and 6:00pm creates a rapid increase in grid electricity demand, the differences between the "availability" and "demand" curves show there is opportunity to shift recharging to presently existing off-peak electricity demand periods. Compared to weekdays, weekends present even greater opportunity to time-shift grid power for the vehicles since 1) fewer are plugged in, 2) those that are plugged in require less electricity to fully recharge, and 3) those that are plugged in tend to remain plugged in longer into the next morning. Furthermore, there are differences in opportunities to use PHEVs as "sinks" for excess electricity, based on the differences in how many vehicles are plugged in between weekdays and weekend days.

While the electricity availability and instantaneous power demand characterized by this report are representations of what happened across the Project households' PHEV trials, it is important to emphasize that individual household charging behavior, vehicle use, and vehicle performance varied across days, recharging intervals, and trips. Essentially, while we have accurately represented households' last week or month of driving the PHEV-conversion, that record of actual driving during the PHEV trial may not have been representative of every week or month of a household's life. In an effort to demonstrate the different ways households could plausibly use these vehicles, we disaggregated the real month PHEV trial of the Kermode family and offered an alternate month based on their interview and vehicle data. The two months—the month as measured including multiple, away-from-home weekend tours and a constructed month that substitutes local weekend travel for the longest of these tours—provide descriptions within which most of the Kermodes' vehicle driving and recharging will fall. Depending on which month and which comparative vehicle(s) one references, the effect on the gasoline-intensity of the Kermodes' travel is bounded by estimates of ten to 180 percent. Further, the marginal effect of recharging on their total energy displaced by driving and recharging the PHEV ranges from four percent in their actual month of using the PHEV to 14 percent in a month plausibly constructed to represent other months of their life (keeping in mind their actual month with the PHEV does represent some months of their lives).

The total energy savings and gasoline (tank-to-wheels) displaced by electricity (battery-to-wheels) are modest in aggregate and highly variable across households. Those households who are closely able to match their travel to (multiples of) their achieved CD range of these PHEV conversions are able to achieve much higher percent of their travel in CD mode and thus greater percentage total energy (gasoline plus electricity) reductions through the substitution of electricity for gasoline. These households achieve higher percentages of CD mode driving because either, their common daily travel is less than their achieved CD range or they had access to away-from-home (and in this case, workplace) recharging so that they recharged multiple times per day.

# 3C. PROJECT RESULTS: NARRATIVES

## Narrative Analysis: What, why and how?

This section highlights the importance of talking to consumers and the value in hearing their stories. We have two purposes in employing narrative: synthesis and analysis. First, we have a tremendous amount of disparate information about each household. Narrative provides a framework to organize, analyze, and report all these data: quantitative and qualitative; numeric and text; researcher observations, transcripts of oral interviews, on-line questionnaire responses, and vehicle and recharging data. Second, the purpose of narratives is to explain, to provide coherence, to show causality; individual datum record what happened; narratives tell us why.

### *What is a Narrative?*

At its most basic level, we use narrative as a description of a story by a researcher (Berger and Quinney, 2005). Generally, narratives are produced in conversation. However, the data to construct narratives have also been collected through conversational interviews and field notes based on observations (Lieblich et al. 1998). For the Project, each household's narrative was compiled from multiple in-person interviews, enhanced by field notes from the researchers, as well as data from the questionnaires completed by each household at the start and end of their PHEV demonstration period and quantitative measures of driving and recharging reported by the data systems onboard the vehicles. Our role as researchers is to tell the households' stories of their month with a PHEV.

> "Stories provide coherence and continuity to one's experience and have a central role in our communication with others…Stories imitate life and present an inner reality to the outside world; at the same time, however, they shape and construct the narrator's personality and reality. The story *is* one's identity…We know or discover ourselves, and reveal ourselves to others, by the stories we tell." [Emphasis in the original.] (Lieblich et al. 1998)

Narratives allow researchers to understand people's beliefs and the meanings behind their actions by creating a stage for people to tell their story and outline who they are. Lieblich et al. (1998) states that a narrative researcher does not take the story as being a complete and accurate representation of reality; instead, meaning must be drawn from the story that was told.

The criteria of what constitutes a narrative vary, though there are commonalities. Reissman (1993) states that a narrative must tell a story and have a clear beginning and end. The narrative takes chronological events and uncovers the meanings of what came before and what might come in the future; in essence, there is a plot, and the narrative has a purpose (Berger and Quinney, 2005). A narrative, without a plot is not an accurate representation of what happened. E.M Forster offers an example, "The king died, and then the queen died." (Cited in Herman and Vervaeck, 2005). This is a chronology of events, but not a narrative. Only when plot is added does the story represent what transpired; in Forster's example, "The king died and then the queen died of grief." The queen dieing of grief indicates causality, a plot emerges, and a narrative is formed.

Narratives are interpretive (Reissman, 1993) and the stories that are used for the construction of narratives are subjective (Lieblich et al. 1998). Reissman (1993) explains meaning is collaboratively produced by the teller, analyst, and reader and may vary from person to person.

> "A narrative never provides a perfect copy of the reality constituting its subject. A person who narrates what has happened to him will always summarize, expand, embellish, and leave out certain aspects of his experience. Since a narrative text is restricted to language, it will never show reality directly." (Herman and Vervaeck, 2005)

In the present case of this Project, the researchers are responsible for representing the participant as accurately as possible through the process of interpretation because it is in interpreting the narrative that its' meaning is derived. Without interpretation, the narrative would be based solely on the participant's version of reality.

Writing the narrative is an essential step in the research process because it takes chronological events and arranges them in a way to tell a story, complete with a beginning, middle, and end, as well as a plot. Berger and Quinney (2005) explain that having people tell their own stories in the form of an interview is a unique opportunity as story telling extends the reality of our experiences:

> "Stories are ways not merely of telling others about ourselves but of constructing our identities, of finding purpose and meaning in our lives…In the telling we remember, we rework, and reimagine the past, reflect back upon ourselves, and entertain what we have and could become."

Like all forms of data collection, narratives have limitations. Because researchers do not have direct access to a person's experiences they must deal with ambiguous representations that do not allow for the purported neutrality and objectivity of quantitative methods: a researcher cannot represent a participant's story without interpreting it. As Reissman (1993) says,

> "Meaning is ambiguous because it arises out of a process of interaction between people: self, teller, listener, recorder, analyst, and reader. Although the goal may be to tell the whole truth, our narratives about others' narratives are our worldly creations…All we have is talk and texts that represent reality partially, selectively, and imperfectly."

Along with this co-construction between participant and researcher of reality comes another limitation: the co-construction of reality allows for the avoidance of some facts (Schram and Neisser, 1997). Writing a narrative takes caution and a focus on details in order to maintain the integrity of the participant's story without injecting the researcher's own agenda or biases.

### *The Value of Narratives*

Narratives are valuable to the research process for several reasons. According to Reissman (1993), having participants tell their life stories allows them to use human agency and imagination to determine what to include, how events are emplotted, and what they mean. Similarly, Lieblich et al. (1998) explains that the life story creates and transmits a person's individual meaning in addition to cultural meanings. This allows the researcher to understand what the participant believes as well as what their culture prescribes.

A personal experience can be too narrow to highlight important social debates; the personal experience becomes compelling when multiple people duplicate it, therefore, if several participants cite the same issues in their narratives then these should be looked at closely (Berger and Quinney, 2005). This is largely important to policy makers. Schram and Neisser (1997) argue that narratives help realize political space and those in the political sphere use stories to engage in political change. For example, urban legends about international terrorism give voice to anxiety about personal control, which in turn legitimates forms of state action and surveillance. Stories lead to political action; narratives can be used to stimulate change. It is crucial to understand people's stories in order to understand what is happening in society as a whole. A compelling story has the ability to connect personal experiences to public narratives, essentially allowing society to speak through each individual (Berger and Quinney, 2005). This is highly valuable when dealing with public policy and cultural change because it can allow the researcher to foresee the reaction of the general population and suggest alterations to attempt to affect the speed and direction of change.

### *How do We Create Household Narratives?*

Narrative creation begins with the household interviews. Interview protocols, i.e., an outline of topics to be included in the interview. These topics come from the research questions for this Project. The protocols use open-ended questions to allow the respondents the freedom to go in directions they choose. The interviews are recorded and the mid-term and final interviews are transcribed.[22] Referring back to both, the interviews are coded by a researcher reading through the entire record several times to locate patterns or reoccurring themes. A list is made of all the themes and they are put into sub-categories determined by the scope of the study. As Lieblich et al. (1998) explain, a separate read-through is done for each theme and notes are based on the researcher's initial conclusions. Analysis is drawn from these notes, an overall picture of the participant's story is created, and a narrative is written. Additional material is brought in from the on-line questionnaires, especially as one of the topics for the final interview is to review the PHEV designs created by households in the final questionnaire. Further, as

[22] The initial interviews that are part of the vehicle drop-off procedures are not transcribed in-full primarily because they largely consist the formalities of completing paperwork, checking on the intended parking and charging location for the vehicle, and explaining the vehicle operation and research process. That is, too much of these initial "interviews" consist of the researchers talking, not the households, to warrant the transcription of the audio recordings. The recordings are reviewed and relevant passages are noted.

was done for the Kermodes in the previous section on recharging, data from the vehicle is analyzed and incorporated in the story about each household's month with a PHEV.

### Illustrative Stories from Three Households

There are three major types of household narratives that have emerged from the first 34 households to participate in the Project. The first type consists of people who understood the PHEV technology before they started their demonstration, represented here by Rick and Samantha Lake.[23, 24] The second type did not understand the PHEV technology—even after their PHEV trial period, represented by Nancy. The third type started out their PHEV trial not understanding the PHEV technology but developed a better understanding over the course of their trial, represented by Octavia. Brief introductions to these three households' narratives are presented here; fuller versions are included in Appendix F. (They are also discussed in the previous recharging section.)

#### *The Lakes*

Rick and Samantha Lake are married with two young children and live in a large house in a gated community. Rick drives a 2002 Honda Accord, mostly to commute to work; Samantha drives a 2004 Honda Odyssey to run errands, shuttle children, and generally run their household. The Odyssey is also used for longer family road trips. They substitute the PHEV for the Accord.

Prior to the trial, Rick and Samantha were fairly familiar with electric-drive vehicles, especially compared to other households in the study. They knew neighbors that drove neighborhood EVs, such as the GEM, and Rick had ridden in a hybrid Civic. Rick had seen a news clip featuring UC Davis PHEV Research Center Director, Tom Turrentine, showing off the battery of the PHEV-conversion. Rick recalled the statement that a driver could get 100 mpg for the first 40 miles, so he was "shooting for 100 mpg."

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[23] "Understanding" is a relative concept in this context. No household had a sophisticated, expert understanding of PHEVs. The group referred to here understood that the car ran on both gasoline and electricity, that it could be plugged into the electrical grid.

[24] As noted in the previous section, all names used throughout this report to refer to participants are pseudonyms.

The Lakes enjoyed driving the PHEV. Rick drove it for his 19-mile roundtrip commutes most days. He said, "…for day-to-day commute, it's great" and fit into their lifestyle "fairly seamlessly." Rick was "expecting high mileage and it delivered." Rick's assessment of the PHEV was at least partially related to his perceptions of pure EVs, "for me it was the combination of having the gas and electric assist, it made it easier to integrate into our life than pure electric, because it had that gas component you never really worried." Rick was frustrated that the engine would come on even during short trips, when "it's burning gas, and I don't need it…just a half mile…why doesn't it just run on electricity?" Every night Rick plugged in the PHEV and unplugged it every morning. Sometimes he would plug it in during the afternoon if they were going to use it at night. Samantha drove the car only five or six times, mostly for errands or taking the children to school.

Rick liked to monitor how he was doing by watching his fuel economy as well as the Energy Monitor screen in the vehicle to see if the [supplemental conversion] battery was being used.[25,26] He would experiment with different behaviors, "I'd gas it and watch it…put my foot off the throttle and watch it…out of curiosity to see how my actions affected things…air conditioner, no air conditioner." Rick was also motivated by his goal of achieving 100 mpg or higher, which he successfully reached several times according to data from the vehicle.

In contrast to Rick's initial focus on the energy instrumentation, Samantha said, "I'm the opposite, oblivious…just driving…I pay attention to the road mainly." She figured that the PHEV was "gonna do what it was gonna do." Once the Lakes were given access to their data on the V2Green website, Rick visited the website often and seemed to integrate the provided information into his assessment of the vehicle.

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[25] Throughout these discussions of the households, the phrase "fuel economy" refers only to gasoline use. This corresponds to the households' understanding and use of language regarding these vehicles.

[26] Detailed descriptions of the in-vehicle instrumentation and the website providing further information about the vehicles' performance are given in the next section on interfaces and information.

The Lakes seemed especially interested in two topics relating to the PHEV: the idea of a payback period and helping the environment. When discussing whether he would purchase a PHEV, Rick said, "I would do a little cost-benefit analysis…you can kick in a little premium, maybe a 10% premium just to go green or do your part for the environment to be a good citizen." When asked specifically what he liked about the PHEV, Rick included the potential to reduce $CO_2$ emissions through reduced gasoline use, at least "in theory." He further states, "I don't know whether or not it really reduces pollution…but it's nice to think it does…nice to have the perception that you are doing something to help out." Rick's uncertainty seems to stem from a lack of information about the pollution from electricity generation and battery production.

Yet despite his repeated claims to subjecting their PHEV choice to a payback analysis, it is clear that Rick did not subject his PHEV design with 10 miles AER (in the design games in the final questionnaire) to such an analysis.[27] Despite his repeated stories and claims, and despite responding to Samantha's challenge in the final interview about whether CS fuel economy would payoff,[28] the PHEV capability Rick has decided he wants—to be able to drive back and forth between home and work using only electricity—is something he is willing to do without calculating costs and benefits, by shifting his travel times, by attempting to get a plug installed, and even by using a plug he has previously deemed unsuitable (because it is located between elevators).

Samantha brought in more global resource concerns. She described how, when gas prices recently went up, they saw more television shows talking about natural resources: "...how much we have and why, and the other developing countries like India and China who are now playing a bigger role in wanting the resources…I think we need to figure out ways to

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[27] The households complete the final questionnaire before the final interview. In the final interview selected questions from all the questionnaires are reviewed with the household. These include the PHEV designs the household creates. This allows the researchers to explore with the households why they created the designs they did, and to have the kind of exchange with the Lakes described here.

[28] Rick designed his PHEV in the final questionnaire without consulting Samantha. In the final interview, she challenged his design, which did not include CS fuel economy improvements. She felt CS fuel economy improvements would be "worth it." Rick got up from the interview, retrieved his calculator, returned, made some quick calculations, and concurred with Samantha. The interviewers did not press him to share his calculations.

make sure that globally everyone gets what they need…we've got to pass on the world to the next generation."

Overall, the Lakes enjoyed using the PHEV. When asked if they would consider purchasing a PHEV Samantha said, "The increased fuel economy sounds good, to save money and contribute to the solution of global resource problems. But we are not willing to compromise much on functionality, the vehicle would have to fit into our family's lifestyle, such as storing groceries and allowing long road trips."

### *Nancy*

Nancy is a single, retired grandmother who lives in an older, modestly sized, attached home. She is the primary caregiver for her young grandson. As a caregiver with a single income, Nancy admittedly watches her money closely and is always looking to get the most for it. She substituted the PHEV completely for her only vehicle, a 1991 Toyota Camry with 253,000 miles.

Nancy did not know what to expect from the PHEV. Having no experience with any hybrid vehicle, she seemed to struggle with the concept of how the car worked and how it was different from a conventional Prius. However, she was quick to understand that using electricity could save her money on gasoline.

Nancy did not notice a difference between when the vehicle was in CD or CS operation. Nor was she aware of where the energy to move the vehicle was coming from. She said, "I don't know when it's using gas…or electricity. I can't tell. Am I supposed to be able to tell? Can you tell?" Nancy knew that by using electricity she got "good mileage." She said, "I'd rather use the battery, then you don't have to fill up as much. The gas will last longer." Nancy explained that she had a feeling she was getting good mileage based on how far she could travel on $20.00 worth of gas, and that as a consumer she generally has an instinct for good value: she "just knows" when she is getting her money's worth or a good deal.

Nancy claimed that looking at the fuel consumption and energy monitor displays did not influence her driving. She saw the instantaneous mpg reading, but the numbers "kept changing from 17 to 99 mpg" and she found it too much to process. She was also confused about what the arrows meant on the Energy Monitor screen, or what the display was telling her. She said, "I try to watch (the screen)…I thought I was getting it…but I think I am just confused."

Nancy found charging the PHEV to be very easy, both at home and on a trip to Southern California. When at her own home she only charged at night and was adamant that this was the way to go, calling herself a "nighttime charging gal." Nancy charged the vehicle 18 times during her four weeks with the PHEV, usually plugging in between 8:00 pm and 12:00 am and unplugging the next day before a trip. She seemed to fall into a charging routine with the vehicle even though she could not tell when the battery was discharged.

Despite her confusion about how the car worked, Nancy enjoyed driving the PHEV. She especially enjoyed showing off the vehicle to her friends and family during a trip to Southern California. Overall, Nancy concluded, "I never would have picked that car, but after driving it for a month, it just feels right. I really would like to buy one with a plug if I could afford it, because I really feel like I am getting the most for my money when I use the electricity."

### *Octavia*

Octavia is a middle-aged woman who lives with her retired mother in an attached home, works as a librarian, and drives a new Honda Civic. She was not familiar with any hybrid vehicle technologies prior to this study. She completely substituted the PHEV for her Honda Civic.

Octavia said the car performed "great" without any "compromise" for the added benefits of fuel economy. She felt the PHEV was quiet and smooth, although she did occasionally feel a "lurch" when the engine kicked in. While driving, Octavia focused on the fuel economy information in the vehicle; she found the battery state of charge indicators to be confusing. She was surprised by the "phenomenal" increase in gas mileage relative to her Honda Civic and said the accompanying reductions in carbon emissions were "even better." She linked gas savings with energy independence and reducing environmental impacts. Octavia said that in the world today, “we have people dying…corruption and big business…due to the whole dependence on oil…we are in trouble…we can’t keep going this way.” She felt that the PHEV gauges would help people make a stronger connection between their personal actions and global problems.

Octavia greatly changed her recharging behavior over the course of her four-week trial. During the first two weeks she was unsure how to judge the battery’s state of charge and would plug-in for 3-5 hours every other day or so. She was just “guessing” and did not follow a consistent pattern. After being introduced to the V2Green website, she saw that there was strong potential for her to improve her fuel economy. She felt her understanding of the car improved further a week later when she read the PHEV “buyer’s guide” in preparation for her PHEV design exercises in her final questionnaire. With this information she said, “Now I get it…I’m not charging it enough…I’m (switching) to gasoline half way through my day…I’m not utilizing the battery component…I need to start at 100% every day.” The handout helped her pull together the information of how long it took to recharge the vehicle to maximize her gasoline savings.

At the close of her PHEV trial, Octavia really liked the car and regretted having just bought a new Honda Civic without at least test-driving a hybrid. In the future she would consider PHEV options, but would have to think further about the specific attributes she would like, such as all-electric vs. blended operation. She also noted that for a longer-term scenario she would likely seek out additional recharge opportunities other than her home, and potentially modify her driving behavior to further reduce gasoline usage.

## Themes from Households’ Narratives

Here, we use elements from these three narratives to illustrate the themes that emerge from narratives of the first 34 households. Supporting material from other household’s narratives will also be included. These themes relate to driving and recharging behaviors, confusion about PHEVs, and the issue of whether and how households think about payback periods when evaluating whether a PHEV is a good idea.

*Changing Driving Behavior*

Some households discussed a change in their driving behavior, specifically accelerations, top speed, and coasting. Like Rick Lake, these drivers stated that seeing their instantaneous fuel economy affected how they drove because they could determine what behaviors led to a drop or rise in mpg. Rick's monitoring and experimentation, "I'd gas it and watch it…" seemed to be a fairly common behavior among those households who watched the in-vehicle screens. Another participant discussed a change in his behavior, "…it helps you watch your driving habits, like not driving too fast…if I'm going to point A and point B I don't want to drive too fast because…you'll be using more gas. If I slow down…then you're using both gas and electric…" The instantaneous fuel economy reading on the Energy Monitor screen created an opportunity for nearly constant monitoring of driving behavior for some participants. These drivers were aware of how their actions were impacting the performance of the car and their overall fuel economy.

Others, and most so far are women, said they drove the PHEV like their normal car, and did not continuously monitor their fuel economy. Recall that in contrast to Rick's initial focus on the energy-use instrumentation, his wife Samantha stated: "I'm the opposite: oblivious…just driving…." She reasons that because she is driving fast she has "got to pay attention [to the road]," and thinks that Rick looks at the Energy Monitor too much. She and many like her did not make the connection that their behavior impacted the fuel economy of the vehicle.

Several people, especially those who constantly monitored their fuel economy, saw driving as a test or a game and tried to attain a certain mpg or maximize the distance over which the supplemental battery charge would last. A few households were able to enact a friendly competition between household drivers to see who could get the highest fuel economy. Rick Lake used the information from V2Green to (playfully) compare his fuel economy with Samantha's:

Rick: "When I drive it's about 75 [mpg], when [Samantha] drives it's about 50…I looked on the Internet (laughs).

Samantha: "…what does that mean—highway vs. city?

Rick: "…could be…or more aggressive accelerations…I coast a lot.

Samantha: "…I'm in a rush to get somewhere…

Rick: "…right, nobody passes mommy (laughs)."

Rick Lake used the vehicle information reported and summarized on the website to determine whether he or Samantha was the more economical driver, but she would not engage in a competition.

Other households though were able to use their energy information to stimulate a competitive game between drivers in a household. When asked if they looked at the average miles per gallon during the trial, one household responded, "…yeah, I looked at that, and so my husband would have a contest, okay, let's see who had the best." It was not uncommon for households with more than one participating driver to engage in a friendly competition to see who could get the higher fuel economy. This seemed to turn driving the PHEV into a game and allowed the households to engage the car in a way they had not prior vehicles.

### *Recharging Habits and Etiquette*

Most households spoke of recharging becoming part of their daily routine, like recharging a cell phone or feeding the dog. Some, like Nancy, referred to it as an additional daily chore. The majority of participants said plugging-in was easy and not a hassle, except for the awkward extension cord—many observed that a retractable cord would be a welcome change. Most people recharged at home because of the time needed to recharge the battery, availability of an electrical outlet, and safety of the car (and cord). Most stated that recharging at night was ideal because they could plug-in the car when they got home and un-plug it in the morning before heading to work. Several, including the Lakes, Nancy, and Octavia, were concerned about plugging in their car if it was parked outside of their garage for fear of a tripping hazard or someone stealing the cord.

Some looked for recharging at local malls, job sites, or during out-of-town trips; none found it easy to locate an appropriate outlet. They report no etiquette for recharging behavior, so they were unsure if asking to plug in would be rude or presumptuous. One participant, Casper, who worked in construction, discussed his hesitancy to recharge at a work site he had to visit, "…it didn't seem like it would be appropriate to just pull right in there and plug into their power." Without making a calculation, Casper rationalized that normally plugging in at a job site would not be a problem because, "…the amount of energy that I'm going to take from him [the contractor who pays the electricity bill] doesn't even equal six guys with power saws cutting lumber…all day." However, several times during his interviews, Casper wondered whether it would be appropriate or not to plug in at a variety of other places.

Several participants specifically related that they did not ask to recharge at the houses of friends or family because they were unsure of the etiquette, while others saw recharging away from home as an opportunity to show off the car and explain the technology. A few of the households said they would request an outlet be installed at their work location and/or around their community if they were to own a PHEV.

One issue of particular importance to the larger social and policy discourse about PHEVs is recharging frequency. By the end of their PHEV trials, if the participants understood how to maximize the use of the supplemental battery, they were recharging every night. Those who did not understand battery SOC, or PHEV technology in general, did not necessarily recharge nightly or, in some households, in any apparent pattern.

When asked about recharging, most participants discussed the actual act of plugging in the cord but not the frequency with which they recharged. Despite several households questioning us about how often to recharge when the PHEV was first delivered to them, it appears that recharging either 1) quickly became a daily routine or chore—irrespective of the level of understanding of why they would plug the car into the grid—or 2) that differences in the performance of the PHEV in CD and CS mode were not adequately represented to some households for them to understand why and when to recharge the car. We will return to this latter possibility in the section on interfaces and information.

### *Confusion*

As might be expected from a group of people in which few had prior experience with electric-drive vehicles, many respondents were initially confused by the idea of a PHEV. Whether this confusion remained or was replaced by a more grounded understanding over the course of their trial month distinguishes some households from others. For example, Nancy and a few other households knew recharging helps increase fuel-only economy but did not understand how. Nancy did not notice a difference between when the vehicle was in CD or CS operation. Nor was she aware of where the energy to move the vehicle was coming from. Nancy was arguably the most confused participant, but many households were unfamiliar and uncomfortable with the PHEV technology—some even after they had spent a month with the vehicle.

Most of the households were confused about the state of charge of the battery. The battery SOC indicator on the Energy Monitor screen will flicker and then switch between two colors as the vehicle transitions from CD to CS operation. This bit of feedback was missed by most people and understood by few. Some thought they could determine when the supplemental battery expired based on the relatively large drop in fuel economy when switching from CD to CD operation. Drivers were more likely to notice this change in fuel economy if it happened to coincide with some regular set of trips. For example, one household determined that if he paid attention to moderating his driving, his one-way commute trip was just about as long as he could keep the car in CD mode.

But many drivers had no idea. This—combined with incorrect mental models of batteries—caused some participants, like Octavia initially, to recharge less frequently than they would have if they had known how to determine the state of charge of the battery and if they had understood what the benefits might be. Octavia cited the example of her cellular phone—so long as it had some charge, she derived full value from the phone calls she made or received on it. Many households voiced a desire to have a clear reading of the state of charge of the battery in order to determine how far they could travel using the battery and when it should be recharged.

Most found the in-vehicle instrumentation to be poorly designed, but only a few did not understand the information being displayed. Nancy was one who never seemed to learn what the car might have been trying to tell, rather she felt overwhelmed by the PHEV display screen. She saw the instantaneous mpg reading, but found it too much to process. She was also confused about what the arrows meant on the Energy Monitor, and about what the display was telling her. She said, "I try to watch [the screen]…I thought I was getting it…but I think I am just confused."

### *Payback*

Many households discussed using some form of a cost-benefit analysis to determine whether the PHEV was "worth it." Most of these households discussed simple payback analysis comparing differences between a higher purchase price and lower operating cost. A few households discussed more sophisticated net present value calculations. Despite these discussions, no households appear to have completed either simple payback or net present value calculations. Most households made mistakes in describing how to make such calculations and demonstrated they did not know the values of the costs and benefits that would enter into such a calculation.

Throughout the trial Rick Lake repeatedly discussed the idea of payback and whether the PHEV was "worth it." However, during the design games prior to the final interview he used no such calculation to determine his PHEV designs. When asked if he performed a payback calculation he admitted that he had not; he did do one during the final interview on a PHEV design that Samantha suggested as an alternative to his. That Rick had not done this calculation for his design was shocking to the researchers because he (and Samantha) had repeatedly emphasized how important such calculations are to him, even telling a story about a (friendly) argument between Rick and his brother-in-law regarding the payback time for an on-demand water heater.

Even for those who discussed payback, existing prices were not always the preferred values. As an adjustment to such calculations, many households factored in the environment and "doing their part," for example Rick and Samantha Lake who stated, “you throw in another 10 percent for the environment.” They saw helping reduce environmental concerns as a benefit and worth the cost of the additional battery.

In contrast, other people made more intuitive evaluations. For Octavia, using less gas “was a great feeling” because it “has got be a good thing.” She linked gas savings with energy independence and reducing environmental impacts. Octavia felt that the PHEV instrumentation would help people make a stronger connection between their personal actions and such global problems. For her, this awareness was a large benefit to driving a PHEV. She figured that most current HEV buyers were driven by financial motives, whereas if she were to buy an HEV, it would be for environmental reasons. She believed that climate change is a real, human-caused problem that, along with air pollution and the nation’s dependence on foreign oil, requires urgent action. She sees owning a PHEV as part of the solution for these problems.

### Narrative Conclusions

This form of data collection, analysis, and synthesis allows the researchers, policymakers, and manufacturers to understand people’s beliefs and the motivation behind their actions. By listening to people’s stories researchers in this Project were able to focus on what and how the participants communicated their experience. Some people changed how they drive the car after seeing their instantaneous fuel economy; others drove the PHEV as any other car, and specifically like they had no particular control over energy use. Some people likened plugging in the PHEV to recharging a cell phone and made it part of their daily routine, but were hesitant to recharge outside of their homes due to a lack in social etiquette and concerns for safety. This group may feel a need for recharging locations in the public sphere to solve the problems of social relations as much as to maximize their CD miles. Many people were confused about the state of charge of the battery; this influences how often they recharged. Some were concerned about the cost of the PHEV and payback; they saw PHEVs as helping with environmental problems but wondered how much they were paying to do so.

In the context of the present Project, locating the reasoning behind people’s actions and decisions allows for researchers, policymakers, vehicle manufacturers, and electricity and fuel suppliers to recognize how households arrive at actions and decision. This is useful because it allows those interested to shape the direction of the market and the future of the product, in this instance, PHEVs. Narratives are a vital part of this study as they help formulate a comprehensive view of each household and their reaction to PHEVs.

## 3D. PROJECT RESULTS: INTERFACES AND INSTRUMENTATION

In this section we describe the information interfaces that were available to drivers of the PHEV-conversions used in this Project and the observed impacts of and problems with those interfaces. The first part of this section describes each interface (Figures 28 through 34). The second part of this section describes the reactions of PHEV drivers to the information in the form of themes that arose from the household interviews. Finally, the possible impacts of the interfaces on driving behavior are discussed.

The people we discuss in this section were in the first twenty-one households in the Project. [29] These households all had the PHEV-conversions for four weeks; the vehicles had the conversions on-line for the entire time. However, we did not provide these households with access to their vehicle data via a website until our mid-term visit to the household two weeks subsequent to the delivery of the car. Thus, these households first had access only to the instrumentation in the car, then were provided with an explanation of, and access to, the website for the last two weeks they had the PHEV.

### Interface Details

There are two main sources of vehicle information available to study participants. First, the primary vehicle interface is the stock display console screen in the 2007 and 2008 model Priuses used in the Project. The Energy Monitor screen shown in Figure 28 is a schematic representation of energy flows in the vehicle as well as the instantaneous fuel economy (labeled "Current" at the bottom of the screen). The schematic shows the type of energy (Gas, Electric, Electric Regenerative) by both arrow color and direction.

The PHEV conversion process amends the Energy Monitor screen to distinguish between the stock Prius battery and the supplemental conversion battery. The Energy Monitor screen was probably the most viewed by drivers in the study, at least in part because it is programmed to appear automatically at the start of a trip. Although the interface allows

[29] Based on the results reported here, households after these initial twenty-one have been provided with access to their data on the website from the beginning of their PHEV trial.

users to turn off the screens, the PHEV-conversions tend to switch the screen on when the car is started even if a driver had previously turned it off. The in-vehicle interface was fairly successful in generating interest from participants because of its place as the default screen option in the vehicles, as well as its relative simplicity.

**Figure 28: Energy Monitor**


The Consumption screen shown in Figure 29 shows instantaneous fuel economy as a column chart on the far right. To the left appear columns indicating five-minute averages of fuel economy, with the most recent five-minute period on the right. Every five minutes the chart indexes one place to the left and the new five-minute-average column appears at the right-hand side of the graphic. In addition, small green car icons, or "turtles" as some of the households called them, appear within the columns of this chart. Each represents fifty watt-hours of regenerated electricity from the generator, as noted in small text below the screen title at top-left. From right to left at the bottom right of the screen there is a button to reset average fuel economy, the distance driven since the last reset, and the average fuel economy since the last reset.

**Figure 29: Consumption Monitor**

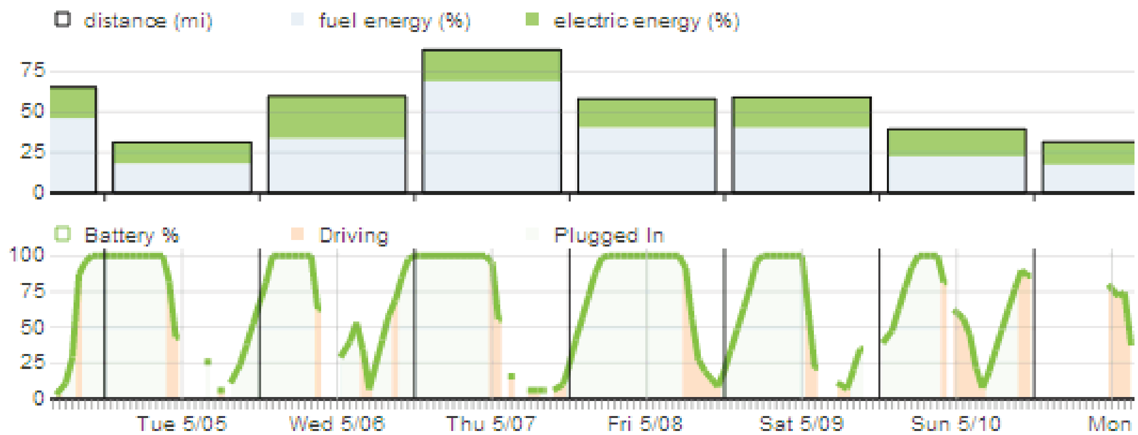

Second, participants had access to the data they generated through driving, recharging, and refueling the vehicle via a website designed by the on-board data system provider. The website displays vehicle summary data as well as the location and status of the vehicle. The web tool was not originally intended for use by individual drivers, but rather by fleet managers, and although changes were made to make the site accessible by the participants in this study, the information is in general highly detailed, located across multiple pages and behind tabs, and presented (with one exception) in numeric and tabular form rather than iconic and graphical forms that might illustrate relationships. Example screenshots of the web-based interface are shown in Figures 30 through 34.

Although the website provides detailed summary information—for example, driving data are summarized by trip, day, week, fortnight, and month—few participants reported being influenced by the website due to the effort required to access and then interpret the information. The website requires participants to view their vehicle’s information on a web-connected device—typically, the household’s home computer—rather than having it presented to them automatically and in the vehicle. Furthermore, once a participant views the website, they must then exert additional effort to make use of the resource due to the variety and complexity of the information presented.

Figure 30 displays the entry page of the website. The graphic at the top is enlarged in Figure 31. This graphic remains across all pages and tabs. The top half of the graphic shows the distance driven each day (bar height) as well as the proportion of electric and gas energy used to accomplish that driving (green represents electric energy). The bottom half of the graph shows the supplemental battery’s SOC (green line).

**Figure 30: Entry Page**

**Figure 31: Entry Page Energy Use Chart**




The Performance Comparison table at bottom-left of the entry page (shown in Figure 32) summarizes the driver-vehicle's (gasoline-only) fuel economy, carbon-dioxide equivalent per mile ($CO_2$e/mi) emissions, and estimated cost per mile—all over three time spans and in comparison with the fleet of PHEV-conversions in the Project (Fleet), and estimates for the national US light-duty vehicle fleet (National Average). In general this table didn't attract the interest of participants, though a few households reported that the cost per mile information was useful to them.

**Figure 32: Entry Page Performance Comparison**

**Performance Comparision**

| | MPG | $c0_2$e (lbs) / mi | $ / mi |
|---|---|---|---|
| | | Today | |
| UC Davis 1763 00 | 62.6 | 0.4 | $0.08 |
| Fleet | 54.9 | 0.4 | $0.08 |
| National Average | 19.8 | 1.2 | $0.20 |
| | | Last 7 Days | |
| UC Davis 1763 00 | 58.1 | 0.4 | $0.08 |
| Fleet | 55.2 | 0.4 | $0.08 |
| National Average | 19.8 | 1.2 | $0.20 |
| | | Last 30 days | |
| UC Davis 1763 00 | 57.6 | 0.4 | $0.08 |
| Fleet | 54.6 | 0.4 | $0.08 |
| National Average | 19.8 | 1.2 | $0.20 |

The Detail Table shown in Figure 33 shows various indicators for the car over three time periods. Very few participants reported using this table.

### Figure 33: Entry Page Detail Table

| | Today | Last 7 Days | Last 30 Days |
|---|---|---|---|
| | | Trip Statistics | |
| Time Driving | 57 m | 10 h 14 m | 1 d 10 h 7 m |
| Trips | 5 | 36 | 109 |
| Distance (mi) | 31.5 | 367.8 | 1308.6 |
| Fuel (gal) | 0.5 | 6.3 | 22.7 |
| Net Dc (kWh) | -3.7 | -30.6 | -104.1 |
| Est. Cost ($) | $2.54 | $29.69 | $105.79 |
| Est. $C0_2$ (lbs) | 11.9 | 149.4 | 536.4 |
| | | Charge Statistics | |
| Time Plugged In | 1 h 4 m | 3 d 13 h 1 m | 15 d 7 h 29 m |
| Charge Sessions | 1 | 10 | 35 |
| Net Ac (kWh) | 0.8 | 28.5 | 105.4 |

Clicking on the Trips tab on the Entry Page causes the table shown in Figure 34 to appear underneath the graphic shown in Figure 31. This table was by far the most interesting part of the website to the largest number of participating drivers. Summary information about each trip, including duration, distance, battery SOC at the beginning and end of the trip, (gasoline-only) fuel economy, and (gasoline plus electricity) estimated cost are presented. The indicators are then reported for the whole day in aggregate. Many users were particularly interested in trip fuel economy.

### Figure 34: Trips Tab

Performance Report | Timeline | **Trips** | Charge Sessions

| Start Time | Duration | Distance (mi) | Battery Start ... | Battery End (%) | MPG | Estimated Cost ($) |
|---|---|---|---|---|---|---|
| **Mon 05-11-2009 (5 Trips)** | | | | | | |
| 3:43 pm PDT | 28 minutes | 21.1 | 25 | 13 | 46.58 | 1.88 |
| 3:16 pm PDT | 5 minutes | 0.4 | 28 | 25 | 84.63 | 0.04 |
| 2:42 pm PDT | 33 minutes | 26.1 | 86 | 28 | 64.57 | 1.99 |
| 1:30 pm PDT | 8 minutes | 2.1 | 77 | 67 | 64.50 | 0.20 |
| 12:18 pm PDT | 8 minutes | 2.0 | 84 | 77 | 44.31 | 0.23 |
| | 1 hour 21 minutes | 51.7 mi | 84% | 13% | 55.00 mpg | $4.33 |

An additional bit of feedback technology was not installed or visible in all vehicles: a small LED that lit when the supplemental conversion battery was active. Some participants found that it was a useful piece of information.

## Interface Themes from Household Interviews

Participant perceptions and use of the interfaces were included in the household interviews to varying degrees depending on participant's interest. These responses were then integrated into the household narrative using the methods described in the Narrative Analysis section. Relevant narrative excerpts from all of the 21 households were then collected into a single document and read specifically for the purpose of interface theme development. Common ideas, perceptions, or statements of interest relevant to the interfaces were identified and followed through the set of narratives. In describing the themes that were found, the greatest weight was placed on themes that occurred in many households, although ideas found in as few as two households are discussed here. In addition, an attempt was made to qualify the extent to which a given theme is common or uncommon across the twenty-one households in the group; interesting statements from a single household were identified as being singular.

### *Limited use of Web Resources*

Accessing the website was a major barrier to some households due to inconsistent Internet access, the complexity of the information presented on the website, or simply because it required additional time and effort on the part of the driver. In addition, household-specific dynamics caused problems in some households. For example, Nancy cares for her elementary-school aged grandson. When asked about the website, she replied that her grandson was too much of a distraction to let her concentrate on the website for long. Rick Lake also commented his children made it difficult to peruse the website at home. Still, children were not the only cause of inattention to website; several households without children also found that logging on to the website was one more task they were unable or unwilling to fit into their daily lives.

### *Abstract Information*

Many participants had trouble placing the information from the interfaces into a useful context. In particular, instantaneous and even time-averaged fuel economy available in the vehicle seemed to raise, rather than answer, questions: "[the interface] doesn't really tell me if I am doing better than yesterday," said Frank. Similarly, Sarah told us, "I did notice that the car was using more battery, but there was nowhere I could see how the car performed differently when the battery was charged or depleted." Many participants did not perceive that they had control over fuel economy, as reflected in Samantha Lake's comment that, "the car is going to do what it is going to do."[30]

Although the vehicle and website interfaces gave users detailed information about this vehicle, it was a challenge for participants to integrate this information into an overall sense of savings, in part because the concept of savings requires a comparison to another vehicle. Possibly for this reason, many participants estimated their savings by using the difference in the total cost of a tank of gasoline, gallons pumped, or refueling frequency between the PHEV and a familiar household vehicle.

### *Confusion*

The in-vehicle screens and website both caused considerable confusion among many study participants. As Nancy told us referring to the in-vehicle interface, "I watch. I try to watch…I thought that I was getting it, but I think I am just confused." A few of the main sources of confusion are outlined below.

#### **Conversion Battery Information**

There was no clear indicator of the energy battery charge state and most users wanted a clearer indicator. Again, Nancy had difficulty, saying, "I am not sure when I'm using the gas or the battery."

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[30] It is not clear in this context whether information and feedback would help these people develop a sense of control, or that a sense they lack control is a more pervasive stance that these people have toward automobiles or even life more generally. This will be explored in subsequent research.

**IFE (Instantaneous Fuel Economy) Fluctuation**

Drivers were generally unable to draw conclusions from the IFE reading on the Fuel Consumption screen. Some were put off by the rapid fluctuations, and many reported they were unable to make a good measure of overall fuel economy from that metric. When asked to estimate his fuel economy, Rick Lake said he observed the IFE indicator to be "99.9 half the time, and 50 otherwise," making a precise estimate impossible for him.

**Reinforcement of Counter-productive Braking Behavior**

The IFE and "turtles" displaying regenerative energy both perversely indicate that decelerations and braking result in the highest fuel economy, whereas any unnecessary deceleration is always a loss of energy from a system perspective—even if some of that energy is recaptured through the electric drive system. Many drivers seemed to be attracted to the 99.9 IFE readouts and the accumulation of turtles, without correctly connecting those to the effect on fuel economy. As Penny said, "[I] tried to get the little green cars going."

### *Novelty*

For some users, the screen information is reported to be interesting only for a short period, and these users don't think they would stay engaged in using the information to drive more efficiently over the long term. Similarly, some participants enjoy looking at the interfaces, but don't consciously connect that information to possible behavior change. Billy Woods told us, "It's like changing stations on the radio," and, "I'm always looking at that screen…out of curiosity…I'm going this speed, is it using gas? Are the tires generating [electricity to] the battery…and more so during the beginning of the study because I was trying to figure out how everything was going." Similarly, the Millers also reported that the V2Green website was interesting, but only the first few times they viewed it.

### *Learning from Interfaces*

**Slowing Down**

Many drivers report slowing down on the freeway due to the low IFE readings during high-speed driving. Some of these readings appear to have been misinterpreted due to the mixed effects of vehicle cruising speed, accelerations, and decelerations. However, the overall behavior changes reported by drivers using the IFE measure were sensible, such as driving more slowly than their normal freeway cruising speeds. Casper told us that when observing the in-vehicle interface he would "slow down a little more," on the highway, reducing his cruising speed from 80 to 70MPG in order to achieve higher fuel economy. Devon seemed even more motivated by the in-vehicle display, stating, "Coming home I stayed in the slow lane, 65 or not even 65, to get the [consumption screen] bars all the way [up], watch[ing] to see the consumption."

**Learning to use Lower Accelerations**

Some drivers reported attempting to keep the IFE high by accelerating slowly, and generally assumed the instantaneous impact correlates with overall reductions in fuel use, "if you are nicer to the [accelerator] it gets a lot better mileage," said Cindy Mackson. Sarah told us, "It gets me to slow down, rather than giving you that gunshot start…It gets you in that gear to pay attention to how fast you are starting up, versus just going in a normal car."

**Learning to Recharge**

The website was instrumental in teaching a number of participants to recharge their PHEV-conversions more often. Some had either incorrectly plugged-in the vehicle or erroneously assumed that the battery was still charged. Said Billy Woods, "that's how I knew that the socket was bad at my girlfriend's house…I went into the website and it said I was disconnected." Devon simply didn't realize how much of a difference the battery made until he was given access to the V2Green website. After receiving the login information Devon reported looking at the website almost every night. Both the battery SOC as well as trip summary mpg information seemed to motivate participants to recharge more frequently.

### *Gender Differences*

Many households displayed a gender difference in regards to responsibility for, and interest in, fuel economy, watching the in-vehicle interface, and going online to check performance summaries. It was common across households with a female and male head of household for men to play these roles; more women reported they drive to simply get places with less concern for the details. It was clear that these were pre-existing roles in many of these households and the in-vehicle and website information were novel sources whose use fit patterns of existing behavior. One notable exception is the Mackson family, wherein Michael and his daughter Cindy vied in friendly competition to get the highest fuel economy (this household is described in more detail below).

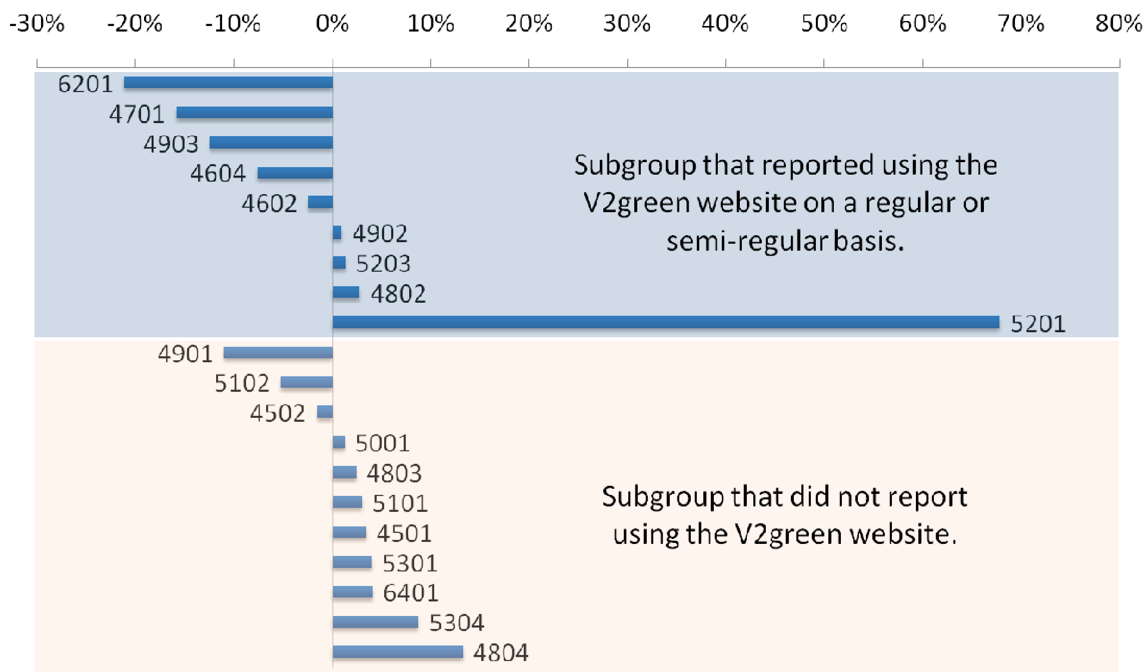
### *Goal Setting*

Some drivers used the interfaces to set, or check the achievement of, goals. Although a minority of participants reported setting fuel economy goals, those who did tended to be in households with the highest overall average fuel economy, indicating that goal setting may be an important part of achieving and maintaining high fuel economy. Fred Sampson used the energy screen to help him drive "to midtown without using the engine at all." Rick Lake used the V2Green website to verify he had achieved his goal of a round-trip to work with a trip average of 100mpg. Rainn Thompson used the battery charge indicator to try to make a commute roundtrip without exhausting the supplemental battery.

## Impact of Additional Summary information on Fuel Economy

We hypothesized that the additional information provided by the website would lead to an increase in overall fuel economy. However, due to the wide variation in factors between the periods when the households had access to different types and levels of information, such as city or highway driving proportion, weather, and road conditions, long trips taken during either the without- or with-access to the website phases, a wide variance was seen between these two phases of the study. The performances of households in these two phases are summarized in Figure 35, which shows the change in average (gasoline-only) fuel economy from the without- to the with-website phase for each of 20 households.[31] Counter to our hypothesis, people who reported using the website were more likely to decrease, not increase, their overall fuel economy than were non-users of the website.

**Figure 35 Change in fuel economy from without-access to with-access to the V2Green website (change is represented as the percentage change from the harmonic means of the first and second phases).**




One reason for these changes appeared to be a regression to the mean, as many of the households in the website users group had higher fuel economy from the beginning of the study, yet lost motivation to continue modifying their driving behavior as intensively—despite the additional information on the website. Household 5201, who had by far the greatest mpg increase, kept the vehicle in CD mode during the entire second half of their placement. Their increase was due to 1) changes in driving behavior—the couple

[31] Data from one household was excluded due to anomalies generated by the in-vehicle data system.

reported that they were interested mainly in the information from the stock Energy Monitor and Consumption screens and had used the information to modify their driving behavior to achieve higher fuel economy, and 2) an unrelated decrease in trip lengths between the without- and the with-website phases.

Although it would be inappropriate to generalize from a sample with such varied outcomes, a few participants related their own experiences clearly enough to discuss at greater length below. These two households show the complex relationship between fuel economy information, initial knowledge, motivation, and short-term behavior change.

### *Michael and Cindy Mackson (5203)*

Michael and Cindy live in an older part of central Sacramento. They both drive Volvo station wagons they purchased used. They engage in numerous pro-environmental behaviors such as vegetarianism and recycling. From the beginning of the study, they were both very interested in the PHEV as a way to reduce their environmental impact.

When asked about the vehicle interfaces, Michael reported constantly scanning the fuel economy information on the Energy Monitor screen. Cindy also reported looking at the Energy Monitor and Consumption screens, using them to help keep her accelerations low. Both were "feathering" the gas pedal (using a light touch to accelerate and ease off) to see if they could get better mileage, a technique Cindy uses with her other car as well. They both reported trying to keep the Energy Monitor screen "in the blue," meaning all-electric operation in CD mode.[32] Cindy mentioned that having the screen helps her moderate accelerations from stop signs and traffic signals, although she and Michael were concerned about irritating other drivers by driving or accelerating slowly. Michael mentioned that people driving quickly from the stop sign have a "crowd mentality" that is easy to fall back into. He finds himself anticipating lights and leaving more room between his car and cars in front of him, both to give him time to look at instruments and to stay a little behind traffic. He estimated that half the time he drives normally, the other

[32] In the PHEV conversions, the supplemental conversion battery is shown as blue and the stock battery as green on the Energy Monitor.

half he is actively trying to save gas, and that he could see a 10% overall difference between the two. (This seems like he is making a rough estimate, not a careful calculation or observation.) Cindy also characterized saving gas as a fun experiment or challenge.

After giving them access to more information about their vehicle on the website, Michael reported looking at it “all the time,” even using it to track Cindy for fun. Michael mostly used the website to look at (gasoline-only) fuel economy (mpg) for the day, although he would also look at individual trips. They were both interested in tracking $CO_2$ for environmental reasons, but Cindy felt that the information on the website was too abstract: she didn’t know if a given amount of $CO_2$ per trip, day, week, or month was good or bad and wanted an easier way to understand their emissions, stating, “…you can’t attach [$CO_2$] to anything to make it make sense.” She mentioned that seeing how many trees it would take to soak up her $CO_2$ output would be motivating. Michael wanted to see a comparison to well-known vehicles, telling us “You know, if you want to get down to nuts and bolts and compare these to like a Honda Civic or a [Toyota] Corolla it would be interesting to see how it does against that.”

Overall, the Macksons increased their aggregate gasoline-only fuel economy from 58 to 59 mpg from the first half to the second half of the study.[33] Although they at first appear to be a model household for improvement due to their high level of motivation, their previous use and knowledge of fuel economy techniques and high initial average fuel economy also means that they had less room for improvement in the second half of the study. The Macksons also had a very consistent commute patterns and did not take many out-of-town trips, making it easier to compare the first and second halves of their trial.

### *Rick and Samantha Lake (6201)*

Rick described a shift in his use of the PHEV over the course of the trial: “it was a novelty at the beginning…I was babying it a lot…now I just drive it normal.” At first he

[33] The fuel economy numbers discussed by households and presented throughout this discussion are aggregate measures covering both CD and CS operation of the vehicle; they do not include any of the electricity used in CD mode. We adhere to this incomplete measure of energy use in this discussion because it is how these households perceived and reported their experience.

liked to monitor his IFE as well as the Energy Monitor diagram of the energy flows in the drive system to see if the battery was being used. He would experiment with different behaviors: "I'd gas it and watch it…put my foot off the throttle and watch it …out of curiosity to see how my actions affected things." He said it was this curiosity that caused him to watch the instrumentation "more than [he] should." Rick was also motivated by his goal of achieving 100 mpg or higher during his commute.

In contrast to Rick's initial focus on the fuel economy instrumentation, his spouse Samantha stated: "I'm the opposite: oblivious…just driving…I pay attention to the road mainly." She reasons that because she is driving fast she has "got to pay attention," and thinks that Rick looks at the screen too much. As Rick talked about trying to achieve an IFE of 99.9 mpg on the highway, Samantha added, "People are honking at you."

Once the household was given access to the website, Rick made regular use of it, but Samantha reported that she did not use it. At the midterm interview, prior to being given website access, Rick was highly uncertain about his overall fuel economy. He noted he had not yet had the chance to make a precise estimate because he hadn't refueled the PHEV, and he normally calculates fuel economy when he fuels his vehicle. After getting website access, he would regularly scan the website at work, mentioning that the kids were too distracting at home. He says he looked at everything on the website, but found the trip and daily average fuel economy most useful—the rest was less useful, "gee-whiz" information. While he claims not to have used the website to change his driving habits, he feels he would use the website at least weekly in the long-term. Due to his continued monitoring of his vehicle performance on the website, Rick was more knowledgeable about his fuel economy by the end of their four-week PHEV placement.

Rick and Samantha achieved a relatively high average 63 mpg over their whole four weeks driving the PHEV; but it dropped from 75 to 61 mpg from the without- to the with-website phase. Rick and Samantha identified two reasons for the sharp drop: longer trips out of town in the PHEV and Rick driving "more normally, more aggressively" in the second two weeks. Although we don't know the relative impact of those two factors, Rick's behavior vis-à-vis the additional information on the website was prevalent among the group with the highest fuel economy in the first half of the study—they lost motivation to maintain new driving practices that allowed them to achieve high fuel economy in the first half of their PHEV trial.

### Information Interface Conclusions

It is impossible at this time to generalize the impact of in-vehicle and internet-based information interfaces on fuel economy based solely on the information gathered as part of this Project. Certainly it is not possible to conclude that energy interfaces have no or deleterious effects on energy use, despite the data in Figure 35. Each participant interacted with the available vehicle information in a different way. Some of the major reasons for the differences seemed to be their prior interest in fuel economy (interest in fuel economy changed and often increased over the course of the study), technological fluency, their role in the household in regards to vehicles or technology, as well as many other factors. Some participants completely ignored the information while others found the information to be a stimulating and engaging learning tool. From the themes identified in this section, we propose a few basic lessons that may help future interface designs facilitate driver improvement in fuel economy:

- The closer the information is to the point of interest and action, i.e. in the car vs. on the home computer, the more likely it is that the information will be used.
- Simplicity in representation and interpretation is critical to driver understanding.
- The interface should support drivers in setting and achieving goals by providing relevant summary information.
- Instantaneous Fuel Economy can provide drivers with erroneous information, especially during braking events.
- Whenever possible, information should be presented in a grounded context so that drivers can quickly understand the relative impact of their behavior.

Although these general lessons are by no means definitive or complete, they represent a simplified interpretive summary of the many participants' responses to the interfaces included in this study and as the basis for the design of ongoing research to elaborate and specify these lessons.

## 3E. Project Results: Social Influence

### Background

The question of how and why consumers buy new products is central to the successful deployment of alternative fuel and electric-drive vehicles. In conceptualizing the role of interpersonal interactions in the adoption of new products, one approach has dominated: diffusion of innovations (DOI), conceptualized as the process of information diffusing from innovators and early adopters to the remaining majority via interpersonal communication.[34] DOI offers some advantages, e.g., a common language across disciplines, but it has important limitations that are exacerbated when DOI is uncritically applied to the adoption of complex technologies and ideas. Electric-drive vehicles exemplify such complexity; they are innovative in a technological and functional sense, but also present a radical shift in symbolic, and in particular, pro-societal benefits.[35] In the DOI approach, a PHEV or another electric-drive vehicle is typically labeled a technological "innovation" (e.g. Rogers, 2003). From a manufacturers' perspective what is new about electric-drive vehicles (EVs, HEVs, and PHEVs) is that electricity is used to power the vehicle. Consumer perceptions are more complex and amorphous than this. Not only must we consider how an innovation is functionally different from its predecessor, but we must also ask how the new functional and symbolic attributes of this technology are important to consumers. Table 6 presents a conceptualization of PHEV attributes according to two dimensions: functional/symbolic and private/societal.

PHEVs and other electric-drive vehicles *are* innovations because of what they can physically do: new battery and drivetrain technology allows users to offset gasoline use with electric-drive capabilities and to plug-in to the electrical grid, often at home. From a functional perspective, consumers may interpret the desirability of electric-drive

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[34] Due to the ubiquity of DOI, before we introduce alternative perspectives we will rely on DOI terminology, including: "innovation" as the object, idea or practice of interest; "adoption" as the purchase or taking on of the innovation; and "diffusion" as the spread of information about the innovation through a social system.

[35] Both the terms "pro-societal" and "pro-social" refer to benefits that can only be collectively realized by multiple parties; we use the former term to avoid confusion with the social processes discussed here, i.e. interpersonal interaction.

technology according to its ability to save them money on transportation, to improve drivetrain reliability, or to simply improve the experience of driving.

**Table 6: Conceptualization of PHEV attributes (hypothetical examples)**

| | Functional | Symbolic |
|---|---|---|
| **Private** | • Save money<br>• Reliable<br>• Fun to drive (experiential) | • Expression of self-identity<br>• Convey personal status to others<br>• Attain group membership |
| **Societal** | • Reduce air pollution<br>• Reduce global warming<br>• Reduce oil use | • Inspire other consumers<br>• Send message to automakers, government, oil companies |

However, a singular focus on function neglects important aspects of human behavior. Hirschman (1981) proposes a second category of innovation: symbolism. In addition to tangible and functional services, Hirschman (1981, p537) defines symbolic innovations as being able to communicate a "different social meaning" than a previous technology, and hypothesizes that such innovations may "possess fundamentally different properties and diffuse according to fundamentally different principles" relative to purely technological innovations. Heffner et al. (2007) investigated the role of symbolism among HEV owners, finding five general symbolized meanings that motivated HEV purchase: preserve the environment, oppose war, manage personal finances, reduce support to oil producers, and embrace new technology.

In addition, electric drive vehicles embody another class of attribute that differentiates them from conventional vehicles: the potential to benefit society. Green (1992, p133) provides a framework to classify goods on a private/public scale, where private good are characterized by "exclusive and personal consumption and individual payment; not associated with the public welfare," whereas societal or public goods are characterized by "nonexclusive consumption and collective payment" such as "clean air" and "saving endangered species." Canzler (1999, p25) asserts that to date, motor vehicles have been primarily perceived as private goods, dating back to the original "race-travel-limousine" of early car buyers motivated by goals of luxury and prestigious racing. However, electric-drive vehicles may present a divergence from private goods due to their potential to produce pro-societal benefits, such as contributing to reductions in air pollution, greenhouse gas emissions, and oil dependence—or by encouraging others to think of and act on such issues. Thus, electric-drive vehicles can be associated with public welfare, leading Brown (2001) to classify the EV as a mixed good, that is, having aspects of both a private and a public good. Further, such interpretations and reinterpretations may develop over time; for instance, Gjoen and Hard (2002, p264) describe how one consumer's experience with an EV led her to "become an agent contributing to the deconstruction of what a car is meant to be and to the construction of a new sense of mobility." In summary, the so-called "diffusion" of electric-drive vehicles will entail an ongoing social discourse about the functional, symbolic, and pro-societal benefits.

To investigate the role of interpersonal influence in the formation of functional, symbolic and pro-societal interpretations of electric-drive vehicles, three general research questions are posed:

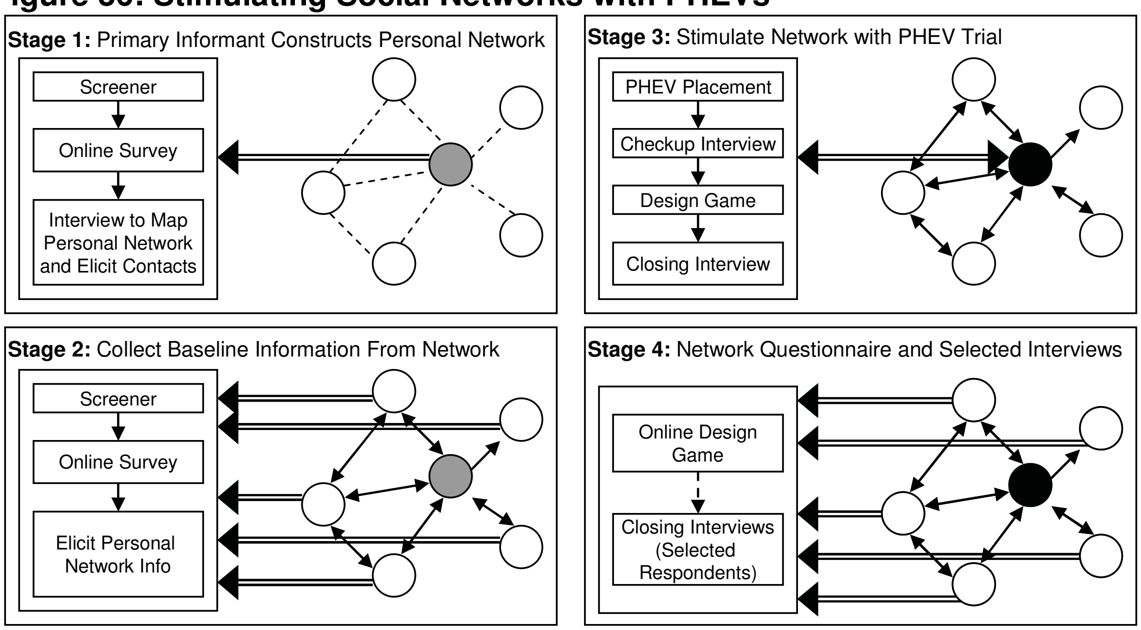
1. Do interpersonal interactions play a significant role in the assessment and adoption of electric drive vehicles?
2. If so, how can we characterize the interpersonal interactions that influence consumer perceptions of functional, symbolic, and pro-societal attributes?
3. Under what social conditions might households adopt electric drive vehicles and the pro-societal car? (And how might policy create those social conditions?)

## Methods: Observing Interpersonal Influence

To explore the potential roles of interpersonal interactions in the adoption of pro-societal cars, an extended methodology is being applied to the social networks of a subsample of 10 to 15 households participating in the Project; analysis of the networks of four households have been completed as of the writing of this report. Researchers work with each of these households to map, measure, and stimulate episodes of social interaction within the households' social networks, as illustrated in Figure 36.

Social network analysis has been frequently applied to diffusion studies; instead of emphasizing the individual as the unit of analysis it explores the role of linkages between individuals (Rogers 2003). Social network analysis investigates how the structure of these linkages (or ties or relationships) influences the diffusion process (Granovetter, 1973; Degenne and Forse, 1994). While it may be ideal to study social processes and structure at the "total" network level—by accounting for every link among all individuals in a social system—in most situations it is only feasible to collect data from different personal networks (Degenne and Forse, 1994; Carrasco, Hogan et al., 2008). A personal, or egocentric, network is represented by: i) the primary individual (the grey and black circle in Figure 36), ii) the other individuals they are socially connected to (the white circles), and iii) characterizations of the relationships, or ties, between all individuals (the connecting arrows) (Carrasco, Hogan et al., 2008).

**Figure 36: Stimulating Social Networks with PHEVs**




Eliciting personal network data can be very challenging, including efforts to scope network size, overcome limitations in respondent recall, and mitigate respondent burden (Marsden, 1990; Carrasco, Hogan et al., 2008). In this project, we use a technique outlined by Hogan et al. (2007), which assists participants in the creation of a sociogram—a graphical depiction of their personal network. Participants are asked to generate a list of “very close” and “somewhat close” contacts—terms kept intentionally vague—on a series of post-it notes, then arrange the names on a poster with four concentric circles representing social closeness.

This project follows a “multi-method” approach (McCracken, 1988, p28) including structured interviews and internet-based questionnaires, as well as social episode diaries. In social network studies, asking respondents to keep diaries of social episodes can be invaluable to enhance recall of interactions with other contacts during a particular period (Degenne and Forse, 1994, p19). The four stages illustrated in Figure 36 are implemented as follows.

*Stage 1: Contact primary household and elicit personal network.*

Households were selected from the same sampling frame used for all Project participants. Along with being screened for eligibility and completing the online questionnaire, the Project participants in this personal network study (Primary Households) engage in an extended household interview, including:

1. *Household vehicle purchase history:* draw out narratives of the vehicles currently and previously owned by the household, including the perceived benefits and drawbacks of each.
2. *Future vehicle purchase intention:* elicit potential future plans to purchase a new vehicle, including the primary objectives of purchase and any specific models being considered.
3. *Personal network mapping:* identify a network of people who are “very close” and “somewhat close” to the household’s, i.e., the “ego” in an egocentric network. Primary households are then instructed to personally invite members of their network to the study.
4. *Social-episode diary:* provide a diary for the primary household to make brief notes regarding any social episodes in which they discuss PHEVs,

electric drive, or vehicle purchases in general over the multi-week period of the PHEV trial in Stage 3.

*Stage 2: Collect baseline information from the personal network.*

The primary household recruits members of their primary personal network to the study (secondary participants). Those network members willing to participate complete the same screener and internet-based questionnaire as the primary household. Secondary participants confirm the existence and nature of the relationships (connecting lines in the sociogram) as elicited from the primary household

*Stage 3: Stimulate personal network with PHEV trial.*

After the personal network has been mapped, the primary household begins their PHEV trial, completing several tasks, including:

1. The *social episode diary.*
2. The online PHEV design questionnaire.
3. Midterm interviews every two weeks.
4. A closing interview, consisting of questions regarding the following:
    a. The household's overall experience with the PHEV (narrative).
    b. Recharging, driving, and fueling behavior.
    c. Functional, symbolic, and pro-societal interpretations of the vehicle, and the dynamics of these interpretations over the course of the trial.
    d. Contacts with members of the personal network (and others) including the content and frequency of such discussions, as well as the perceived influence over the primary household's assessment of PHEV technology.
    e. Assessment of interests in future vehicle purchases (assisted by previously elicited responses in the PHEV design questionnaire).

*Stage 4: Network questionnaire and selected interviews.*

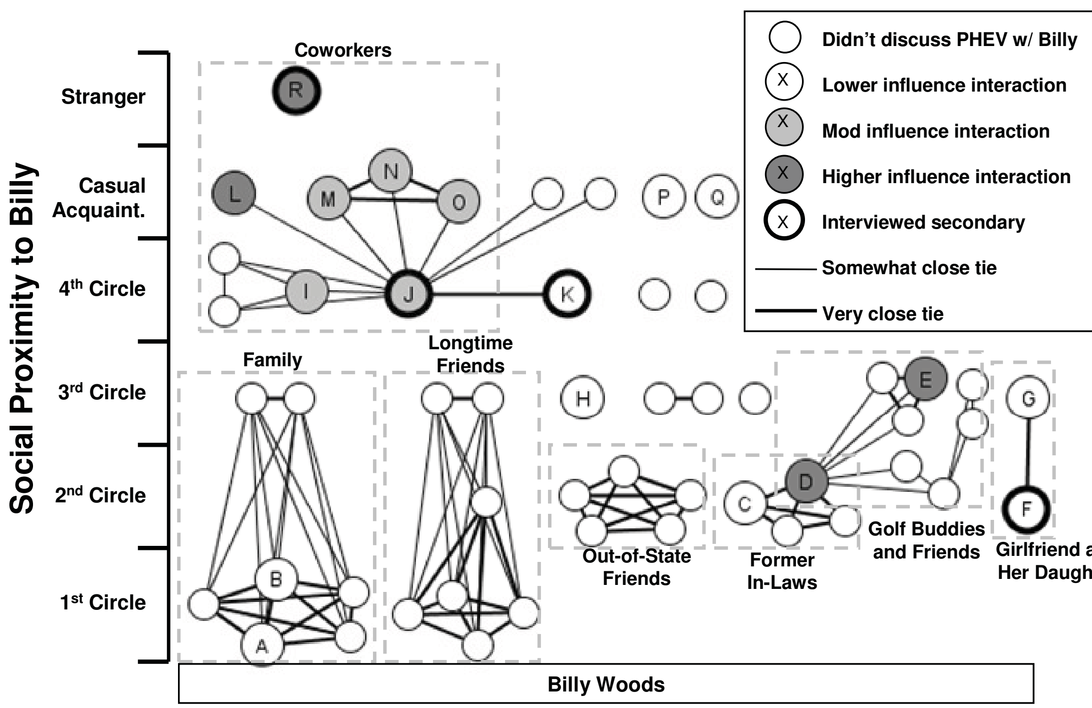
At the close of the primary household's PHEV trial, secondary participants are again contacted to share their observations of the primary household's PHEV trial. All secondary participants complete the online PHEV design questionnaire, which also elicits information about any social episodes that occurred with the primary household during the trial. A subset of secondary participants take part in a telephone interview, including details of any experience with the PHEV, interpretations of the vehicle over the trial, specific social interactions with the primary household or others during the trial, and interests in future vehicle purchases.

### Some Preliminary Results

To illustrate the methodology used to elicit network data, Figure 37 portrays the sociogram of Billy Woods, as well as the patterns of interaction observed within his network during his PHEV trial. Billy identified 44 people as "very close" or "somewhat close" as categorized on the y-axis—circles closer to Billy, i.e., closer to the bottom of the figure, represent a closer social relationship to Billy. Billy mentioned or discussed the PHEV with 11 of these contacts during his trial, identified by letters A through K. Billy also mentioned or discussed the PHEV with eight casual acquaintances (letters I through Q) who he did not place close to him in his network map, and one stranger that he met during his PHEV trial (letter R). Figure 37 also groups Billy's social contacts according to his descriptions of how close they are to one another (with line thickness proportional to the strength of ties), with subgroups labeled where possible, such as "family," "coworkers" and "golf buddies and friends." People recruited as secondary participants are identified with a thicker circle (F, J, K and R). Finally, the darker shading in circles indicates that Billy considered interactions with that individual to have had relatively higher influence on his assessment of PHEV technology. Thus, his interactions with the stranger "R," casual acquaintance "L," and friends "D" and "E" were more influential to Billy than his interactions with family members "A" or "B," his girlfriend "F," or others. Figure 37 can be viewed as one map of Billy's social network as well as an overview of how his PHEV trial stimulated this network.

Table 7 provides summary details of the four networks investigated so far, including the primary households—Billy Woods, the Noels, the McAdams and the Rhodes—and the secondary participants they recruited. Table 7 also shows the primary households' perspective of the social proximity of the secondary participants and the influence of interactions with them, as well as the perspective of the secondary respondents. These perspectives are not always symmetrical; for example, although "Chris" (K) considers Billy to be a very close friend who had a strong impact on his perception of PHEVs, Billy did not recall having spoken with Chris during his trial. Asymmetry occurs in the other direction also; Billy rated his interaction with a stranger who was an EV driver, Harry (R), to be highly influential, while Harry in turn did not consider the interaction to be influential for himself.

**Figure 37: Billy Woods' Sociogram**




While Figure 37 and Table 7 provide interesting overviews of some general patterns of interpersonal interaction, they exclude important finer details. The data collected in this Project is quite extensive, with over 100 person-to-person interactions described by the four households—most are brief, but some are very important to either the primary or secondary participants' evaluation of the PHEV-conversion and PHEVs more generally.

One starting point for differentiation among these interactions is the networks themselves, which include individuals engaged in different lifestyle practices, resulting in different levels of experience and interest with electric-drive vehicles, “green” technology, and pro-societal behavior. Giddens (1991) describes a lifestyle as a package of practices associated with an individual’s particular trajectory in which behavior is guided by efforts to establish a sense of order, direction, and development for the individual’s self-concept. These practices include fashion, eating, and any other “means of symbolic display…giving form to narratives of self-identity” (Giddens 1991 p. 62). As discussed earlier, the symbolic aspects of automobiles place the purchase and use of motor vehicles within this process of creating and enacting a lifestyle. This differentiation of lifestyles is illustrated with a brief summary of each of the networks in Table 7.

### *The Noels as electric-drive novices*

Rupert and Amy Noel live with their three young children in Sacramento. They are highly family-oriented—demonstrated not only by their devotion to their children, but also by frequent interactions with their large extended family. The Noels had no experience with electric-drive vehicles prior to their PHEV trial and they have no electric-drive experts within their social network. Throughout their trial, Rupert’s interactions mainly consisted of “showing off” the vehicle to friends and coworkers, but he reported these interactions had little influence on him. In contrast, Amy more actively attempted to advance her functional understanding and assessment of the PHEV by eliciting the perceptions of friends, family, coworkers, and even her dentist. Above all else, the Noels’ agreed that the most influential interactions they had were in sharing the PHEV experience with their own children, such as adding the words “hybrid” and “plug-in” to their 4-year-old’s vocabulary. In all their conversations with members of their personal network, the Noels’ talked only about basic private-functional aspects of the PHEVs, e.g. recharging and fuel economy. These concepts were not well understood by the Noels or clearly communicated to others—all interviewed secondary participants (John, Ray and Anita) were unsure of the differences between an HEV and PHEV, and none had a strong sense of what benefits the PHEV offered, beyond generally improved fuel economy.

**Table 7: Summary of primary households and secondary participants in the personal network study to date**

| Primary household (network size and interactions) | | Secondary participant | Age | Household income | Lifestyle and values | Relationship to primary | For primary: Social proximity[1] | For primary: Infl. | For secondary: Social proximity | For secondary: Infl. |
|---|---|---|---|---|---|---|---|---|---|---|
| **Billy Woods** | | | 40s | $100-124k | Recreation | | | | | |
| Total close: | 44 | Pat (F)[2] | 40s | $70-80k | Family | Girlfriend | 2$^{nd}$ circle | Lo | Very close | Hi |
| Close contacted: | 11 | June (J) | 40s | $80-90k | Recreation | Friend/coworker | 4$^{th}$ circle | Hi | Very close | Hi |
| Total contacted: | 18 | Chris (K) | 40s | $80-90k | Recreation | Friend | 4$^{th}$ circle | n/a | Very close | Hi |
| | | Harry (R) | 40s | $125-149k | Enviro./tech. | Coworker | Stranger | Hi | Stranger | Lo |
| **Rupert and Amy Noel** | | | 40s | $80-89k | Family | | | | | |
| Total close: | 101 | John | 60s | $125-149k | Family/tech. | Coworker | 4$^{th}$ circle | Mod | Casual | Mod |
| Close contacted: | 29 | Ray | 20s | $70-79k | Family | Friend | 3$^{rd}$ circle | Hi | Very close | Mod |
| Total contacted: | 31 | Anita | 30s | $125-149k | Family | Friend | 1$^{st}$ circle | Mod | Very close | Hi |
| **Craig and Siobhan McAdam** | | | 40s | >$150k | Enviro./tech | | | | | |
| Total close: | 50 | Hannah | 30s | $20-29k | Enviro. | Friend | 1$^{st}$ circle | Mod | Very close | Hi |
| Close contacted: | 14 | Steve | 40s | >$150k | Enviro./tech | Friend | 1$^{st}$ circle | Mod | Very close | Mod |
| Total contacted: | 31 | Donna | 20s | $20-29k | Unknown | Coworker | Casual | Lo | Some. close | Mod |
| **Larry and Cheryl Rhodes** | | | 30-40s | >$150k | Family/enviro. | | | | | |
| Total close: | 49 | Nicole | 50s | $100-124k | Family/enviro. | Neighbor | 3$^{rd}$ circle | Lo | Some. close | Lo |
| Close contacted: | 23 | Betty | 30s | $100-124k | Family/enviro. | Friend/teacher | 3$^{rd}$ circle | Hi | Some. close | Lo |
| Total contacted: | 26 | | | | | | | | | |

1. Smaller numbered circles represent closer social ties.

2. Letters correspond to those in Figure 37.

*Billy Woods as an electric drive novice with an EV enthusiast in his network*

Billy Woods lives alone in a detached home. He engages in many social and recreational activities—frequent golfing, skiing, and visiting bars and clubs. As a self-described "social guy," he discussed the PHEV extensively within his large social network, including his technology-oriented coworkers at a computer company. He explored the PHEV's "bells and whistles" with June (J), a close work friend and mentioned the car to other coworkers, golf buddies, and family. Many of his conversations consisted of "small talk" and "showing off" the PHEV's private-functional attributes, but he considered such interactions to be of low influence on him. At one point he brought up the idea of pro-societal attributes among coworkers by asking them which would provide the greater motivation to purchase a hybrid: the ability to save money or the environment. Ultimately, he agreed with his coworkers that saving money was more motivational. However, Billy demonstrated an openness to alternate interpretations. Interestingly, some of Billy's friends thought he was driving the PHEV in an effort to be green. Billy's most influential interaction was a with an EV driver at work, Harry (R), who was concerned the PHEV might overload the circuit they were sharing to recharge their vehicles at the workplace parking lot. This interaction seemed to be Billy's only contact with an electric-drive expert—a man who built his own EV and charged it at home via a solar array—but the conversation didn't progress beyond a brief functional explanation by Billy of the PHEV demonstration. From the perspectives of others in Billy's network, including Pat (F), June (J), and Chris (K), Billy's trial was more of a functional demonstration that an electric-drive vehicle could be easy to recharge and provide performance comparable to a conventional vehicle.

*The McAdams as pro-societal technology enthusiasts*

Craig and Siobhan McAdam have strong environmental and pro-societal values which are demonstrated throughout their home, including solar panels, a high efficiency electric heater and air conditioner, efficient light bulbs, and a Toyota Prius in the driveway. Craig sees the PHEV as an extension to his Prius, i.e., a way to further reduce their environmental impacts and dependence on foreign oil, as well as sending a message to automakers to support the technology. The McAdams' social network includes people with similar pro-societal values and interests in advanced technology—Craig has already influenced at least three of them in their purchases of HEVs. Surprisingly, the PHEV trial did not stimulate many "real conversations" in the McAdams' network; Craig and Siobhan explain that because environmental issues and actions are already such a big part of their lives, the trial of a PHEV-conversion did not have an enormous impact. Two secondary respondents in the McAdams social network described how they already have ongoing dialogues with Craig about different environmental technologies and were already aware of PHEV conversion kits—the McAdams' PHEV trial was just another experience in lifestyles they regarded to be pro-societal. Craig also mentioned his PHEV trial to more socially distant coworkers, but he found them to be generally disinterested—a fact that the McAdams' found to be disappointing.

### *The Rhodes as pro-societal technology enthusiasts with family values*

Larry and Cheryl Rhodes blend environmental sensibilities with family values. Larry considers that he is a "tree hugger" and tells everyone how much he loves the fuel economy of his Honda Civic hybrid. He and Cheryl dream of living in an off-grid home powered by solar and wind energy. But they see such environmental action not just as a way to reduce their environmental footprint, but also as a way to shape and support pro-societal actions in the next generation, starting with their preschool aged son, Tristan, and his schoolmates. The Rhodes' liked that Tristan was excited about their PHEV trial—he would enthusiastically demonstrate the car's features to friends and teachers. Around the same time, Larry taught a class at the preschool on batteries, bringing even more attention to the electric-drive vehicles. With the excitement of these children, Cheryl felt she might be witness to "a societal shift in perspective…that they're saving things the earth needs."

## Preliminary Discussion and Conclusions

The first question in this research asks whether interpersonal influence plays a significant role in the assessment and adoption of electric-drive vehicles. Table 7 suggests that the observed social interactions are influential for primary households and secondary participants. The second research question delves deeper to explore and characterize specific processes of social interaction and influence. We describe these interactions from five perspectives: contagion, conformity, dissemination, translation, and reflexivity. Table 8 illustrates these perspectives as demonstrated by the primary households.

First, contagion describes social interactions as the point-to-point communication of information. Contagion includes diffusion of innovations (DOI). In DOI, adoption is driven by communication, including word-of-mouth and mass media, but communication that is primarily in one direction, flowing from earlier adopters, e.g., "innovators," to later adopters, e.g., "early adopters." This approach superficially describes some patterns of interaction observed in this study, such as the "showing off" of the PHEV and engaging in "small talk" about its basic features. For example, Billy Woods frequently informed people he was driving a PHEV and briefly explained that it was different from regular HEV. Such information could be described as *diffusing* through his social network, where secondary participants became aware of Billy's trial and were able to grasp what was new about the PHEV. However, the notion of contagion neglects many of the subtle but important nuances of interpersonal influence, such as why particular types information are selected to share, why particular types of information are remembered by the listener, and how such information is interpreted in various contexts.

Further, the notion that information diffuses in one direction, from innovators toward the majority, is limiting. While it may be tempting to label the McAdams or Rhodes as electric-drive "innovators," even they learn from, and exchange information with, others (and others who are not "innovators") on an ongoing basis. Similarly, Billy Woods, the Noels, and their network members did not draw their perceptions from one particular "innovator" or set of experiences. Rather, they formed a general understanding of the PHEV through an ongoing discourse of social interactions that they integrated with their existing background knowledge. In addition, although notions of contagion and diffusion may apply to certain "simpler" interactions, such interactions are typically identified by participants as less influential.

Second, conformity focuses on individual's perception of social norms and the actions of others. The approach typically includes the idea of thresholds, i.e., the proportion of the relevant social system that must engage in the behavior before the observed individual will join (Strange and Soule, 1988). Thresholds may vary according to the strength of ties with other individuals, physical proximity, or other factors (Granovetter, 1978; Valente, 2005), which can be linked to social norm theory (Cialdini, 2003).

**Table 8: Characterizing interpersonal interaction in each social network**

| | Network | | | |
|---|---|---|---|---|
| Approach: | Billy Woods | The Noels | The McAdams | The Rhodes |
| Diffusion | Explaining how the PHEV differs from an HEV | Telling others the PHEV saves trips to the gas station | Explaining they are taking part in a PHEV trial. | Detailing the fuel economy of the PHEV relative to their HEV. |
| Conformity | Perceiving that PHEV is not attractive enough for bar/club scene. | Perceiving the PHEV as "turning heads," as a "status symbol." | Seeing the PHEV as fairly normal in their social circle. | Feeling an added sense of "fitting in" with a pro-environmental reference group. |
| Dissemination | Not observed. | Not observed. | Advocating electric-drive technology, and buying their Prius to promote production of green technology. | "Spreading the word" about PHEV technology to improve the technology—also taught a preschool class on batteries. |
| Translation | Interpretive flexibility: asking others if cost savings or environment is more important motive for electric-drive. | Interpretive flexibility: learning about different functional benefits of the PHEV, such as "less trips to the gas station." | Interpretation: seeing the PHEV is an extension of their Prius—pro-environment and supporting green technology. | Interpretation: seeing the PHEV is a good way to reduce oil use, but renewable energy source is needed to make it truly "green." |
| Reflexivity | Using the PHEV to learn more about a pro-societal lifestyle trajectory, but remaining more engaged and interested in his recreational lifestyle. | Becoming vaguely aware of a pro-societal lifestyle trajectory, but remaining far more concerned with family-oriented living, such as emphasizing vehicle space and cost savings. | Remaining fully engaged in a pro-societal lifestyle, where PHEV is just another stage of the trajectory—supporting further production, but not as big a step as purchasing their conventional Prius. | Remaining fully engaged in a pro-societal lifestyle, using the PHEV to further "spread the word" about green technology—seeing the PHEV is a "stop-gap" to clean technology, and encouraging the next generation (e.g. their son). |

Examples in this study illustrate how parting from certain norms can be undesirable or desirable. Billy Woods describes that although he generally liked the PHEV, he thought it was ugly, and as a "single guy" he can't drive around "in a car that looks like an egg." Billy was not describing a particular interaction, but a general perception of the expectations and norms of one of his reference groups—the clubbing crowd—that a car should be attractive. On the other hand, the Noels' excitedly describe how driving the PHEV would "turn heads" because it was a "status symbol" potentially in a sense of wealth as well as environmental motives. For the McAdams, driving the PHEV supported existing norms of their social network; Siobhan explains: "the idea of…plugging in a car is not that…'Jetsons' to our group of friends."[36] While the Rhodes expressed similar sentiments, Cheryl Rhodes added that relative to her SUV, driving the Prius (whether or not it was a plug-in conversion) made her feel "more self-righteous" when she shopped at a pro-environmental grocery store in her area—"like I really fit in."

Third, dissemination is "diffusion that is directed and managed" by an organized group (Rogers, 2003, p6), including processes of collective action in the provision of pro-societal goods. To date, this Project has not included any participants that are members of any formal groups of PHEV dissemination, e.g. Plug-in America. Further, while Billy Woods and Noels did describe "showing off" the PHEV in many instances, such interactions were not dissemination—they were more of a reaction to the novelty of the PHEV trial. However, the McAdams did describe themselves as advocates for electric-drive technology and Craig explained one motive for buying his Prius was to "promote the production of further hybrid cars." Similarly, Larry Rhodes described how during his PHEV trial he would talk to others in order to "get the word out…(to) proselytize the eco-friendliness" of the PHEV.

Fourth, translation defines innovations as dynamic, socially-constructed artifacts (Bruun and Hukkinen, 2003).[37] At first, a newly introduced artifact has a high degree of

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[36] The Jetsons© was a cartoon television show in the US first produced in the 1960s. It was set in a future of flying cars, robot housekeepers, levitating chairs, and other technological wonders.

[37] As used here, translation is a combination of two related sociological approaches to innovation: social construction of technology (SCOT) and actor-network theory (ANT).

interpretive flexibility, where different social groups' differing interpretations of its meaning and content influence further technological development (Pinch and Bijker, 1984). Eventually the stages of interpretive flexibility reach a state of closure and stabilization as the perspectives of various social groups converge (Bruun and Hukkinen, 2003) or align (Callon, 1991; Hannemyr, 2003). Participants with less electric-drive experience are in a state of interpretive flexibility: the Noels were coming to terms with the basic functions of the PHEV, and became excited when someone made the simple observation that it allowed them to "make less trips to the gas station" and while Billy Woods was quicker to understand the PHEV's basic functions, he became interested in talking to others about the broader interpretations of electric drive—private, e.g., saving money, versus pro-societal, e.g., environmental motives. In contrast, the McAdams and Rhodes already had established understandings of electric-drive and alternative fuel technology, and saw the PHEV as further articulation of their understandings.

Fifth, reflexivity as we use the term here is not limited to innovation, communication, or social influence. Giddens' (1991) structuration approach describes personal self-development in an uncertain, social world, i.e., modernity, which lacks the set roles and expected behaviors enforced by tradition. Individuals must actively seek out and define their self-identity through "a reflexive project" (Giddens, 1991, p32). Reflexivity is the dynamic, continuous process of defining and expressing oneself: it moves us beyond assessment of the specific features of PHEV technology to focus on how individuals incorporate technology into their lifestyle trajectories. Reflexivity can be used to better understand the underlying motives of each participant, as well as integrating patterns described by the other perspectives. For instance, Billy Woods takes part in recreation and social activities he links to his interest in having an attractive vehicle. However, several individuals in his network are interested in other trajectories, such as green living and technological development. To an extent, Billy used his PHEV trial as an opportunity to try an alternative lifestyle trajectory and learn more about how it fit within his current trajectory as represented by his social network—demonstrated by his query to coworkers about their private versus pro-societal motives. In contrast, the Noels have far fewer connections with environmental and pro-societal groups, and far more integration into a family-oriented community, so they focus on the family aspects of the PHEV, such as enjoying the excitement of their children and judging they would need a PHEV larger than the Prius to accommodate their family. The McAdams are already fully engaged in a pro-societal lifestyle and see the PHEV as another step in their trajectory. The Rhodes are of a similar mind to the McAdams, but also link the PHEV to their family values, going out of their way to induce interest and support for green technology among a younger generation. In summary, from the perspective of reflexivity, when participants talk about the PHEV, they not only share information about the technology, they are also share information about different identities and ways of living.

# 4. Discussion and Conclusions

## Putting Discussion and Conclusions in Context

The discussion presented here summarizes and interprets the preceding analyses. Conclusions, such as may be drawn, should be regarded as provisional and subject to elaboration or even contradiction as the Project continues and we learn from more households how they drive, recharge, and value PHEVs, and in particular, the specific incarnation of a PHEV they are driving. In general, we believe the behaviors we observe are more likely to be generalized than are the specific numerical results.

To remind the reader of some of the important context in which the Project is being conducted, it is one in a series of related research tasks at the UCD PHEV Research Center focusing on household markets for PHEVs. In particular, one prior research activity was a large-sample internet-based survey of new car buyers. That survey was based on a nationally representative sample, with over-samples of California and northern California. The results from those over-samples and the participants in the present Project are compared where possible. Regarding the PHEVs in this study, they are conversions of Toyota Priuses using A123Systems' conversion. The conversion involves the installation of a 5KWh (nominal) lithium-ion battery in the spare tire well and the necessary electrical and communications connections to incorporate the battery into the vehicle's drive system and to recharge the battery. The battery charges from a standard US three-prong, grounded, 110-volt outlet. A "fully" discharged battery takes approximately five hours to recharge. The PHEV-conversions are still subject to the underlying architecture and control strategy of the stock vehicle. Notably, during CD mode, the vehicles more or less continuously "blend" electricity and gasoline to power the car, though using far more electricity in CD than CS operation. It is easier, though by no means easy, to keep the ICE off during CD mode in the PHEV-conversions than in a stock Prius.

The participating households were selected, in part, because they could recharge the PHEV-conversions at their homes. This makes them a sub-set of all car-owning households and of all new-car buying households. While this makes them suitable to model the behaviors of other people who can recharge a PHEV at home, clearly their behaviors should not be simply extrapolated to the entire car market. (We judged it more important to learn what we can from people capable of regularly recharging a PHEV than to attempt to represent the entire population of car-owning households by including households who cannot regularly recharge at home.)

Almost all socio-economic and demographic differences between the Project households (measured as a group) and the general population and the population of new-car buying households flow from this initial recharging capability condition. The Project participants are skewed toward people with higher incomes and education—even compared to our California and northern California over-samples. Respondents in all three of our CA-based samples are much more likely to be between the ages of 35 and 54 than the general population. Our Project and survey respondents are more like to live in detached homes than are the general population. The present gender balance of the Project participants is similar to that of the general US, California, and California over-sample of new car buying households.

Other than these general correlations between income, education, home ownership and new vehicle buying, the Project households cannot be consider to be so pro-PHEV, pro-electric-drive technology, or pro-environmental compared to other samples of new car buyers as to skew their reports in favor of PHEVs. The Project sample contains a slightly higher percentage of people who state that air quality, climate change and oil dependence are "serious problem[s], and immediate action is necessary" than in the California and northern California over-samples. Still the differences are small and we judge them to be unlikely to make a substantive difference to any conclusions we may draw between the samples on PHEV designs created by participants in their design games.

There is little to distinguish the knowledge of electric drive vehicles of the Project participants from the survey respondents—except on the specific issue of plug-in hybrids. Across all samples, very high percentages of respondents know that a plug-in hybrid can be both fueled and plugged-in; the highest percentage is among our Project participants. There are a few opportunities for "information leaks" about PHEVs to respondents in the present Project: the recruiting phone call and the information unavoidably provided to households when the PHEV is first delivered. (The questions about electric-drive knowledge are part of a longer, more substantive questionnaire that cannot be administered until after the household is fully enrolled in the Project, which occurs when the vehicle is delivered.)

Most Project participants faced lower gasoline prices during their PHEV trial month than did the prior survey respondents. However, the first Project participants were paying well in excess of $4.00 per gallon for gasoline in August 2008. Whether they faced higher gasoline prices during their PHEV trial period or whether they simply recall such higher prices from last summer, we expect that all other Project participants may be more sensitive to the uncertainty of gasoline prices than the national and California survey respondents. This may make Project participants less like our prior survey respondents, but more like their peers, i.e., all present day car-buying households who have lived through this same history of gasoline prices.

### Assessing PHEV Purchase Intentions and Design Priorities

We assess the interest of respondents in buying PHEVs—and which PHEVs—through a series of design games. The games rely on two different contexts and have two different goals. One explores what is interesting and valuable to respondents about PHEVs *per se*. The other more directly addresses the question of interest in buying a PHEV. We limit our conclusions about PHEV designs to the subset of respondents who can recharge a vehicle at home (which includes all Project participants) and demonstrate a PHEV purchase intention in the highest price version of the PHEV design games.

#### *It (still) isn't about all-electric driving; it's about fuel economy*

In summary, in the Project to date we find more evidence to support our prior conclusion from the national survey that consumers create PHEV designs that emphasize (gasoline-only) fuel economy and, conversely find no evidence to contradict our prior finding of low demand at present for PHEVs offering all-electric operation in CD mode. Most respondents in both studies and across both design games designed PHEVs based on blended operation in CD mode. In effect, they designed PHEVs that emphasized improvements in (gasoline-only) fuel economy over designs that emphasized all-electric driving. While it is possible that the Project participants PHEV designs were "anchored" by their driving a blended-mode PHEV that does not easily provide all-electric operation throughout its CD range, it is still the case that experience with a PHEV has not led our Project participants to be more likely to emphasize all-electric CD operation than our prior survey respondents who had no PHEV experience. This conclusion is further supported by the relatively greater emphasis that respondents across all samples placed on improving the fuel economy of the vehicle in CS operation than in either dimensions of CD performance: all-electric (vs. blended) operation and longer CD driving range. Further, only a tiny subset combined both all-electric driving and 40 miles CD range (the longest CD range offered in the games)

### *Project results do differ from survey results in some important ways*

Project participants who had driven a (blended-operation) PHEV for a month were more likely than the previous survey respondents to 1) design a PHEV they are interested to buy rather than opt to buy a conventional vehicle, 2) design a PHEV that had better PHEV performance than the base PHEV design offered to them, and 3) to chose an HEV as the base vehicle they considered for redesign as a PHEV. Still, these differences are at the margin, and the overall conclusions one draws from the Project participants are similar to those we drew from the survey. The Project does appear to have a slightly greater persuasive effect of convincing participants that a PHEV is a worthwhile and desirable vehicle for their household, as well as an effect of convincing them that an HEV is a worthwhile vehicle for their household. Given that they have designed a PHEV they want, few Project participants were interested in faster recharging times than the base offering of eight hours—recall, all these households were selected to participate in the Project in part because they can recharge a vehicle at home. Project participants are more likely than survey respondents to improve CD mode—both operating mode and range. Yet as noted above, the slightly higher prevalence of all-electric designs compared to previous survey samples (~five percent in the Project compared to ~one percent in the survey) does not overrule the larger conclusion that only a small minority of new car buyers presently value all-electric PHEV designs. There is little difference between samples in the probability to improve CS fuel economy performance—in large part because this is the most common attribute to be improved by respondents in all samples.

These findings contrast with the earlier findings of Kurani et al.'s (2007) interviews with "pioneer" PHEV conversion drivers who exhibited strong interest in maximizing CD range in all-electric mode—effectively approaching the capabilities of pure electric vehicles. This difference suggests that while all-electric CD operation may presently be attractive to a small subset of consumers including those who are already knowledgeable and experienced with electric vehicles, at this point in time most households who buy new vehicles are more interested in high fuel economy, even after completing a multi-week trial with one (blended) PHEV incarnation.

### *If it's not about all-electric driving now, can it be in the future?*

The wide variety of PHEV designs created by survey respondent and Project participants supports the conclusion that the car-buying pubic has widely varying, and perhaps as yet unformed, PHEV performance expectations. Their desired PHEV designs and capabilities may be subject to change. Project participants and survey respondents had little pre-existing understanding of PHEVs and the responses we elicited may be sensitive to the PHEV information we provided. As information about PHEV technology, costs, benefits, and meanings are transmitted throughout the population, interest in PHEV attributes and performances could shift. For example, all-electric CD operation could become more meaningful to car buyers as they gain experience with all-electric operation and as they participate in the process of identifying just what all-electric operation means to people. In the meantime, this analysis provides a baseline of market potential—one that could be subject to influence. The messages and actions of policymakers, automakers, electric utilities, and other interest groups could have significant influence over future development of PHEVs.

### Charging and refueling behaviors

#### *Recharging: How often, where, and when*

As outlined in the introduction to this report, the benefits of PHEVs compared to conventional vehicles, HEVs, and battery EVs depend on recharging behavior. There may be no more fundamental question about PHEVs than whether or not people will plug-in a vehicle that does not have to be plugged-in. The answer from the Project participants to date is, "Yes, we will." The households who have participated in this Project, on average, plugged-in these PHEV-conversions about once per day, and did so more often on weekdays than weekend days. There was large variation in the mean frequency of PHEV recharging across households—from zero to 2.6 times per weekday and zero to 1.5 times per weekend day. Higher frequency of plugging-in on weekdays is associated with 1) recharging at work during the workday, and 2) recharging at home during the day by retired households. The frequency of plugging-in on weekend days was also lower than on weekdays because the PHEVs were more likely to be away from home, and thus away from the households' primary or sole recharging location. Only a few households found away-from-home recharging locations they used on a regular basis. These were associated with trips to work; the electrical outlets were either in the employers' parking lots or public parking garages.

By the end of their PHEV trial, if the participants understood how to maximize the use of the supplemental battery, they were recharging every night (that the vehicle was home). Those who did not understand the state of charge of the battery, or the PHEV technology in general, did not necessarily recharge nightly or, in some households in any apparent pattern. When asked about recharging, most participants discussed the actual act of plugging into the electrical outlet but not the frequency with which they recharged. Despite the fact that most households asked us about how often to recharge when the PHEV was first delivered to them, it appears that recharging either 1) quickly became a daily routine or chore—irrespective of the level of understanding of why they would plug the car into the grid—or 2) that differences in the performance of the PHEV in CD and

CS mode were not adequately represented to some households for them to understand why and when to recharge the car.

In general, most households plugged in their PHEVs after 4:00pm on weekdays and left them plugged in until 6:00am the next morning. While the weekday electricity demand from vehicles being plugged in between 5:00pm and 6:00pm creates a rapid increase in grid electricity demand, the differences between “availability,” i.e., when the vehicle is plugged-in to the grid, and “demand,” i.e., when the vehicle draws electricity from the grid to recharge the battery, show there is opportunity to shift electricity demand for PHEV recharging to presently existing off-peak electricity demand periods for these households (and vehicles). Weekend days present even greater opportunity to manage grid power to the vehicles since 1) fewer vehicles are plugged in, 2) those vehicles that are plugged in require less electricity to fully recharge, and 3) those vehicles that are plugged-in tend to remain plugged in longer into the next morning.

While off-peak recharging of PHEVs would be advantageous to electricity providers, it could produce other benefits, such as reduced carbon content of the electricity used to recharge electric-drive vehicles, given that most wind power is produced during the night. Hence, off-peak charging, or even control over the type of electricity used to recharge electric drive vehicles, could significantly decrease the carbon emissions of the electricity used to power electric drive vehicles, thus providing greater transportation related GHG reductions. However, the construction of new renewable energy resources that operate primarily during present off-peak electricity demand periods competes with electricity providers goal (and one of the oft cited reasons to promote electrifying transportation) to increase the value of sunk investments in existing power production through increasing capacity factors.

It is important to emphasize that individual household’s charging behavior, vehicle use, and vehicle performance varied across days, recharging intervals, and trips. In an effort to demonstrate the different ways households could plausibly use these vehicles, we disaggregated the PHEV trial of the Kermode family and constructed an alternate month based on their interview data. The two months—the month as measured in the Project including multiple, away-from-home weekend tours and 2) a constructed month that substitutes measures of their in-town weekend travel for the longest of these tours—provide descriptions within which most of the Kermodes' vehicle use is likely to fall. Depending on which month and which comparative vehicle(s) one references, the improvement resulting from the substitution of the PHEV-conversion into the Kermodes' life on the gasoline-intensity of their travel is bounded by estimates of ten to 180 percent.

### *Total Energy, with and without recharging*

We compared the total energy (gasoline plus electricity) used by the households to drive the PHEV-conversions for their four-week trial to the gasoline they would have used had they not recharged at all. This is a close approximation to the question, "What difference does it make that this PHEV-conversion can be plugged into the electrical grid?" The gasoline displaced by electricity ranges from one to 19 percent of the gasoline that would have been consumed if the households had not recharged at all. This is not the same as the question of what difference it might make if any of these households would buy, drive, and recharge a plug-in vehicle rather than continue to drive any of their existing household vehicles or buy and drive any other conventional (or hybrid) vehicle they might buy.

Recharging causes differences in total energy use through the frequency of recharging, as moderated by the (mis)match between households' travel distances per recharging interval and their achieved CD range. Those households who closely match their travel to their achieved CD range of these PHEV conversions are able to achieve a much higher percent of their travel in CD mode (70 to 80 percent) and thus greater percentage energy (gasoline plus electricity) reductions through the substitution of electricity for gasoline (17 to 19 percent). These households achieve higher percentages of CD mode driving because either their common daily travel is less than their achieved CD range or they had access to away-from-home (and in this case, workplace) recharging so that they recharged multiple times per day.

Households are not uniform across their own four-week PHEV trial as to this match to their achieved CD range. A household such as the Kermodes accomplished most travel days within their CD range. But their aggregate (gasoline-only) fuel economy, percent miles driven in CD operation, and gasoline displacement were among the worst of the Project participants to date because of a few multi-day tours out of town. Again relying on all the data available to us though, especially from the interviews, a month can be constructed that is similar to many months of the Kermodes' lives. In this constructed month, their performance is much closer to the norm of the other Project participants, including an increase in aggregate (gasoline-only) fuel economy from 49 to 55mpg, percent miles driven in CD operation from 22 to 36 percent, and percent gasoline displaced from 4 to 13 percent.

Such analysis of total energy is entirely a construction of the analysts—no household has created an integrated accounting of both their gasoline and electricity use. Not even those few households who have used the V2Green website which contains measures of gasoline and electricity use and estimates of costs for both have any idea how much electricity they are using or what it is costing them. A few households have remarked how hard it is to see their electricity use through their monthly utility bill. As one households who tried remarked, changes in weather that caused them to begin to use their air conditioning during their PHEV trial month meant they could not figure out how much their higher electricity bill was due to their AC or the PHEV.

### *Recharging Habits and Etiquette: Infrastructure isn't the only barrier*

From the narrative analysis, we learned that most households spoke about recharging becoming part of their daily routine, similar to recharging a cell phone or feeding the dog. For a few households, the task took on the slightly negative connotation of "chore" rather than a habit or routine. But the majority of the Project participants said plugging-in the PHEV was easy and not a hassle. (The exception was the extension cord—almost universally households observed that a retractable cord would be a welcome design change.) Most people recharged at home because of the time needed to recharge the battery, availability of an electrical outlet, and safety of the car (and cord). Most stated that recharging at night was ideal because they could plug-in the car when they got home and un-plug it in the morning before heading to work. Several were concerned about plugging in their car if it was parked outside of their garage for fear of a tripping hazard or someone stealing the cord.

Some looked for recharging at local malls, job sites, or during out of town trips; none found it easy to locate an appropriate outlet. Many situations in which people did not recharge away from home can be interpreted as a lack knowledge about the of etiquette regarding recharging behavior: people were unsure if asking to plug in would be seen as rude or presumptive. Several participants specifically related that they did not ask to recharge at the houses of friends or family because they were unsure whether it was appropriate.

It can also be said that it is not merely the lack of knowledge by the Project drivers of recharging etiquette, but the lack of a set of social norms and rules altogether. Electric vehicle drivers in California in the 1990s did develop some informal rules about sharing the limited number of public EV recharging locations. But those EV drivers were too small a group to have created a set of more widely recognized and accepted social norms regarding the use of electrical outlets over which the driver does not have sole control, e.g., at home. Ironically, in and around the cities of Sacramento and Davis, CA the lingering presence of public EV parking and recharging facilities caused discussion and confusion on the part of some Project participants who recalled hearing about or seeing such facilities. Those who actually sought out this EV infrastructure were disappointed to find it did not have the appropriate electrical outlet for their PHEV. While some of these Project drivers questioned whether they were allowed to park in these EV spaces, others simply assumed they were allowed.

### *No One Misses Refueling with Gasoline*

We have not presented analyses of gasoline refueling behavior in this report. Summarizing discussions with Project households, the long-refueling intervals of the PHEVs are noted by almost all households. The PHEVs are routinely refueled much less often than the households' own vehicles for which the PHEV substitutes. This is sometimes an important marker for a household—eliciting delight and amazement at the long-periods of times between trips to gasoline stations. For some people, this experience was positive, but did not solve any problem (other than paying for gasoline!). For other people though, the reduction in trips to gasoline stations was more than a novelty. As we have observed in other research (Kurani and Turrentine, 1996; Turrentine and Kurani, 2007), some people identify gasoline stations as dangerous or dirty locations. We note no other reports of changes in refueling behavior. People did not believe they had bought gas at different stations, nor at different points in their daily routines; at least, no such changes were so remarkable that households could recall them.

## Driving behaviors

We treat driving behaviors at two scales. The first is a daily-to-monthly scale at which measures such as the households' percent of miles driven in CD mode is one summary of the relationship between households driving and recharging behavior. The second is at a shorter time scale—within a single trip—where we explored how the vehicle and information interfaces may have changed how people drove.

### *Summary Measures of Driving and Recharging*

As discussed in the opening of this report, the potential energy and environmental effects of PHEVs flow from the amount of electricity that displaces gasoline. This in turn depends on the relationship between PHEV designs and capabilities on the one hand, and PHEV drivers' driving and recharging behaviors on the other. The percentage of miles driven in CD mode is one measure of how all three interact.

One way to measure the performance of a particular technical specification for a PHEV is to recast it in terms of the realized performance based on our participants' driving and recharging behaviors. In this way the vehicle used in this project can be described as:

1. A PHEV that operates in blended mode during CD operation;
2. During which it will return (21 to 101) percent better gasoline-only fuel economy than it otherwise achieves in CS operation;
3. CD operation will last for (25 to 35) miles using a definition of CD range that references only when the switch from CD to CS operation occurs;

4. In exchange for about 4KWh of grid-electricity; and,
5. Achieves (38.0 to 51.5mpg) in CS operation (where percent improvement in CD operation is positively correlated with CS fuel economy *across drivers*).

The ranges of CD and CS performance values above are explained in part by differences in aggressiveness of accelerations, top speeds, mixes of driving on surface street vs. freeway, amenability to playing energy conservation games through the information interfaces, and travel and recharging behavior affecting the match between miles driven per recharging interval and each driver's realized CD range. One measure to encapsulate all of this is the percent of miles driven in CD operation. The particular vehicles used in this Project were driven, on average across the households' four-week trials, in CD operation for 53 percent of their total miles; the range across household means was 17 to 81 percent. It is unsurprising, but important, that the range within a single household across their recharging intervals can be greater, e.g., from less than two percent to 100 percent in one household.

### *Changing Driving Behaviors through User Interfaces*

It is impossible at this time to generalize the impact of in-vehicle and internet-based information interfaces on fuel economy as each participant interacted with the available vehicle information in a different way. Some participants completely ignored the information; others found the information to be a stimulating and engaging learning tool. We can speak about the causes of these differences. Some of the major reasons seem to be prior interest in fuel economy (interest in fuel economy changed and often increased over the course of the study), technological fluency, and each participant's role within their household in regards to vehicles or technology.

From the themes identified through the narrative analysis, we propose a few basic lessons that may help future interface designs to facilitate greater effects on energy use:

- The closer the information is to the point of interest, i.e. in the car vs. on the home computer, the more likely it is that the information will be used.

- Simplicity in representation and interpretation is critical to driver understanding.
- The interface should support drivers in setting and achieving goals by providing relevant summary information.
- Instantaneous Fuel Economy can provide drivers with erroneous information, especially during braking events.
- Whenever possible, information should be presented in a grounded context so that drivers can quickly understand the relative impact of their behavior.

Although these general lessons are by no means definitive or complete, they represent a simplified interpretive summary of the many participants' responses to the interfaces included in this study and as the basis for the design of ongoing research to elaborate and specify these lessons.

### Narrative Themes: Confusion and Payback

Narrative synthesis and analysis plays a confirmatory and explanatory role regarding recharging and driving behaviors discussed already. Two additional themes that emerged from the household narratives are further discussed here: confusion about PHEVs and the use of a payback analysis to assess PHEVs.

#### *Confusion*

Most Project participants were initially confused by the idea of a PHEV. Some remained unfamiliar and uncomfortable with the PHEV technology even after they had spent a month with the vehicle. A few households believed that recharging the car would increase fuel-only economy, but did not really understand how. Most of the households were confused about the state of charge of the battery. This—combined with inappropriate mental models of how batteries work—caused some participants to recharge less frequently than they would have if they had known how to determine the state of charge for the battery and if they had understood what the benefits might be. Households cited the example of their cellular phone's battery—so long as it had some charge, they derived full value from the phone calls made or received on it. The Project shows the extent to which experience and instrumentation can assist some households to develop more refined understandings of PHEVs, and that more needs to be done.

### *Valuing PHEVs: Payback and Intuition*

Many households discussed using some form of a cost-benefit analysis to determine whether the PHEV was "worth it." Most of these households discussed simple payback analysis comparing a purchase price and operating cost differences. A few households discussed more sophisticated net present value calculations. No households appear to have completed either simple payback or net present value calculations, most households made mistakes in describing how to make such calculations and demonstrated they did not know the values of all the costs and benefits that would enter into such a calculation.

In contrast, some households offered an intuitive assessment. Octavia, for example, said that using less gas "was a great feeling" because it "has got be a good thing." She linked gas savings with energy independence and reducing environmental impacts. She said that in the world today "we have people dying…corruption and big business…due to the whole dependence on oil…we are in trouble…" creating "untenable situations for our country"; "we can't keep going this way." Octavia felt that PHEV instrumentation would help people make a stronger connection between their personal actions and such global problems. For her, this awareness was a large benefit to driving a PHEV. She figured that most current HEV buyers were driven by financial motives, whereas if she were to buy an HEV, it would be for environmental reasons. She believed that climate change is a real, human-caused problem that, along with air pollution and the nation's dependence on foreign oil, requires urgent action. She sees owning a PHEV as part of the solution.

## Social Influence

We observe the almost complete lack of attention in prior analyses of electric-drive vehicles to the importance of social networks. The few examples cited in this report are suggestive of the additional understanding of how market, technology, and policy processes can be affected by understanding that not only are new vehicles, e.g., PHEVs, socially constructed, but so too are the processes in which they are developed, marketed, regulated, and used. In this Project, we are focusing on how our participating households construct and communicate their understanding and experience of PHEVs through their interactions within their social networks. This aspect of the Project has been deployed in only a few households to date, but will continue with the rest of the Project.

The first question within this social network research task is whether interpersonal interactions play a significant role in the assessment and adoption of electric-drive vehicles. We have observed that social interactions are influential for primary households (the Project drivers and households) and secondary respondents (selected members of the primary households' social networks). The second research question explores and characterizes specific processes of social interactions. We described these interactions from five perspectives: contagion, conformity, dissemination, translation, and reflexivity.

### *Five Approaches to Describing Social Interactions*

Contagion describes social interactions as point-to-point communication of information. The concept includes diffusion of innovations (DOI). Our preliminary assessment is that the idea of contagion neglects many of the subtle but important nuances of interpersonal influence, such as why particular types information are selected to share, why particular types of information are remembered by the listener, and how such information is interpreted in various contexts. Further, the notion that information diffuses in one direction, from innovators toward the majority, appears limiting. We observe households and their social networks that did not draw their perceptions from an "innovator." Rather, they formed a general understanding of the PHEV through an ongoing discourse of social interactions that they integrated with their existing knowledge.

Conformity focuses on individual's perception of social norms and the actions of others. This study reveals examples of ways in which the PHEV-conversion—or in some cases, the base Prius on which it is based—conforms or fails to conform to social norms of some groups with the participants' social networks. Our primary respondents are left the task of reconciling (or not) the extent to which this new idea, a PHEV, conforms to the social norms that shape other aspects of their lives. Personally, that is to the individuals within the Project households, conformity may be important, but the fact the PHEV may conform to their social networks' norms does not appear to stimulate more social interaction.

Dissemination is "diffusion that is directed and managed" by an organized group. To date, the Project has not included any participants that are members of a formal group attempting to disseminate PHEVs, e.g. Plug-in America. However, two households have demonstrated informal efforts to disseminate information about the pro-societal benefits of electric-drive vehicles within their social networks.

Translation defines innovations as dynamic, socially-constructed artifacts (Bruun and Hukkinen, 2003). A newly introduced artifact has a high degree of interpretive flexibility: different social groups' differing interpretations of its meaning and content influence further technological development (Pinch and Bijker, 1984). Project participants with less prior electric-drive knowledge and experience are in a state of interpretive flexibility, still coming to terms with even the basic functions of a PHEV. In contrast, participants with more electric-drive knowledge and experience are approaching a state of closure or stability, in which the meanings of PHEVs are less flexible, less susceptible to change.

Reflexivity as discussed within Giddens' (1991) structuration approach moves us beyond assessment of specific features of PHEVs to how individuals incorporate technology into their lifestyle trajectories. Within this approach, reflexivity can be used to better understand the underlying motives of each participant, as well as integrating patterns described by the other perspectives. We observed participants view their PHEV trial as an opportunity to try an alternative lifestyle trajectory, for example the young man who "tried on" his friends and co-workers environmental values through his participation in the PHEV research In other households, we observe how the PHEV is evaluated in terms of its ability to further an existing lifestyle trajectory, whether that be the high value of children or a pro-societal lifestyle calculated to induce interest and support for green technology. From the perspective of reflexivity, when participants talk about the PHEV, they not only share information about the technology, they are also share information about different identities and ways of living.

In summary, preliminary results suggest that interpersonal interactions within social networks play an important role in shaping the assessment of these PHEV conversions, and likely electric-drive vehicles more generally. Diffusion, conformity, and dissemination provide useful concepts for particular processes, but translation and reflexivity appear to best provide the language and theoretical depth required to integrate the various motives and perceptions observed among participating social networks. However, before conclusions can be drawn, more networks need to be explored and further analysis is required.

## Looking Forward

The UC Davis PHEV Research Center will continue the Project through at least the end of 2009, and possibly through the first quarter of 2010. Extensions beyond that time will be pursued especially if opportunities to incorporate different types of PHEVs into the Project can be negotiated. The goals of extending the Project in its present form are to increase the number of participating households, extend and refine the application of narrative, conduct an additional set of research activities around driver feedback, and continue the study of the effects of social interactions on the spread of information about PHEVs. Regardless of any future opportunity to incorporate additional types of PHEVs, a final omnibus report similar to this one will be issued on households experience with these PHEV-conversions comparing and contrasting the early and later results. In addition, separate focused articles will be prepared on specific topics derived from each of the main findings sections of this report.

## References

Axsen, J. and K. S. Kurani (2008). *The Early U.S. Market for PHEVs: Anticipating Consumer Awareness, Recharge Potential, Design Priorities and Energy Impacts*. Institute of Transportation Studies, University of California, Davis, University of California, Davis, Research Report UCD-ITS-RR-08-22.

Axsen, J., A. Burke, and K. Kurani (2008). *Batteries for plug-in hybrid electric vehicles (PHEVs): Goals and the state of technology circa 2008*. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-08-14.

Berger, Ronald J. and Quinney, Richard. (2005). The Narrative Turn in Social Inquiry. Storytelling Sociology: Narrative as Social Inquiry. Lynne Reinner Publishers: Boulder, Colorado.

Brown, M. B. (2001). The civic shaping of technology: California's electric vehicle program. *Science Technology & Human Values*, 26(1): 56-81.

Bruun, H. and A. Hukkinen (2003). Crossing boundaries: An integrative framework for studying technological change. *Social Studies of Science*, 33(1): 95-116.

Bunch, D., M. Bradley, T. Golob., R. Kitamura, and G. Occhizzo (1993). Demand for clean-fuel vehicles in California: A discrete choice stated preference survey. *Transportation Research A,* 27, 237-253.

California Air Resources Board – CARB (2003). *California Exhaust Emission Standards and Test Procedures for 2005 and Subsequent Model Zero-Emission Vehicles, and 2002 and Subsequent Model HEVs, in the Passenger Car, Light-Duty Truck and Medium-Duty Vehicle Classes."* Sacramento, CA: California Environmental Protection Agency.

California Air Resources Board – CARB (2008a). *ARB Passes New ZEV Amendment: Measures could produce 65,000 cleaner vehicles by 2012*, Press Release, March

27th, 2007, http://www.arb.ca.gov/newsrel/nr032708b.htm (accessed April 17th, 2008).

California Air Resources Board – CARB (2008b). *2008 Proposed Amendments to the California Zero Emission Vehicle Program Regulations,* Staff Report: Initial Statement of Reasons, February 8th, 2008, http://www.arb.ca.gov/regact/2008/zev2008/zevisor.pdf (accessed April 17th, 2008).

Callon, M. (1991). Techno-economic networks and irreversibility. *A Sociology of Monsters: Essays on Power, Technology and Domination*. J. Law. Routledge: London.

Canzler, W. (1999). Changing speed? From the private car to CashCar Sharing. SPEED - *A workshop on space, time and mobility*. Copenhagen, Denmark: The Danish Transport Council.

Carrasco, J. A., B. Hogan, et al. (2008). Collecting social network data to study social activity-travel behavior: an egocentric approach. *Environment and Planning B: Planning and Design,* 35(6): 961-980.

Cialdini, R. B. (2003). Crafting normative messages to protect the environment. *Current Directions in Psychological Science,* 12(4): 105-109.

Degenne, A. and M. Forse (1994). *Introducing Social Networks*. London, SAGE Publications.

Duvall, M., et al. (2002). *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options for a Compact Sedan and Sport Utility Vehicles*, EPRI, Palo Alto, CA: 2002, Report #1006892.

Ewing, G. and E. Sarigollu (2000). Assessing consumer preferences for clean-fuel vehicles: A discrete choice experiment. *Journal of Public Policy and Marketing*, 19, 106-118.

Gondor, J. and A. Simpson (2007). Measuring and Reporting Fuel Economy of Plug-In Hybrid Electric Vehicles, *WEVA Journal*, Vol.1.

Giddens, A. (1991). *Modernity and Self-Identity: Self and Society in the Late Modern Age*. Stanford, CA, Stanford University Press.

Gjoen, G. and M. Hard (2002). Cultural politics in action: Developing user scripts in relation to the electric vehicle. *Science Technology & Human Values,* 27(2): 262-281.

Granovetter, M. (1973). Strength of weak ties. *American Journal of Sociology*, 78(6): 1360-1380.

Granovetter, M. (1978). Threshold models of collective behavior. *American Journal of Sociology,* 83(6): 1420-1443.

Green, D. P. (1992). The price elasticity of mass preferences. *American Political Science Review*, 86(1): 128-148.

Hannemyr, G. (2003). The Internet as hyperbole: A critical examination of adoption rates. *Information Society*, 19(2): 111-121.

Heffner, R. R. (2007). *Semiotics and Advanced Vehicles: What Hybrid Electric Vehicles (HEVs) Mean and Why it Matters to Consumers*. Institute of Transportation Studies. Davis: CA, University of California, Davis. PhD.

Heffner, R., K. Kurani, and T. Turrentine (2007). Symbolism in California's early market for hybrid electric vehicles. *Transportation Research Part D,* 12, 396-413

Herman, L. and B. Vervaeck (2005). Handbook of Narrative Analysis. Board of Regents of the University of Nebraska.

Hirschman, E. C. (1981). Symbolism and Technology as Sources for the Generation of Innovations. *Advances in Consumer Research*, 9: 537.

Hogan, B., J. A. Carrasco, et al. (2007). Visualizing Personal Networks: Working with Participant-aided Sociograms. *Field Methods*, 19(2): 116-144.

Kalhammer, F.R., B.M. Kopf, D. Swan, V.P. Roan, and M.P. Walsh (2007). *Status and Prospects for Zero Emissions Vehicle Technology: Report of the ARB Independent Expert Panel 2007*, Prepared for State of California Air Resources Board, Sacramento, California, April 13 2007.

Kromer, M. and J. Heywood (2007). *Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet*, LFEE 2007-03 RP. Sloan Automotive Laboratory, Massachusetts Institute of Technology, Cambridge, MA.

Kurani, K., R. Heffner and T. Turrrentine (2007). *Driving Plug-In Hybrid Electric Vehicles: Reports from U.S. Drivers of HEVs Converted to PHEVs, Circa 2006-2007*, Institute of Transportation Studies, University of California, Davis, October 16th, 2007.

Kurani, K., T. Turrentine, and D. Sperling (1996). Testing electric vehicle demand in 'hybrid households' using a reflexive survey, *Transportation Research Part D,* 1(2), 131-150.

Lieblich, A., R. Tuval-Maschiach, and T. Zilber. (1998). Narrative Research: Reading, Analysis, and Interpretation. Applied Social Research Methods Series. Vol 47.

Markel, T. et al. (2006), *Plug-in hybrid vehicle analysis, Milestone Report, National Renewable Energy Laboratory,* NREL-MP-540-40609, November, 2006, http://www.nrel.gov/, accessed on 2008-09-22.

McCracken, G. (1988). *The Long Interview*. Newbury Park, California, Sage Publications.

Pesaran, A., T. Market, H. Tataria, and D. Howell (2007). *Battery Requirements for Plug-In Hybrid Electric Vehicles: Analysis and Rationale*, 23rd International Electric Vehicle Symposium and Exposition (EVS-23), Anaheim, California, December 2-5, 2007.

Pinch, T. J. and W. E. Bijker (1984). The social construction of facts and artifacts - Or how the sociology of science and the sociology of technology might benefit each other. *Social Studies of Science*, 14(3): 399-441.

Potoglou, D. and P. Kanaroglou (2007). Household demand and willingness to pay for clean vehicles, *Transportation Research Part D*, 12, 264-274.

Reissman, C. K. (1993). Narrative Analysis. Qualitative Research Methods Series 30. Sage Publications: Newbury Park, California.

Rogers, E. (2003). *Diffusion of Innovations (5th Ed.).* New York, Free Press.

Schram, S.F. and P.T. Neisser (1997). Introduction. Tales of the State: Narrative in Contemporary U.S. Politics and Public Policy. Rowman and Littlefield Publishers, Inc: Lanham, Maryland.

Strang, D. and S. A. Soule (1998). Diffusion in organizations and social movements: From hybrid corn to poison pills. *Annual Review of Sociology*, 24: 265-290.

Turrentine, T. S. and K. S. Kurani (2007). Car buyers and fuel economy? *Energy Policy*, 35(2): 1213-1223.

Valente, T. (2005). Network Models and Methods for Studying the Diffusion of Innovations. *Models and Methods in Social Network Analysis*. P. Carrington, J. Scott and S. Wasserman. New York, New York, Cambridge University Press**:** 98-116.

## ACRONYMS AND GLOSSARY

***All-Electric Operation:*** Operation in charge-depleting (CD) mode that uses only grid electricity, rather than electricity produced by an on-board generator, to power the vehicle.

***Blended Operation:*** Operation in charge-depleting (CD) mode that uses grid electricity *and* gasoline to power the vehicle; energy from both are "blended" together through the electro-mechanical drivetrain.

***Charge Depleting (CD) Mode:*** Energy stored in the battery is used to power the vehicle by gradually *depleting* the battery's state of charge (SOC) (see "Charge Sustaining").

***CD Range:*** The distance a PHEV can drive in charge depleting (CD) mode before switching to charge sustaining (CS) mode. (Other definitions include 1) the equivalent distance that could be traveled on electricity given on-board storage, and 2) the distance traveled before the ICE first turns on. The last is relevant to series PHEV designs and is equivalent to "all-electric range.")

***Charge Sustaining (CS) Mode:*** The battery's state of charge (SOC) is *sustained* by relying primarily on the gasoline engine to drive the vehicle, only using the battery and electric motor to increase the efficiency of the gasoline engine, as is done in an hybrid-electric vehicle (HEV).

***(Usable) Depth of Discharge (DOD):*** The differences between the battery's maximum and minimum states of charge (SOC); usually less than 100% in practice.

***Electricity availability:*** The time of day vehicles are plugged-in to an electrical outlet

***Energy Density (Wh/kg):*** The amount of energy stored per kg of a battery *pack* or *cell*.

***Electric Vehicle (EV):*** An electric drive vehicle that is only powered by grid electricity.

***Hybrid Electric Vehicle (HEV):*** A vehicle primarily powered by a heat engine (e.g. an internal combustion engine), but uses an electric motor and energy storage system (e.g. an advanced battery) to improve the efficiency of the engine's operation.

***Kilowatt (kW):*** A measure of power (1000 watts), where 1 kW = 1.34 horsepower.

***Kilowatt-hour (kWh):*** A measure of energy use or capacity, where 1 kWh = 1,000 Watts provided for 1 hour.

***Parallel Architecture:*** A PHEV drivetrain that allows a direct connection between the engine and the wheels, as well as between the engine and battery and motor via a generator. The vehicle can be powered by electricity and gasoline simultaneously, electricity only, or by gasoline only. The battery is charged from an electrical outlet, or by the gasoline engine via a generator.

***Plug-In Hybrid Electric Vehicle (PHEV):*** An electric drive vehicle that can be powered by a heat engine (e.g. an internal combustion engine), an electric motor using grid electricity (e.g. stored in a battery), or both.

***Power Density (W/kg):*** The amount of power that can be provided per kg of battery *pack* or *cell*.

***Series Architecture:*** A PHEV drivetrain that powers the vehicle only by an electric motor using electricity from a battery. The battery is charged from an electrical outlet, or by the gasoline engine via a generator (e.g. GM's Volt concept)

***State of Charge (SOC):*** The ratio of energy currently stored in a battery to the battery's maximum capacity.

***Total Energy Capacity:*** The amount of total energy (in kWh or kWh/kg) that can be stored in a battery. Not all of this energy is usable, as operation is limited to using the assigned depth of discharge (DOD) to preserve battery life and safety.

***Zero Emission Vehicle (ZEV):*** A vehicle that produces zero tailpipe emissions.

## APPENDICES

**Appendix A: Household Final Interview Protocol**

**Appendix B: PHEV Buyers' Guide (on-line questionnaire)**

**Appendix C: PHEV Design Games (on-line questionnaire)**

**Appendix D: California and Northern California Survey Over-samples' PHEV Designs**

**Appendix E: PHEV Project Households' Electricity Availability and Instantaneous Power Demand, Daily**

**Appendix F: Three PHEV Project Households' Narratives**

## Appendix A: Household Final Interview Protocol

### Questions about their experience with the PHEV

[Questions and comments in brackets are rhetorical comments to guide the interviewer. The major numbered questions enumerate the topics for the interview. All lower-order questions are merely suggestions and prompts to be used if necessary to promote conversation.]

Why did you want to participate in this research? What were your expectations? Hopes? Concerns?

a. In what ways were your expectations met? [How do people "measure" this?]

b. In what ways were they disappointed?

c. Who drove the car? How did you decide? Did this change throughout the month?

Tell me about driving the PHEV. What did you like? What didn't you like? [Be sure to let people talk here. Their initial driving impressions may have to do with vehicle size, handling, cupholders, or other things. Only after they have told their story should you probe for any specifics of it being a PHEV.]

d. Was your driving of the PHEV "normal" for you? Did you take any unusual trips? Did you not take trips you normally would have taken? How did your use of the PHEV change your travel for the month?

e. Did you change your driving? In response to what? How? Why? [This question is about driving as opposed to travel. Did they drive more or less aggressively? What does that mean to them?]

Could you tell when the vehicle was operating on electricity only? How? Was this important to you? Why, or why not?

f. Tell me about the energy use instrumentation in the vehicle. Did you use it? How? Which screens did you use; to which information did you pay attention?

Tell me about recharging the PHEV? Was it easy or difficult? A convenience or a hassle?

g. How did your recharging behavior change over the month? Why?

h. Can you imagine yourself doing recharging a vehicle over the long-term? Why?

    i. Would you change anything about your parking or access to electricity to improve recharging?

i. Did you recharge away from your home? [No] Why not? [Yes. See prompts.]

    i. If you did, tell me about the places and times you recharged away from home. Were these casual or essential? What were you trying to accomplish?

    ii. How interested would you be in a PHEV if you did not have access to recharging at work?

Did you notice changes (from your household's own vehicles) in gasoline refueling, e.g., frequency, location, and cost?

Did you track both electricity and gasoline use and cost? How?

j. Was the V2Green website useful, interesting?

    i. How much did you use it?

    ii. Suggestions for changing the site? What would you like to see?

Were you able to determine whether the PHEV "saved you energy/money, reduced emissions" anything?

k. Would this be important to you, or would other things motivate you to drive a PHEV?

l. What are these other things? How would you assess if you were getting enough of them to motivate you to drive a PHEV?

### Review questions from the on-line questionnaires

Who answered the questionnaires?

From Part 1, Question 3.11 [repeated below]: Why did they answer the way they did?

> You are offered the choice between two ways to reduce your household's energy use. Both simply require you to install them and then carry on with you usual life. Both are offered to you free. Option A would reduce electricity use in your home, reducing your monthly utility bill by $21. Option B would reduce gasoline use in your vehicles, reducing what you pay each month for gasoline by $21.
>
> Which would you choose?
>
> - ❑ It doesn't matter, I'll take either one
> - ❑ I'd rather spend $21 less per month on my electric bill (Option A)
> - ❑ I'd rather spend $21 less per month on gasoline (Option B)
> - ❑ I don't know

*From Part 2, Review results of design games:*

Did you read the guide? Was the game understandable? What did “all-electric” mean to you?

Why did you create the PHEV designs you did? Did the game seem to get at what you thought would be important about PHEVs? What other feature or capability would you add?

Would you say you would be more motivated to drive a PHEV that operated on electricity-only as much as possible or by a PHEV that had high fuel economy while operating on gasoline?

m. What are your ideas about both these possibilities? What strikes you as interesting and valuable?

n. How would you choose between them?

## APPENDIX B: PHEV BUYERS' GUIDE (ON-LINE QUESTIONNAIRE)

# Your *Plug-In Vehicle Guide*

### Your Plug-In Hybrid Guide:

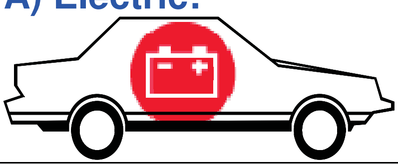
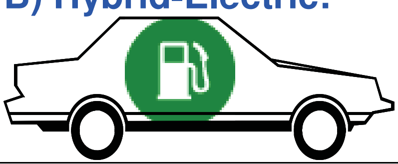
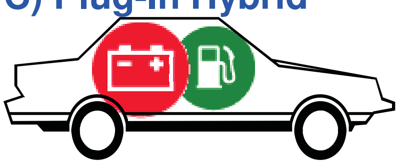


### Why read this guide?

Think of this as a 10 minute shopping guide. Part 3 of the 'Household Vehicle Survey' will allow you to design your own plug-in hybrid vehicle. You will determine how this technology might fit into your household's lifestyle, if at all. This guide explains the design options you will be given in Part 3.

### This Guide Focuses on Plug in Hybrid Vehicles ONLY

A plug-in hybrid is a combination of an electric vehicle and a hybrid-electric vehicle. Recall the descriptions you were provided in Part 1 of the survey:

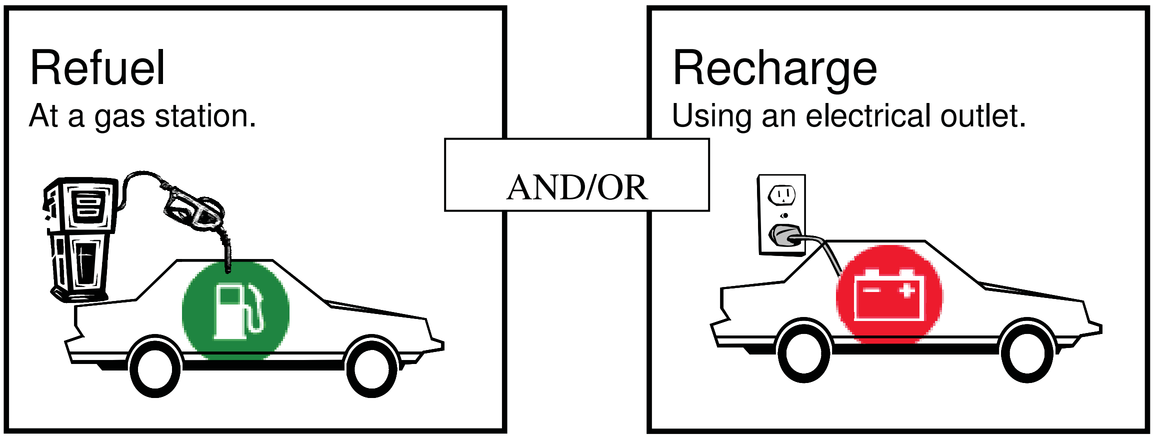
| Vehicle Type | Description |
|---|---|
| **A) Electric:**  | An electric vehicle is fueled by **electricity only**. It is charged by plugging in to an electric outlet. The electricity is stored in the vehicle until it is used to power the vehicle. This technology is not currently produced by any major car companies, but a few smaller companies do. |
| **B) Hybrid-Electric:**  | A hybrid-electric vehicle is fueled by **gasoline only**. It uses a hybrid-electric technology to use gasoline more efficiently. A hybrid-electric vehicle can **not** be plugged in to an electric outlet. This technology includes the Toyota Prius, which has become quite popular in the US. |
| **C) Plug-In Hybrid**  | A plug-in hybrid combines these two technologies. It can be plugged in to an electric outlet to charge up with electricity, and it can be filled with gasoline. A plug-in hybrid **can run on electricity only, gasoline only, or a combination of the two**. No car company currently sells this technology, although several have plans. |

(***Note:** This guide refers to 'gasoline' as your vehicle fuel, but this term includes whatever fuel your current vehicle uses, including diesel or ethanol)

## Lesson 1: Refueling and Recharging

The plug-in hybrid is unique because it can be refueled with gasoline *and* recharged with electricity. Unlike a basic electric vehicle, the plug-in hybrid will still drive if it runs out of electricity (as long as you have gasoline left).

Refueling and recharging your vehicle is simple:




### Gasoline: Refueling

Refuel at any gasoline station. You have the same fuel tank you are used to, which holds the same amount of gas. If you want, you could use *only* gasoline all the time without ever plugging in, just like your current vehicle.

### Electricity: Recharging

Recharge your vehicle using any normal electrical outlet (110-volt) – just like you recharge your cell phone or laptop computer. These are the same types of outlets you use for a TV or toaster. An outlet might be at home, work, a store or a friend's house, and would likely be outside or in a garage.

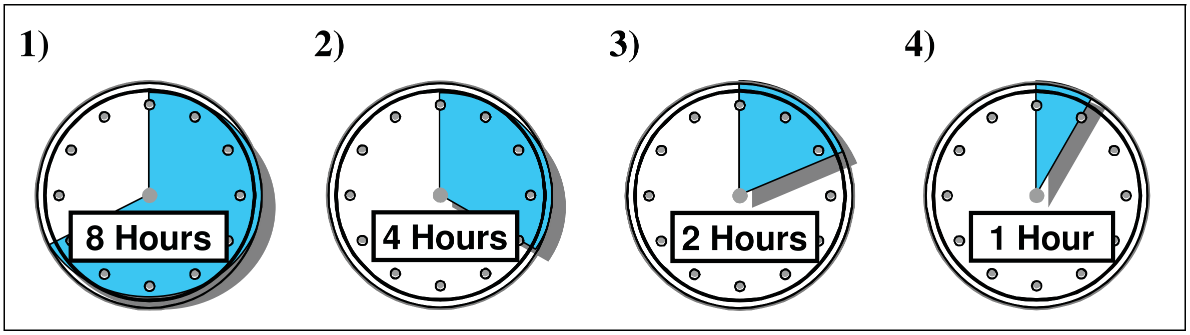
### Why plug-in when I could just use gasoline?

Electricity is generally **cheaper** than gasoline…but it is difficult to say how much cheaper. Gasoline prices change often, and electricity prices vary by region, season, and other factors. In most regions today, driving with *only* electricity would cost 60-80% less per mile than driving with *only* gasoline. This saving is like reducing your gas cost from $3.00/gallon to around $1.00.

Also, driving with electricity usually causes **less air pollution and greenhouse gas emissions** than driving with gasoline. The size of these reductions depends on how your electricity is produced.

## How long does it take to recharge?

Recharge time depends on the vehicle design you choose. An empty battery could take 1 to 8 hours to fully recharge. In Part 3 of the survey, you will be given the following four upgrade options when you design your own plug-in hybrid vehicles:




## Can I interrupt the recharging process?

Yes. For instance, if your vehicle requires 8 hours for a full charge, and you unplug it after 2 hours, you will get one quarter of a full charge. Similarly, you could plug it in for only 1 hour, or even 10 minutes.

### EXAMPLES: Recharge Upgrades

Think of **Paul** and **Sarah**, two different drivers who each designed their own plug-in hybrid vehicles. Each driver completed a *Plug-In Vehicle Diary* to see what opportunities they have to recharge (access to electrical outlets).

**Paul's family** has only one place where they can recharge their vehicle: at their home garage where they park every night. Because Paul can recharge for 12 hours a day, he chose not to improve recharge time beyond 8 hours.

**Sarah** lives in an apartment building, where there are no electric outlets near her parking spot. She drives around on business frequently during the day time, where she may occasionally be parked near an electrical outlet for 1-2 hours at a time. Because she has only brief opportunities to recharge, Sarah chose to upgrade her plug-in vehicle recharge time to the quickest choice: 1 hour.

## Lesson 2: Gasoline Mode (Driving Without Electricity)

All plug-in hybrid vehicles can drive without electricity. Once the battery runs out, the vehicle continues by using gasoline only. You *could* drive your plug-in vehicle without *ever* plugging in.

### ‘Gasoline’ Mode: Efficiency Upgrade

A bonus of a plug-in hybrid vehicle is that once the electric charge runs out, the vehicle switches to ‘Gasoline’ mode and behaves just like a typical hybrid electric vehicle (like a Toyota Prius). This means that even if you don’t plug-in, a plug-in hybrid vehicle uses less gasoline than a regular vehicle. At a minimum, ‘Gasoline’ mode will allow you to drive an extra 10 miles per gallon (+10 MPG) over a typical vehicle. If your current vehicle can travel 27 miles with a gallon of gasoline, the plug-in version could travel at least 37 miles.

You will have 3 options to improve the efficiency of ‘Gasoline’ mode:

**1) Current Vehicle +10 MPG** | **2) Current Vehicle +20 MPG** | **3) Current Vehicle +30 MPG**

Each improvement is relative to your current vehicle. If your current vehicle can drive 30 miles per gallon of fuel, you can upgrade ‘Gasoline’ mode efficiency to 40, 50 or 60 miles per gallon.

### EXAMPLES: Upgrading Gasoline Mode

Again think of **Paul** and **Sarah**, who both vehicles that originally had a fuel efficiency of 27 miles per gallon (MPG).

**Paul’s family** doesn’t drive in ‘Gasoline’ mode very often because they can recharge regularly at home. He chose the minimum upgrade of **37 MPG.**

**Sarah** chose the maximum ‘Gasoline’ mode upgrade of **57 miles per gallon**. She is interested in saving money, and she knows that on many days she can’t recharge at all. She wants to maximize her fuel savings even when she can’t use electricity.

## Lesson 3: Electric Mode (Driving With Electricity)

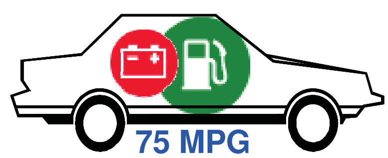
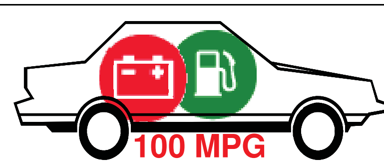
If you recharge your plug-in vehicle, you can drive for some distance using electricity. Depending on your chosen design, electricity would either *reduce* gasoline use (Electric Assist) or *replace* gasoline use (All Electric) for this limited distance.

***Note:*** For all upgrades discussed in this guide, the vehicle's performance does not change. For instance, improving gasoline efficiency or electricity use does not reduce acceleration, horsepower, top speed or towing ability.

### Electric Assist: Reducing Gasoline Use

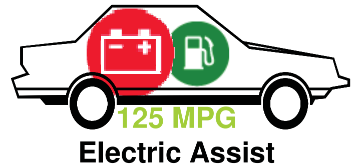
When recharged, a vehicle that is 'Electric Assist' capable will use both electricity and gasoline at the same time. The electricity *helps* the gasoline engine, offsetting the gasoline required to drive. For instance, an average car can travel 27 miles with a gallon of gasoline (27 MPG). However, a charged plug-in hybrid can travel at a rate of at least 75 miles per gallon of gasoline (75 MPG), because the electricity is helping. Once the battery runs out, the vehicle returns to using gasoline only. You will *not* be stuck!

There are **3 types** of 'Electric Assist' plug-in hybrid vehicles. More advanced types use more electricity and less gasoline (represented by the changing size of the battery and gasoline icons in the diagrams below).

| | |
|---|---|
| **Type #1: Electric Assist (75 MPG)**<br>Where electricity *helps* the gasoline engine, improving your gas mileage to **75** miles per gallon (MPG). *Some* gasoline is always required to drive. |  |
| **Type #2: Electric Assist (100 MPG)**<br>Same as above, but improving your gas mileage to **100** miles per gallon (MPG). *Some* gasoline is always required to drive |  |

### Type #3: Electric Assist (125 MPG)

Same as above, but improving your gas mileage to **125** miles per gallon (MPG). *Some* gasoline is always required to drive

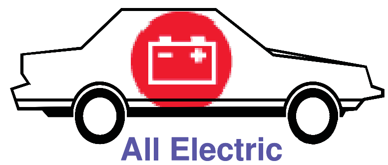



## All Electric: Temporarily Replacing Gasoline Use

A fourth type of electric design is ‘All Electric’ capable. This technology is more advanced than the ‘Electric Assist’ options because electricity can fully replace the use of gasoline for a limited distance. Once the battery has run out, the vehicle returns to using gasoline only. You will *not* be stuck!

### Type #4: All Electric

Where electricity is temporarily used *instead* of gasoline. As long as the vehicle is charged up, no gasoline is required to drive.




## How long does the Electric Charge last?

You can choose the distance your electric charge will last. This distance does not change if you choose Type #1, #2, #3 or #4. You can choose to have a full charge last for the *first* 10, 20 or 40 miles of travel. Beyond this distance, your vehicle returns to ‘Gasoline’ mode. If you choose 20 miles, your fully charged vehicle will drive in electric mode for the first 20 miles (‘Electric Assist’ or ‘All Electric’).

**When Fully Charged**
**Drive in ‘Electric Assist’ or ‘All Electric’ Mode:**

| 1) For the First 10 Miles | 2) For the First 20 Miles | 3) For the First 40 Miles |
|---|---|---|

## EXAMPLES: Upgrading Electric Mode and Electric Distance

Again think of **Paul** and **Sarah**, two different plug-in hybrid owners.

**Paul** likes the idea of driving an electric car in the city, so he chose a **‘Type #4: All Electric’** capable vehicle. He lives 6 miles from work (12 miles round trip), so he chose a vehicle with **10 miles** of distance per charge. He can recharge each night, then commute to work, and most of the way home with only electricity. His vehicle switches to ‘Gasoline’ mode for the last 2 miles of his commute.

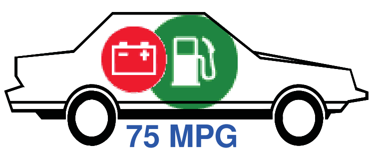
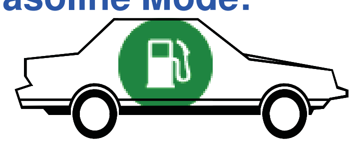
**Sarah** does not care if she uses gasoline or electricity; she just wants to save money. She chose the ‘Electric Assist’ capability, as she doesn’t think ‘All-Electric’ mode is worth the extra cost. She chose **‘Type #2: Electric Assist (100 MPG)’** so she can drive at a rate of 100 miles per gallon of gasoline (MPG). She also chose to upgrade to **40 miles** of distance per charge, because she knows she cannot recharge regularly.

# Lesson 4: Upgrading Your Plug-In Vehicle

## Minimum Upgrade Package

In Part 3 of the survey, you will use an interactive diagram to design your ideal plug-in hybrid vehicle (given different constraints). The diagram below shows the baseline plug-in upgrade package you will be shown, with the minimum values shown for each option:

This plug-in hybrid vehicle requires **8 hours** to fully recharge. When charged, it can drive with **'Type #1: Electric Assist (75 MPG)'** for the first **10 miles**. After 10 miles, the vehicle switches to gasoline mode, which can travel 10 more miles per gallon (MPG) of gasoline than your current vehicle.

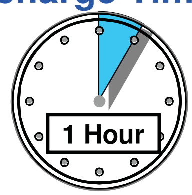
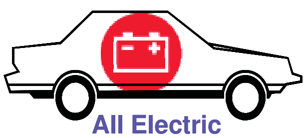
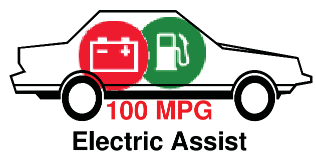
<table>
<tr><th>Your Plug-In Hybrid Vehicle</th><th>Upgrades</th></tr>
<tr><td>Recharge Time:<br>
</td><td>Time to Fully Recharge:<br>● 8 Hours<br>○ 4 Hours<br>○ 2 Hours<br>○ 1 Hour</td></tr>
<tr><td rowspan="2">Electric Mode:<br><br>75 MPG<br>Electric Assist<br><br>For the First<br>10 Miles</td><td>Electric Capability:<br>● Type #1: Electric Assist (75 MPG)<br>○ Type #2: Electric Assist (100 MPG)<br>○ Type #3: Electric Assist (125 MPG)<br>○ Type #4: All Electric</td></tr>
<tr><td>Distance With Electric Capability:<br>● First 10 miles<br>○ First 20 miles<br>○ First 40 miles</td></tr>
<tr><td>Gasoline Mode:<br><br>Your Vehicle +10 MPG</td><td>Gasoline Use:<br>● +10 Miles Per Gallon<br>○ +20 Miles Per Gallon<br>○ +30 Miles Per Gallon</td></tr>
</table>

**EXAMPLES:**

Here is a summary of the plug-in upgrades **Paul** and **Sarah** chose:

**Paul's family** chose a plug-in vehicle that takes 8 hours to fully recharge. When fully charged, the vehicle can drive without any gasoline (Type #4: All Electric) for the first 10 miles. After 10 miles (unless recharged), the vehicle runs out of electricity and uses gasoline only (37 MPG), but still saves fuel compared to a regular vehicle (+10 miles per gallon).

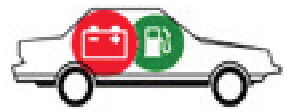
**Sarah** chose a plug-in vehicle that takes only 1 hour to recharge. The fully charged vehicle can drive with Electric Assist (Type #2) for 40 miles, using electricity to boost fuel economy up to 100 miles per gallon. After 40 miles, the vehicle switches to gasoline only, where her vehicle can travel an extra 30 miles per gallon of gasoline (57 MPG) compared to a typical vehicle.

| ***Paul's* Upgrades** | | ***Sarah's* Upgrades** | |
|---|---|---|---|
| **Recharge Time:**   | **Recharge:**<br>● 8 Hours<br>○ 4 Hours<br>○ 2 Hours<br>○ 1 Hour | **Recharge Time:**   | **Recharge:**<br>○ 8 Hours<br>○ 4 Hours<br>○ 2 Hours<br>● 1 Hour |
| **Electric Mode:**   **For the First 10 Miles** | **Electric:**<br>○ Type #1<br>○ Type #2<br>○ Type #3<br>● Type #4<br>**Distance:**<br>● 10 miles<br>○ 20 miles<br>○ 40 miles | **Electric Mode:**   **For the First 40 Miles** | **Electric:**<br>○ Type #1<br>● Type #2<br>○ Type #3<br>○ Type #4<br>**Distance:**<br>○ 10 miles<br>○ 20 miles<br>● 40 miles |
| **Gasoline Mode:**  **37 MPG** | **Gasoline:**<br>● +10 MPG<br>○ +20 MPG<br>○ +30 MPG | **Gasoline Mode:**  **57 MPG** | **Gasoline:**<br>○ +10 MPG<br>○ +20 MPG<br>● +30 MPG |

**Now think about your household. Which upgrades are important? Please consult with your family to prioritize these upgrades.**

## APPENDIX C: PHEV DESIGN GAMES (ON-LINE QUESTIONNAIRE)

**Section 3: Designing Your Plug-In Vehicle**



Now, Imagine that... you have a just won a contest to upgrade your **MINI COOPER** into a plug-in hybrid vehicle, allowing you to use electricity to drive, using less gasoline. This upgrade promises that everything else about your vehicle will stay the same (appearance, performance, safety, warranty, etc.).

Remember, A Plug-in Hybrid is... a vehicle that can be powered by either: electricity (from an electrical outlet), gasoline (like a typical vehicle), or a combination of both, as shown below:


You Have Choices... because your 'Plug-in Prize' allows you to choose what kind of battery upgrade you receive. But first...

First We Need to Know...
What is the average fuel economy of your **MINI COOPER** in miles per gallon (MPG)?
*Choose a value that is the average of city/highway driving.*
*(Remember, a higher MPG means you are required less fuel to drive a given distance.)*

- ☐ 21 MPG - About average for a new truck
- ☐ 27 MPG - About average for a new car
- ☐ 28 MPG - About average for a basic **MINI COOPER**
- ☐ Other - Please Specify: MPG

Next

Now you have the opportunity to upgrade your vehicle. You can upgrade your plug-in vehicle in four different ways, as described in ***Your Plug-In Vehicle Guide***. Please consult this document for explanations if you need help.

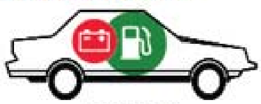
Each upgrade requires a certain number of �points�. We want to know what upgrades you consider to be most important. You will be shown 5 scenarios. Each scenario will give you a different number of �points� to make upgrades. Each scenario is independent, so you can choose different upgrades each time.

**Scenario #1:** If you have **1 point** to make an upgrade, how would you use it?

Please be realistic. Consider how your household uses this vehicle, and where you have access to electrical outlets, if at all (from your plug-in diary).

*Make your selection(s) in the Upgrade column to use your points, then click 'This is My Choice' when you are finished.*

*Your choice is visually represented in the left column.*

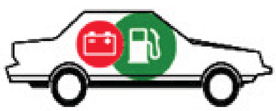
| Your Plug-In Hybrid MINI COOPER | Upgrades | Upgrades Points |
| --- | --- | --- |
| **Recharge Time:**<br><br>8 Hours required to fully recharge vehicle. | **Time to Fully Recharge:**<br>(•) 8 Hours<br>( ) 4 Hours (1 pt) | **Total Points: 1 pts**<br>**Points Used: 0 pts**<br>**Points Left: 1 pts** |
| ↓ | | |
| **Electric Mode:**<br><br>**75 MPG**<br>**Electric Assist**<br>**For the First**<br>**10 Miles** | **Electric Capability:**<br>(•) Type #1: Electric Assist (75 MPG)<br>( ) Type #2: Electric Assist (100 MPG) (1 pt)<br>**Distance With Electric Capability:**<br>(•) First 10 Miles<br>( ) First 20 Miles (1 pt) | |
| ↓ | | |
| **Gasoline Mode:**<br><br>38 MPG<br>Gasoline Only<br>Until Recharged | **Gasoline Use:**<br>(•) 38 Miles Per Gallon<br>( ) 48 Miles Per Gallon (1 pt) | |

**Description of Your Choice:**

The above vehicle takes **8 hours** to recharge. When fully recharged, it can be driven for the **first 10 miles** in **Type #1: Electric Assist (75 MPG)** mode. After this distance, it can only be driven in gasoline mode until recharged, getting **33 Miles Per Gallon**.

This is My Choice

# Scenario #2: If you have **2 point** to make an upgrade, how would you use it?

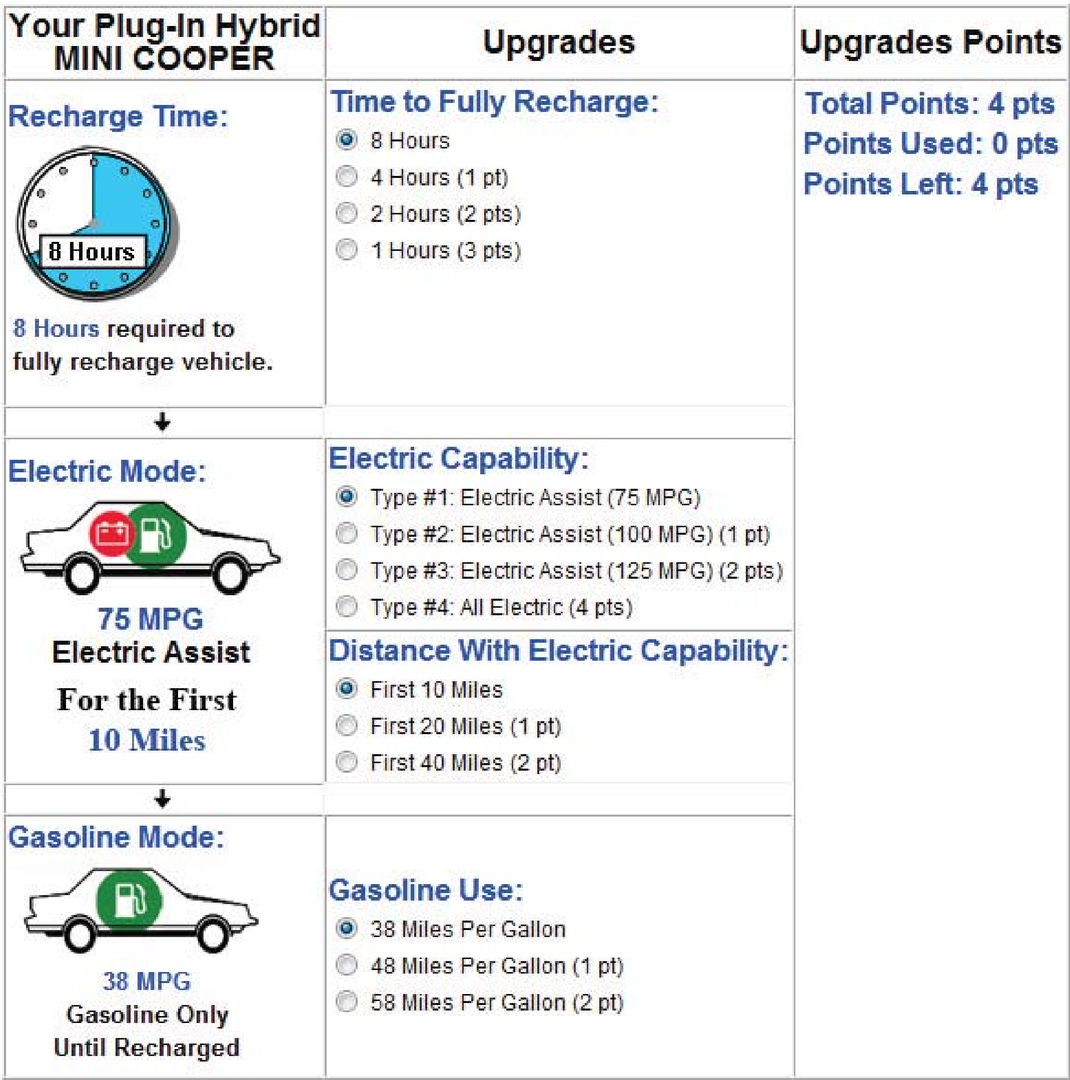
| Your Plug-In Hybrid MINI COOPER | Upgrades | Upgrades Points |
|---|---|---|
| **Recharge Time:**   8 Hours required to fully recharge vehicle. | **Time to Fully Recharge:**<br>◉ 8 Hours<br>○ 4 Hours (1 pt)<br>○ 2 Hours (2 pts) | **Total Points: 2 pts**<br>**Points Used: 0 pts**<br>**Points Left: 2 pts** |
| ↓ | | |
| **Electric Mode:**  75 MPG<br>**Electric Assist**<br>**For the First**<br>**10 Miles** | **Electric Capability:**<br>◉ Type #1: Electric Assist (75 MPG)<br>○ Type #2: Electric Assist (100 MPG) (1 pt)<br>○ Type #3: Electric Assist (125 MPG) (2 pts)<br>**Distance With Electric Capability:**<br>◉ First 10 Miles<br>○ First 20 Miles (1 pt)<br>○ First 40 Miles (2 pt) | |
| ↓ | | |
| **Gasoline Mode:**  38 MPG<br>Gasoline Only<br>Until Recharged | **Gasoline Use:**<br>◉ 38 Miles Per Gallon<br>○ 48 Miles Per Gallon (1 pt)<br>○ 58 Miles Per Gallon (2 pt) | |

**Description of Your Choice:**

The above vehicle takes **8 Hours** to recharge. When fully recharged, it can be driven for the **First 10 miles** in **Type #1: Electric Assist (75 MPG)** mode. After this distance, it can only be driven in gasoline mode until recharged, getting **58 Miles Per Gallon**

[This is My Choice]

**Scenario #3:** If you have **4 point** to make an upgrade, how would you use it?



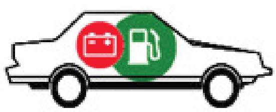
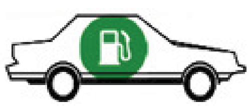
| Your Plug-In Hybrid MINI COOPER | Upgrades | Upgrades Points |
|---|---|---|
| Recharge Time: 8 Hours — 8 Hours required to fully recharge vehicle. | Time to Fully Recharge: (•) 8 Hours; ( ) 4 Hours (1 pt); ( ) 2 Hours (2 pts); ( ) 1 Hours (3 pts) | Total Points: 4 pts<br>Points Used: 0 pts<br>Points Left: 4 pts |
| Electric Mode: 75 MPG Electric Assist For the First 10 Miles | Electric Capability: (•) Type #1: Electric Assist (75 MPG); ( ) Type #2: Electric Assist (100 MPG) (1 pt); ( ) Type #3: Electric Assist (125 MPG) (2 pts); ( ) Type #4: All Electric (4 pts)<br>Distance With Electric Capability: (•) First 10 Miles; ( ) First 20 Miles (1 pt); ( ) First 40 Miles (2 pt) | |
| Gasoline Mode: 38 MPG Gasoline Only Until Recharged | Gasoline Use: (•) 38 Miles Per Gallon; ( ) 48 Miles Per Gallon (1 pt); ( ) 58 Miles Per Gallon (2 pt) | |

**Description of Your Choice:**

The above vehicle takes **8 Hours** to recharge. When fully recharged, it can be driven for the **First 10 miles** in **Type #4: All Electric** mode. After this distance, it can only be driven in gasoline mode until recharged, getting **38 Miles Per Gallon**

[This is My Choice]

# Scenario #4: If you have **6 point** to make an upgrade, how would you use it?

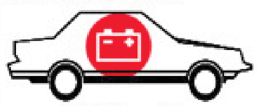
| Your Plug-In Hybrid MINI COOPER | Upgrades | Upgrades Points |
| --- | --- | --- |
| **Recharge Time:**   8 Hours required to fully recharge vehicle. | **Time to Fully Recharge:**<br>(selected) 8 Hours<br>4 Hours (1 pt)<br>2 Hours (2 pts)<br>1 Hours (3 pts) | **Total Points: 6 pts**<br>**Points Used: 0 pts**<br>**Points Left: 6 pts** |
| ↓ | | |
| **Electric Mode:**  75 MPG Electric Assist For the First 10 Miles | **Electric Capability:**<br>(selected) Type #1: Electric Assist (75 MPG)<br>Type #2: Electric Assist (100 MPG) (1 pt)<br>Type #3: Electric Assist (125 MPG) (2 pts)<br>Type #4: All Electric (4 pts)<br>**Distance With Electric Capability:**<br>(selected) First 10 Miles<br>First 20 Miles (1 pt)<br>First 40 Miles (2 pt) | |
| ↓ | | |
| **Gasoline Mode:**  38 MPG Gasoline Only Until Recharged | **Gasoline Use:**<br>(selected) 38 Miles Per Gallon<br>48 Miles Per Gallon (1 pt)<br>58 Miles Per Gallon (2 pt) | |

**Description of Your Choice:**

The above vehicle takes **8 Hours** to recharge. When fully recharged, it can be driven for the **First 40 miles** in **Type #4: All Electric** mode. After this distance, it can only be driven in gasoline mode until recharged, getting **38 Miles Per Gallon**

This is My Choice

# Scenario #5: If you have **8 point** to make an upgrade, how would you use it?

| Your Plug-In Hybrid MINI COOPER | Upgrades | Upgrades Points |
|---|---|---|
| **Recharge Time:**  4 Hours required to fully recharge vehicle. | **Time to Fully Recharge:**<br>○ 8 Hours<br>◉ 4 Hours (1 pt)<br>○ 2 Hours (2 pts)<br>○ 1 Hours (3 pts) | **Total Points: 8 pts**<br>**Points Used: 8pts**<br>**Points Left 0 pts** |
| ↓ | | |
| **Electric Mode:**  All Electric<br>For the First 40 Miles | **Electric Capability:**<br>○ Type #1: Electric Assist (75 MPG)<br>○ Type #2: Electric Assist (100 MPG) (1 pt)<br>○ Type #3: Electric Assist (125 MPG) (2 pts)<br>◉ Type #4: All Electric (4 pts)<br>**Distance With Electric Capability:**<br>○ First 10 Miles<br>○ First 20 Miles (1 pt)<br>◉ First 40 Miles (2 pt) | |
| ↓ | | |
| **Gasoline Mode:**  48 MPG<br>Gasoline Only<br>Until Recharged | **Gasoline Use:**<br>○ 38 Miles Per Gallon<br>◉ 48 Miles Per Gallon (1 pt)<br>○ 58 Miles Per Gallon (2 pt) | |

**Description of Your Choice:**

The above vehicle takes **4 Hours** to recharge. When fully recharged, it can be driven for the **First 40 miles** in **Type #4: All Electric** mode. After this distance, it can only be driven in gasoline mode until recharged, getting **48 Miles Per Gallon**

[This is My Choice]

## Section 4: Next Vehicle Purchase

This section will present a game to simulate your household's next new vehicle purchase. First, we ask several questions about your household's intentions.

1) Which of the following statements best summarizes your household's plans to purchase your next new vehicle?
*My household has...*

- ☐ ...already picked out our next vehicle
- ☐ ...discussed a few different vehicles models, but has not yet decided on one
- ☐ ...a rough idea of what vehicle to buy next, but has not yet looked around
- ☐ ...not yet thought about our next vehicle

2) How soon do you believe your household will buy or lease its next new vehicle?

- ☐ Within the next 6 months
- ☐ Between 6 months and 1 years from now
- ☐ Between 1 and 2 years from now
- ☐ Between 2 and 5 years from now
- ☐ More than 5 years from now
- ☐ We have no idea.

3) Which of the following best describes your next vehicle purchase?
*The next vehicle my household purchases will...*

- ☐ ...replace the **MINI COOPER**
- ☐ ...replace another vehicle
- ☐ ...not replace any vehicle, but will be an addition
- ☐ We have no idea.

4) When your household buys or leases its next new vehicle, which of the following descriptions best describes the vehicle type you will likely choose?

- [ ] Compact car
- [ ] Midsize Car
- [ ] Large Car
- [ ] Small SUV
- [ ] Midsize SUV
- [ ] Large SUV
- [ ] Minivan
- [ ] Cargo van
- [ ] Small pickup truck
- [ ] Large pickup truck
- [ ] We have no idea

Next

5) For this last section, we will refer to the type of vehicle your household will likely buy or lease next. Please select a make and model that best describes your next vehicle. If you are unsure, you can simply select your current vehicle (**MINI COOPER**).

- [ ] I choose **MINI COOPER**
- [x] I would like to select another vehicle. Please specify Make and Model:

**Example:** **Make = Honda**
**Model = Accord**

Make: Make ▾

Model: Model ▾

- [ ] Click here if your vehicle isn't listed above.

Next

From here on, we assume that your household's next vehicle purchase will be a new **FORD MUSTANG**.

6) About how much do you think your household will spend to buy this **FORD MUSTANG**?

- ☐ $27000 - About the base cost of a **FORD MUSTANG**
- ☐ Another value - Please Specify: Thousand

7) What do you think will be the approximate fuel economy (Miles Per Gallon - MPG) of this **FORD MUSTANG** you will buy?
*Choose a value that is the average of city/highway driving.*
*(Remember, a higher MPG means you required less fuel to drive a given distance.)*

- ☐ 21 MPG - About average for a new truck
- ☐ 27 MPG - About average for a new car
- ☐ 28 MPG - About average for your basic **MINI COOPER**
- ☐ 25 MPG - About average for brand new 2007 basic **FORD MUSTANG**
- ☐ Another value - Please Specify: ☐ MPG

Next

You will be shown 3 scenarios. Each scenario you will show you different prices for the plug-in hybrid options and upgrades. Each scenario is independent, so you can choose different vehicles or upgrades each time.

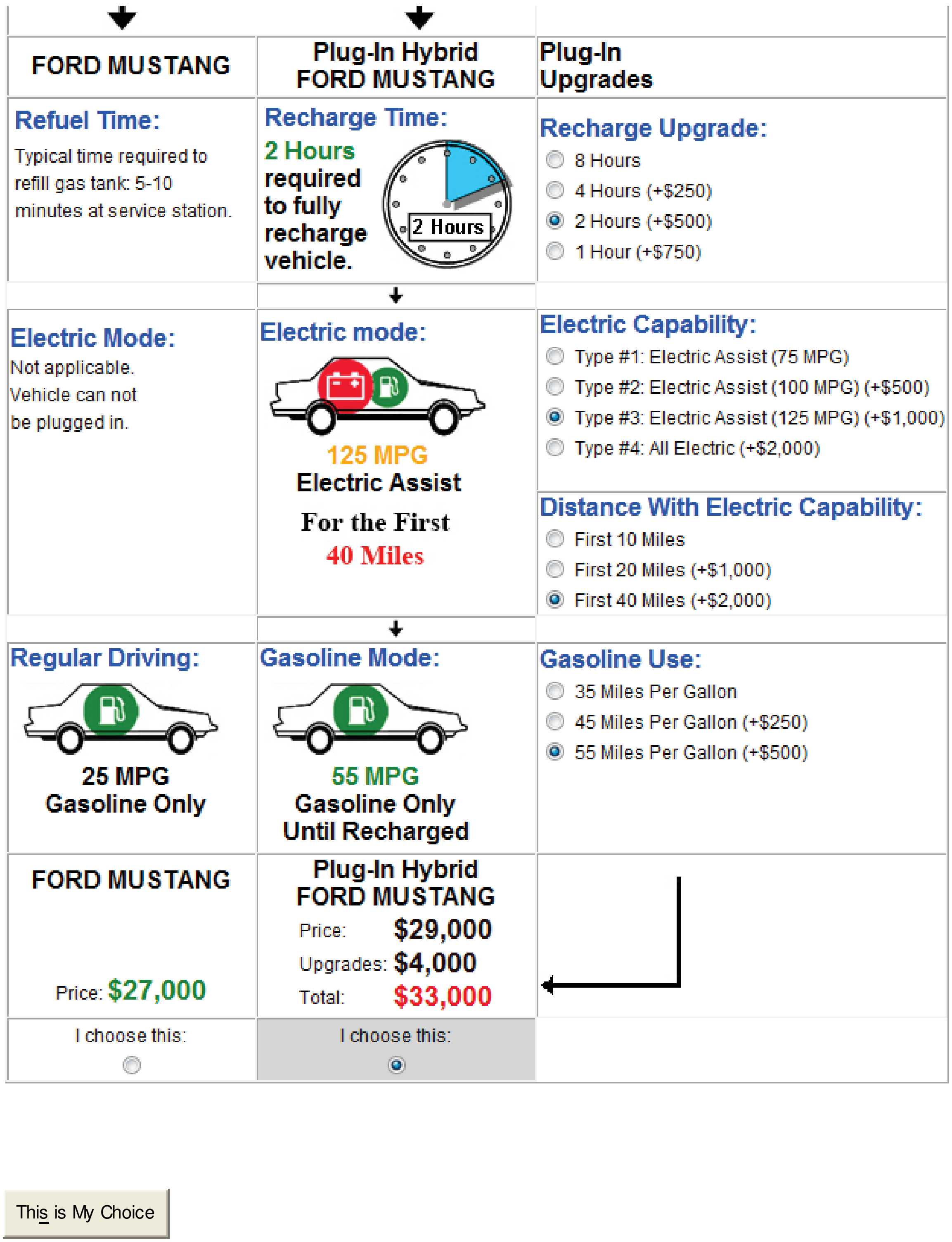
You can customize the specific features of the plug-in version, just as you did in the previous exercise. Again, refer to ***Your Plug-In Vehicle Guide*** for help in choosing upgrades, particularly the summary on **pages 7 to 8**.

Given the two options below, which would your household likely purchase?

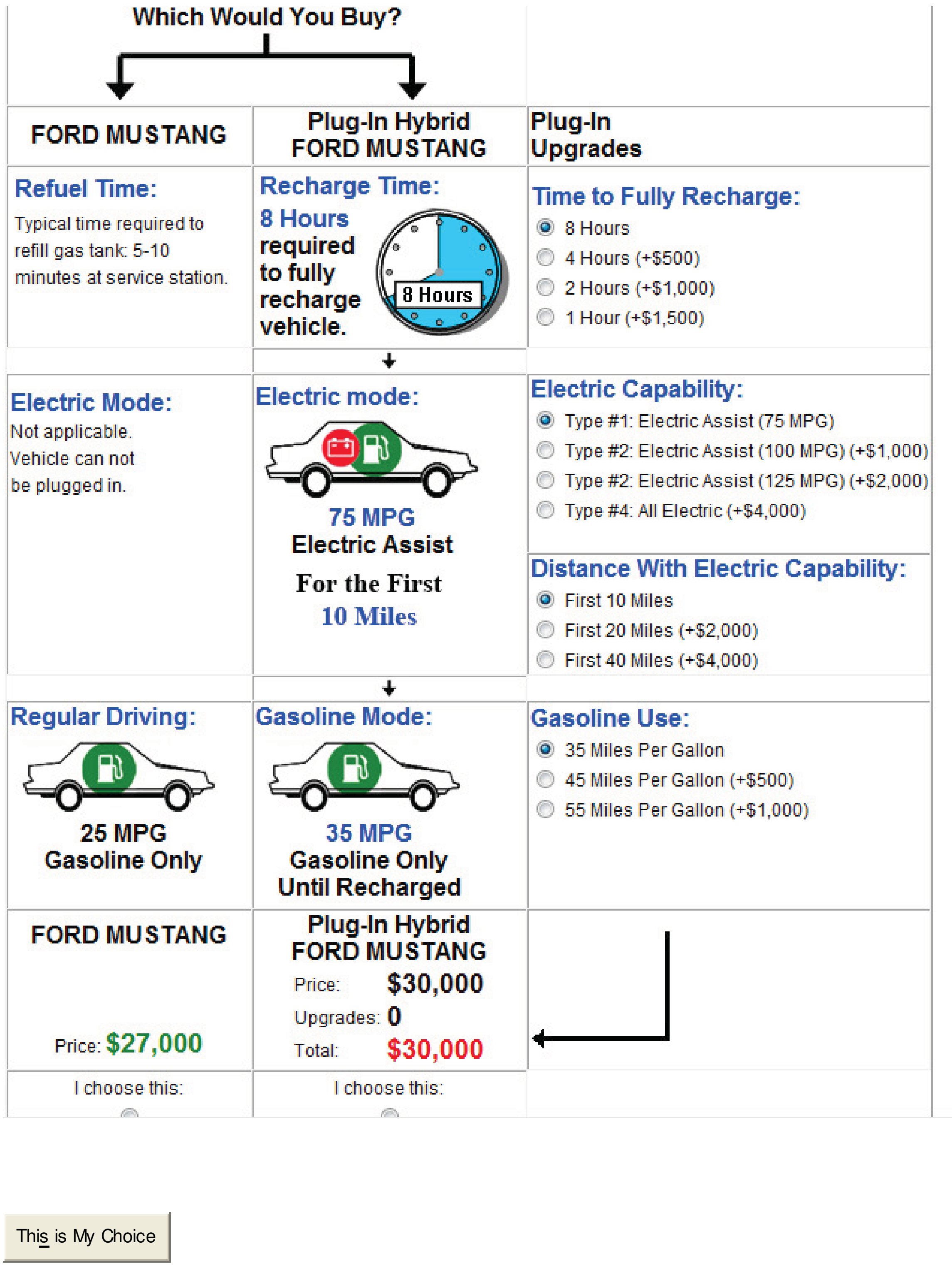
Other than the price, the plug-in feature, and fuel consumption, every other characteristic of the two vehicles are identical. In other words, the plug-in version of the **FORD MUSTANG** has the same body, performance, interior size, etc. as the regular **FORD MUSTANG**.

*Please be realistic, and consider your expected household budget constraints*

Price Scenario #1 (Low Cost Scenario – Order Randomized)



Price Scenario #2 (Medium Cost Scenario – Order Randomized)



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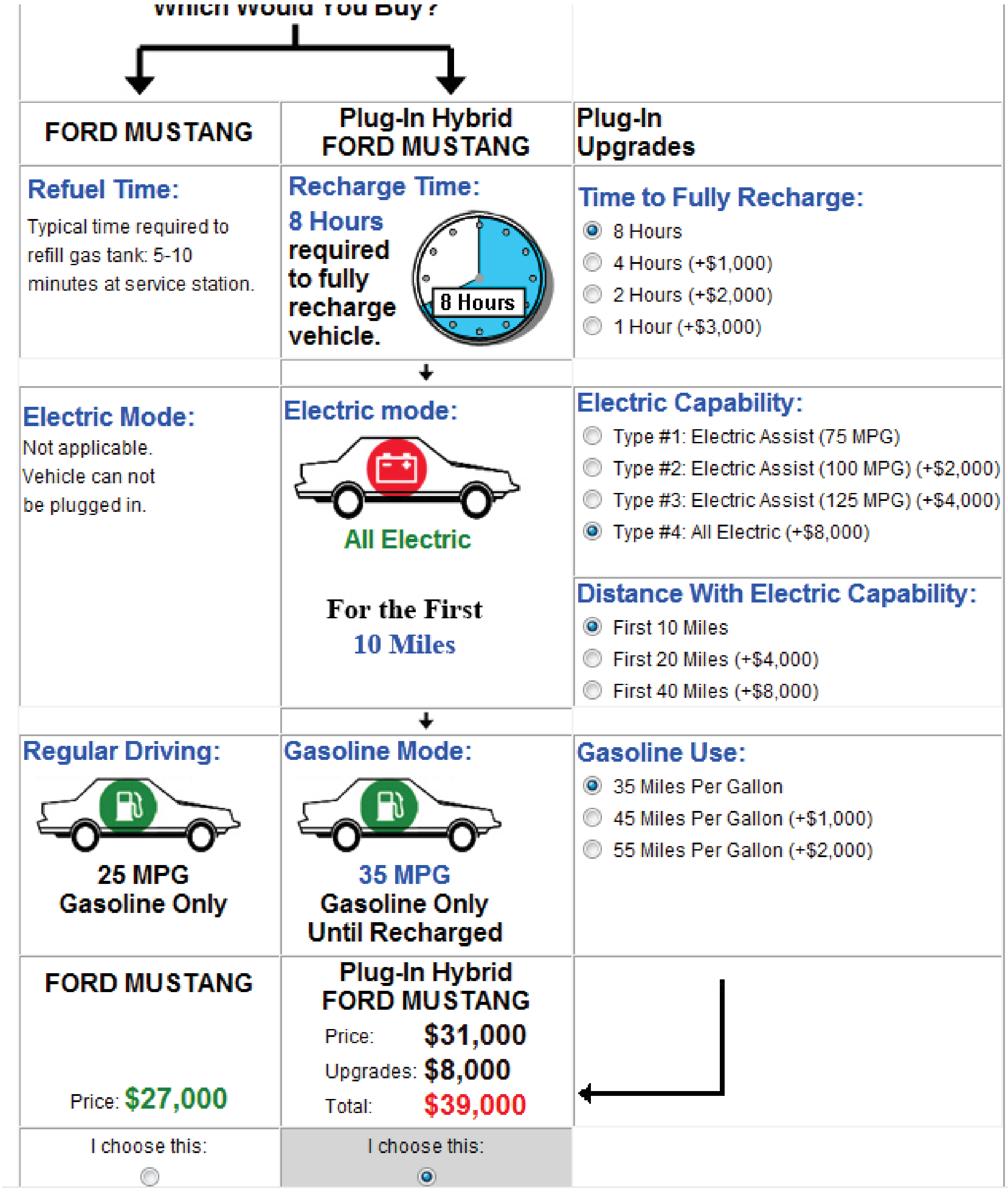
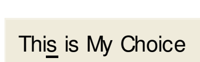


## APPENDIX D: CALIFORNIA AND NORTHERN CALIFORNIA SURVEY OVER-SAMPLES' PHEV DESIGNS

**Figure D1: Upgrades selected in PHEV design games by California *plausible early market* only, n=286**

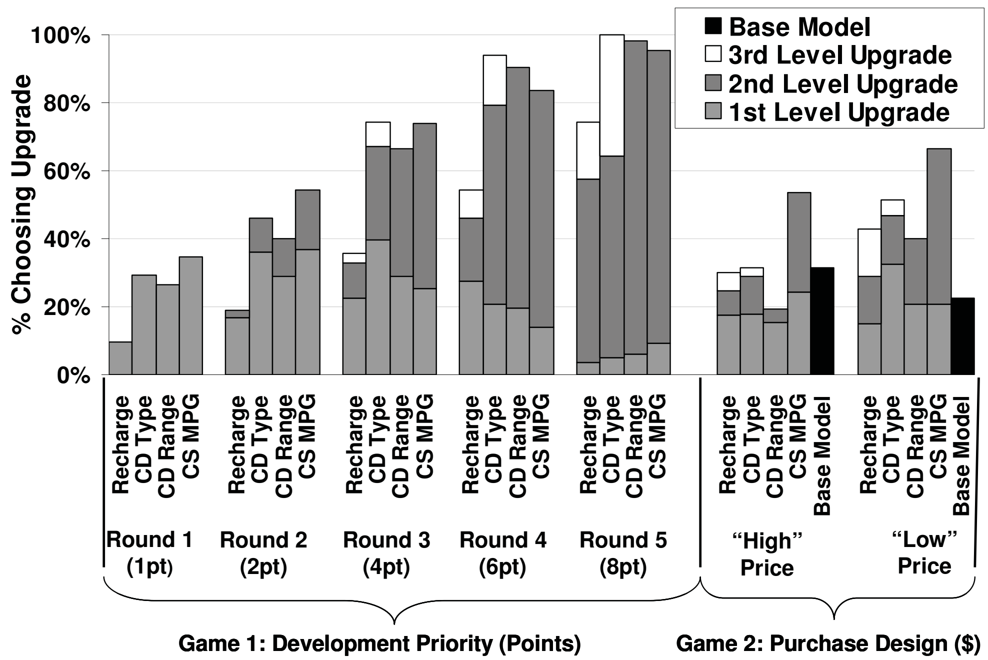
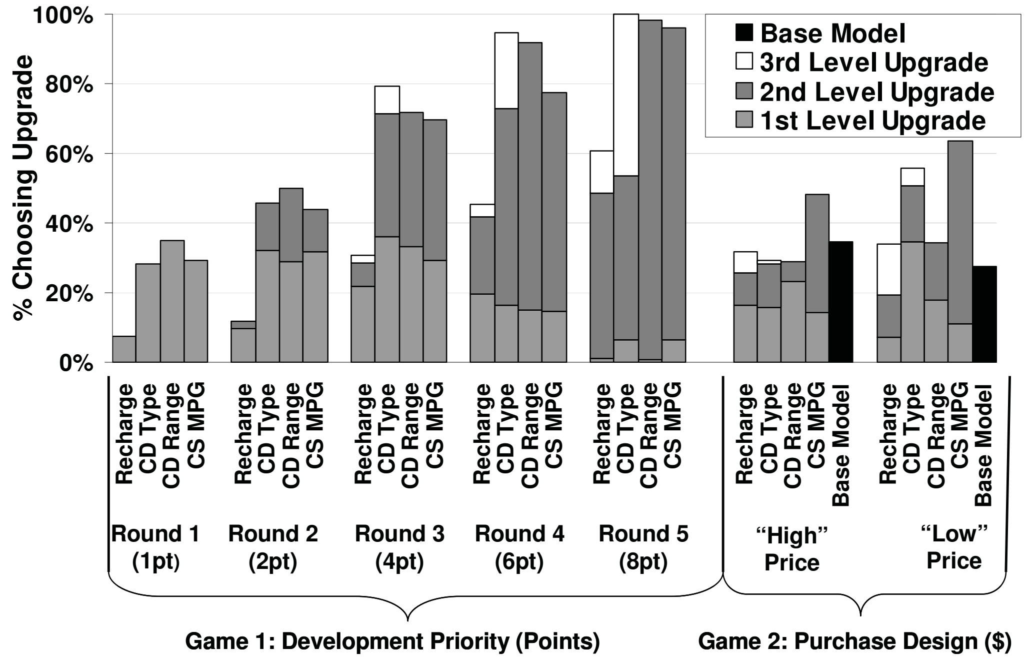
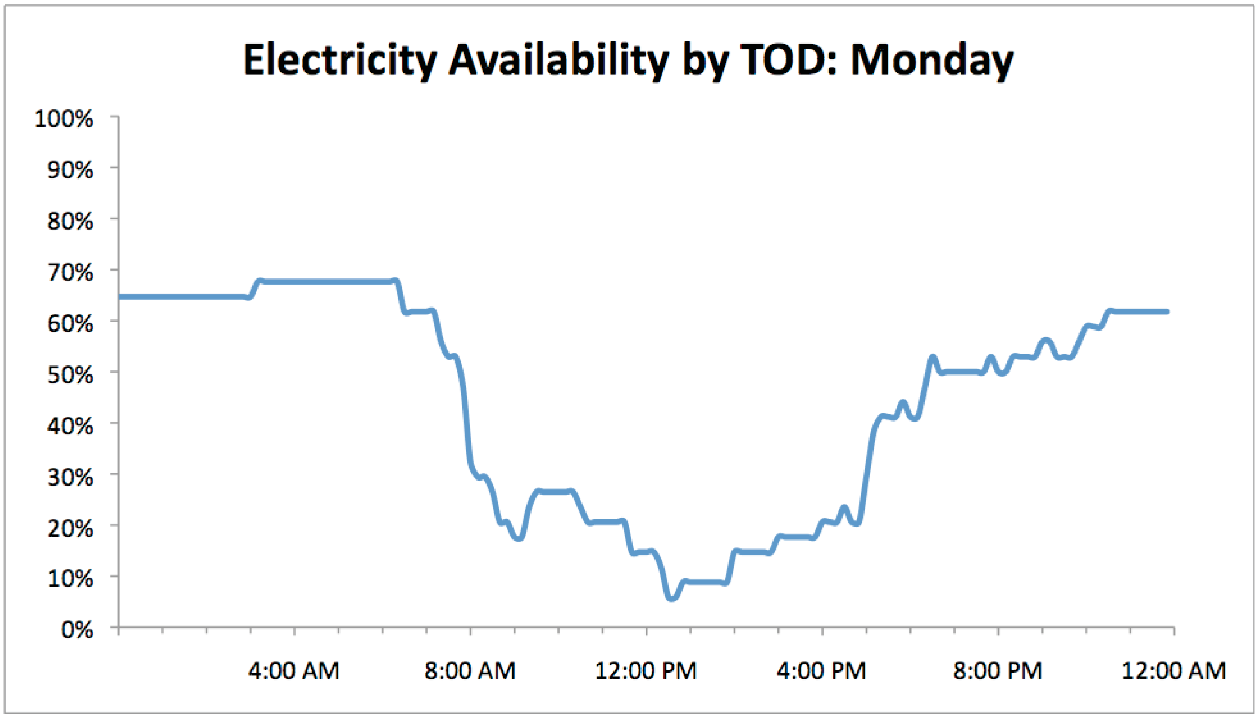


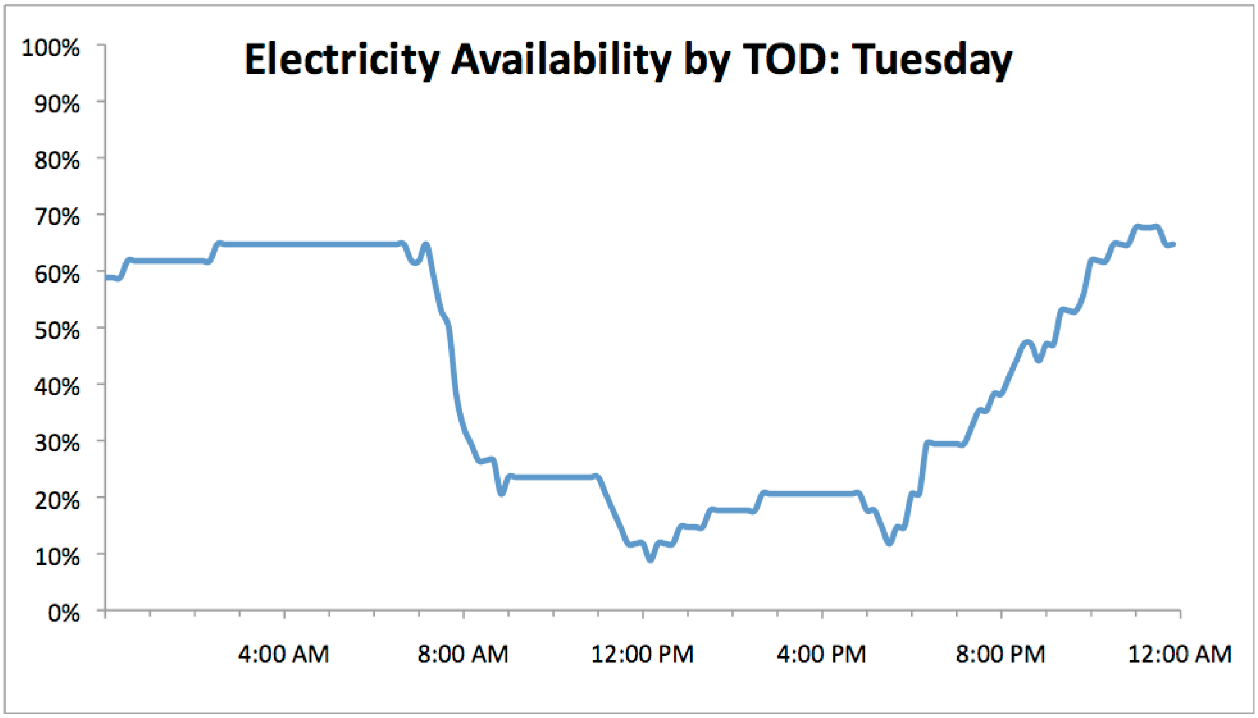
**Figure D2: Upgrades selected in PHEV design games by northern California *plausible early market* only, n=63)**

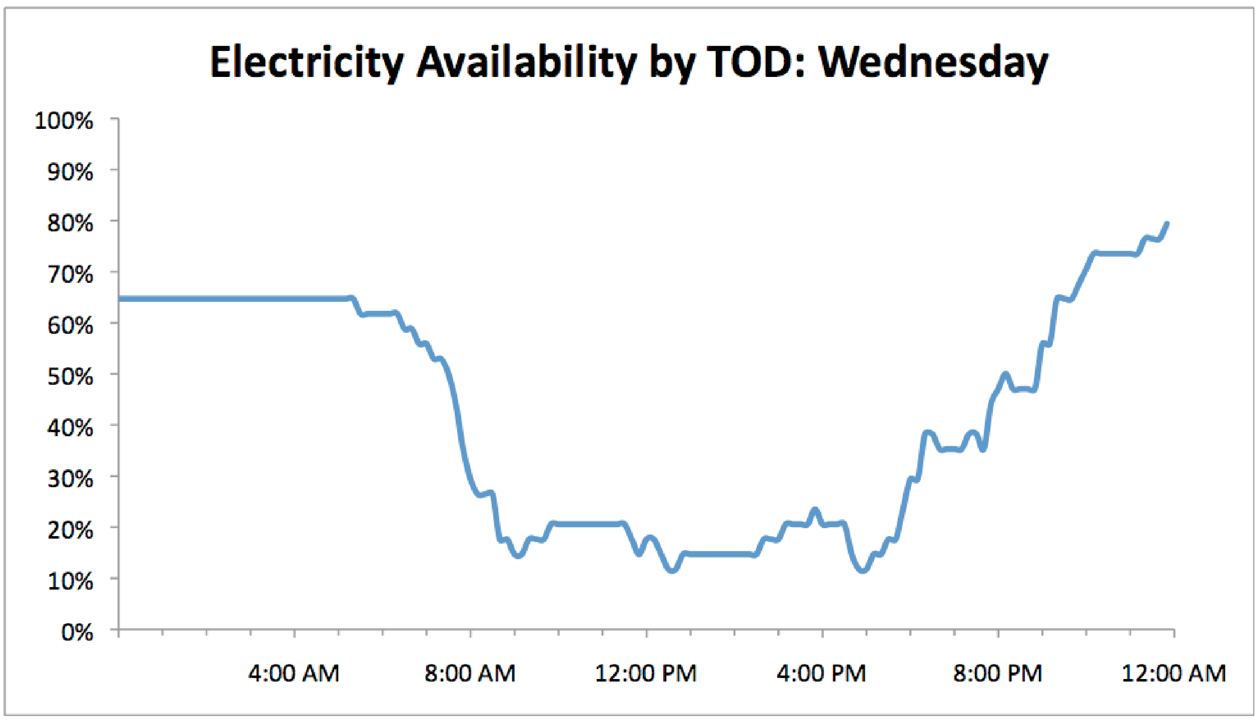


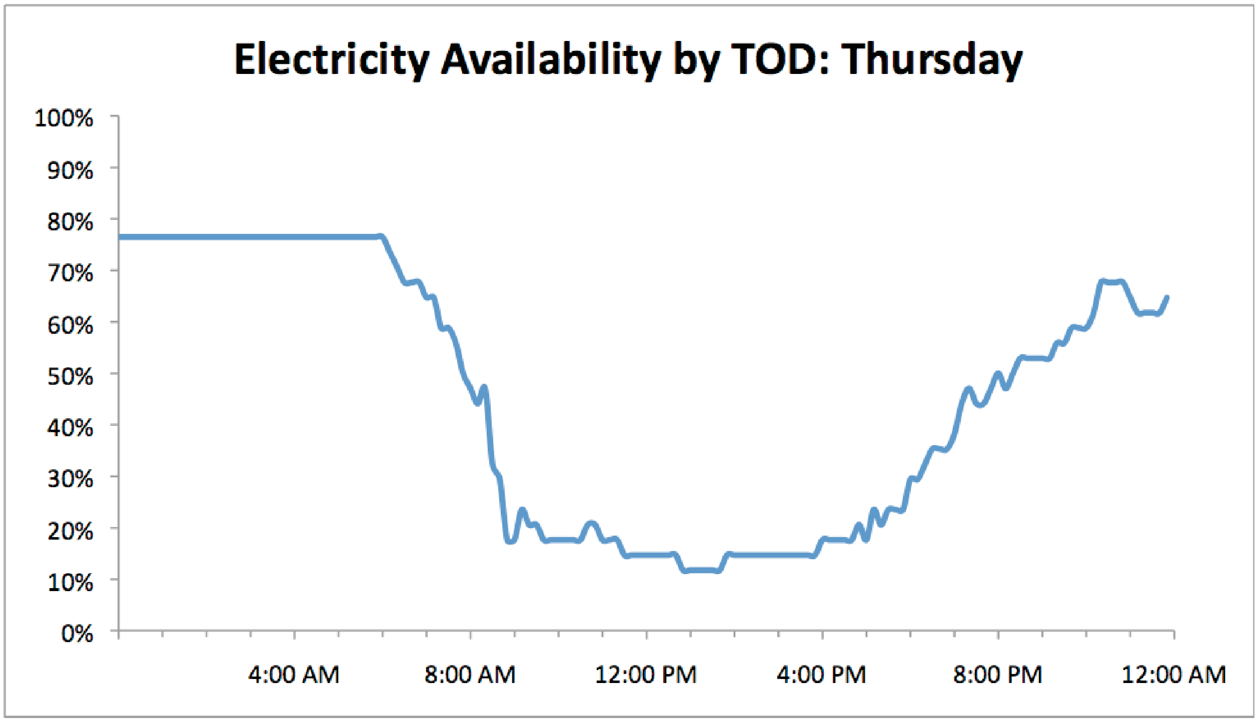
## APPENDIX E: PHEV PROJECT HOUSEHOLDS' ELECTRICITY AVAILABILITY AND INSTANTANEOUS POWER DEMAND, DAILY

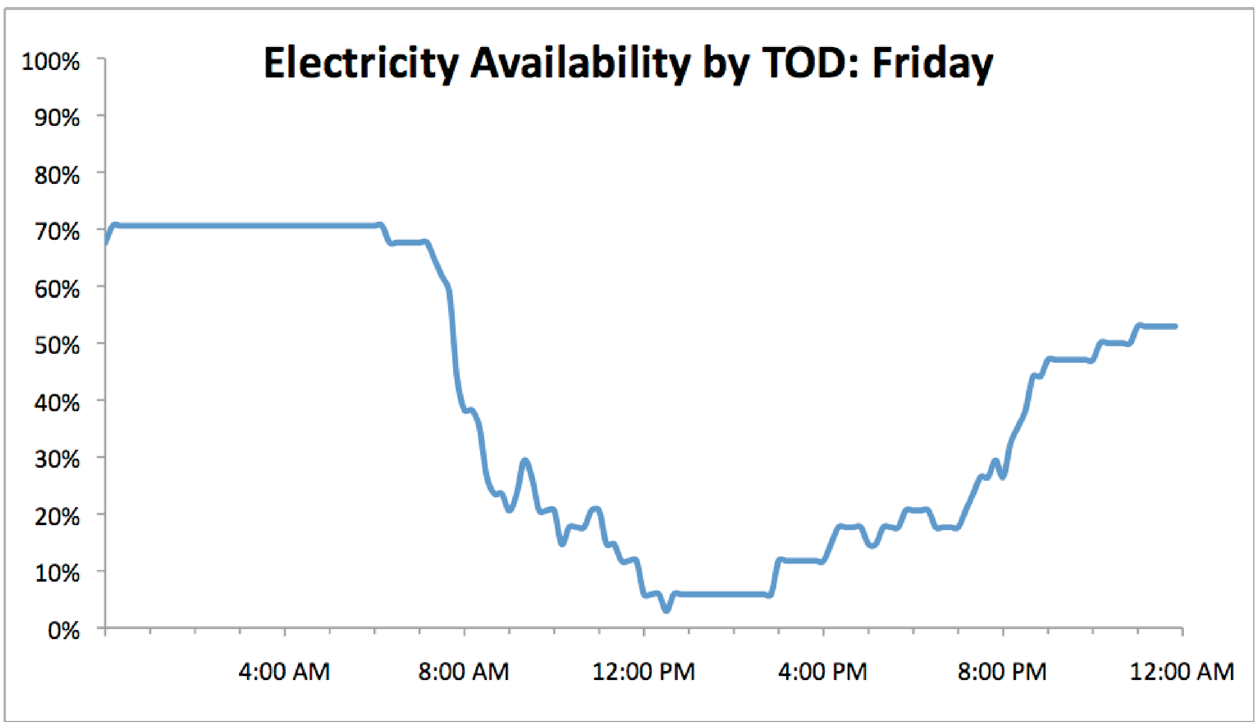
### Electricity Availability, Percent of PHEVs Plugged-in throughout each Day of the Week

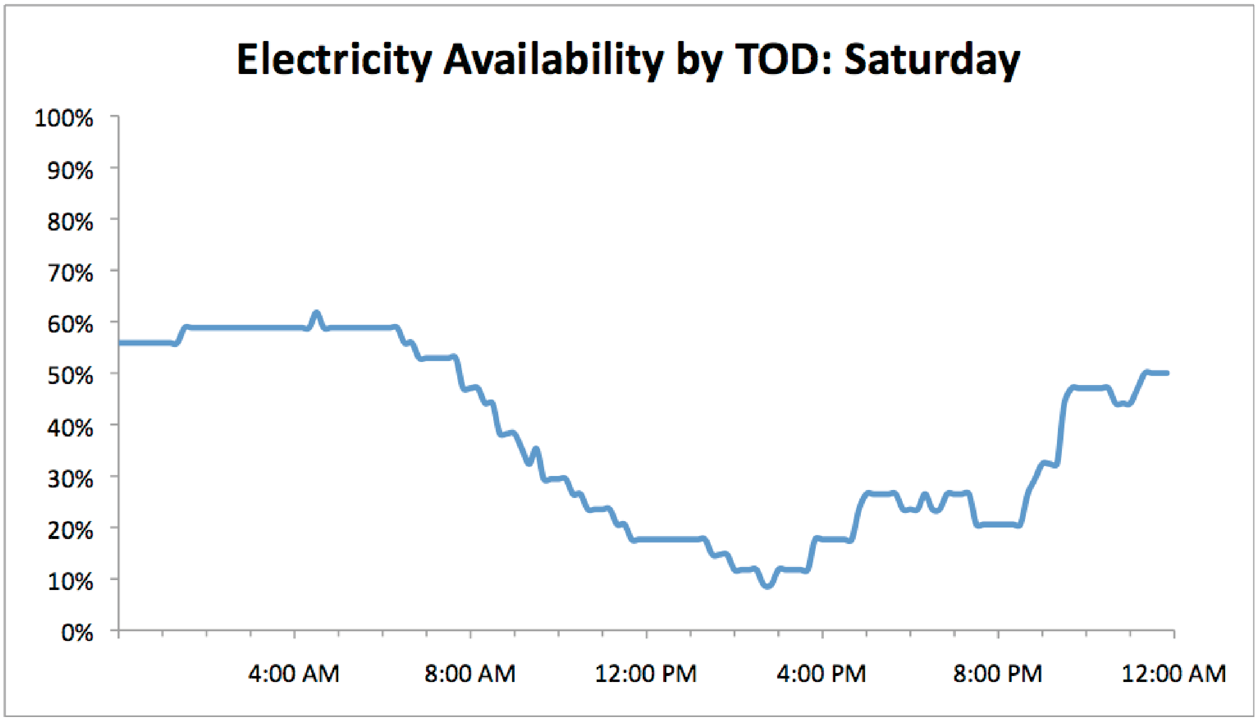


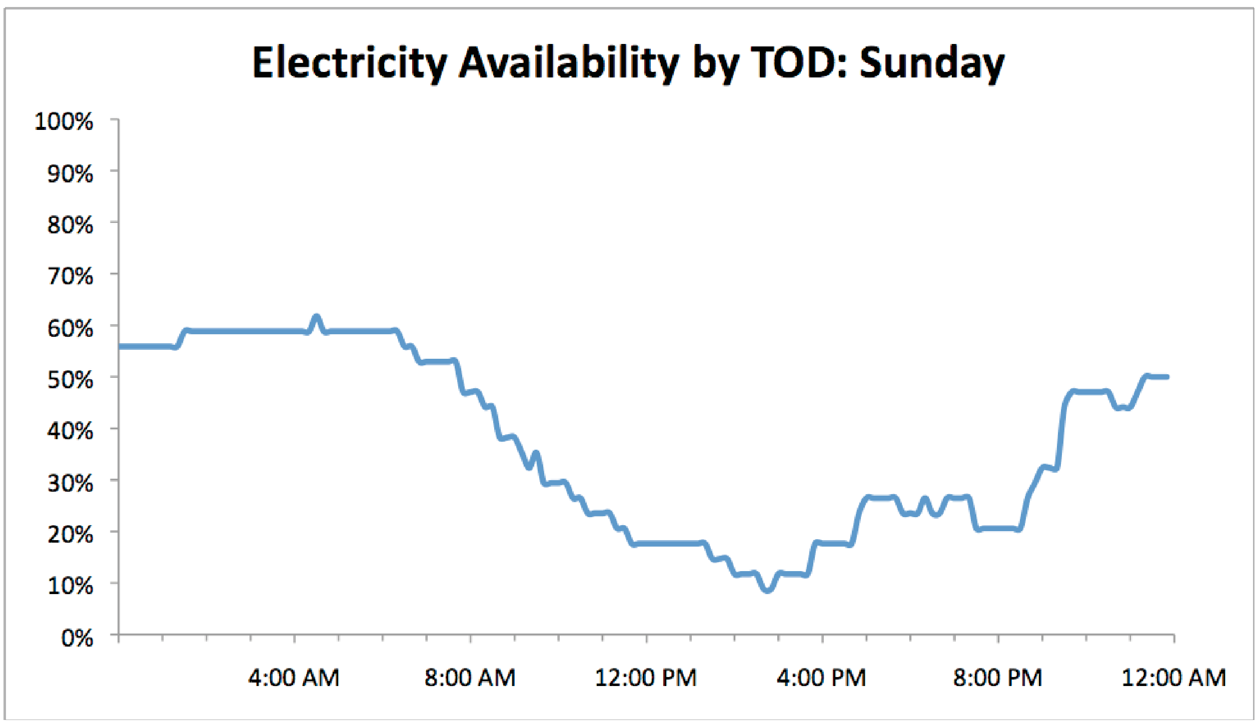

Electricity Availability by TOD: Tuesday
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
12:00 AM


Electricity Availability by TOD: Wednesday
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
12:00 AM

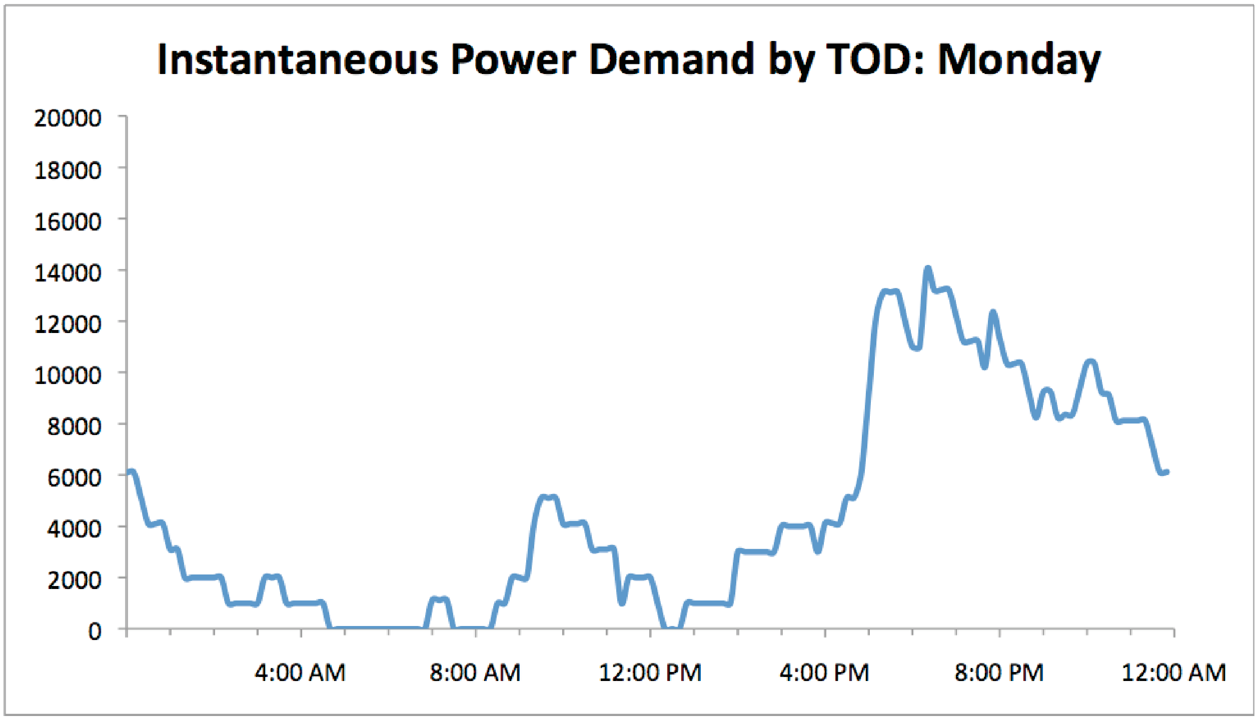

Electricity Availability by TOD: Thursday
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
12:00 AM

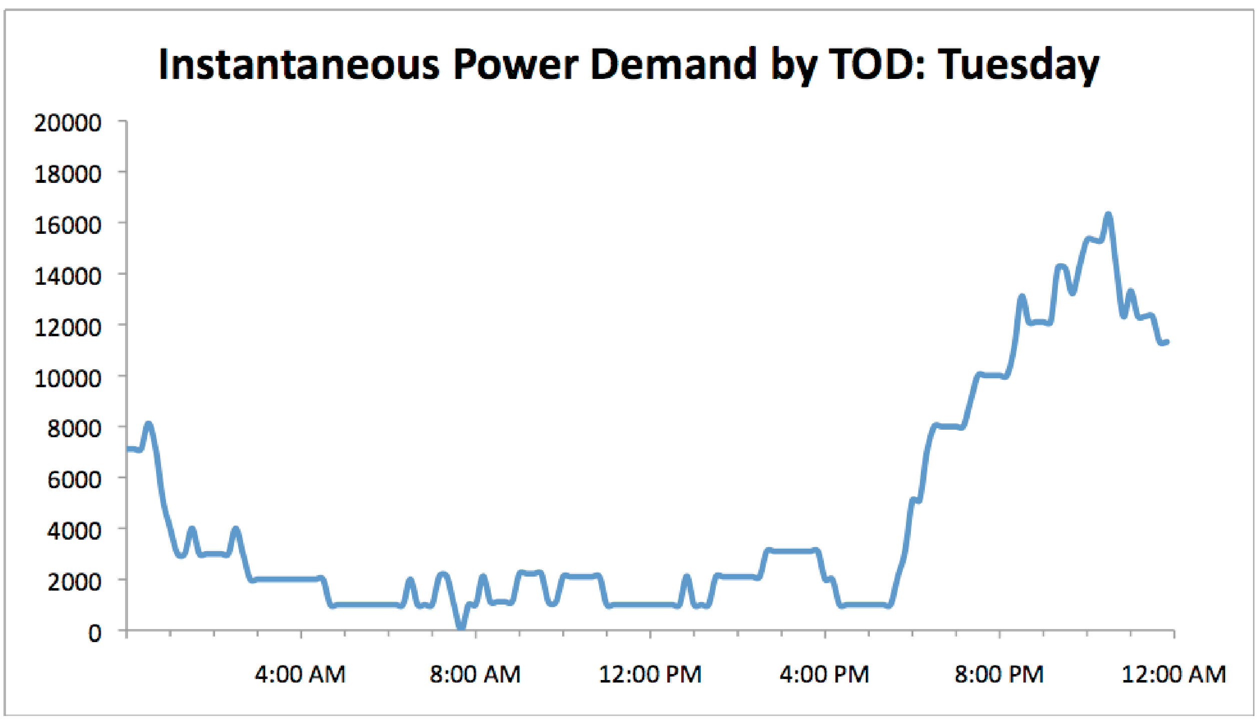

Electricity Availability by TOD: Friday
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
12:00 AM

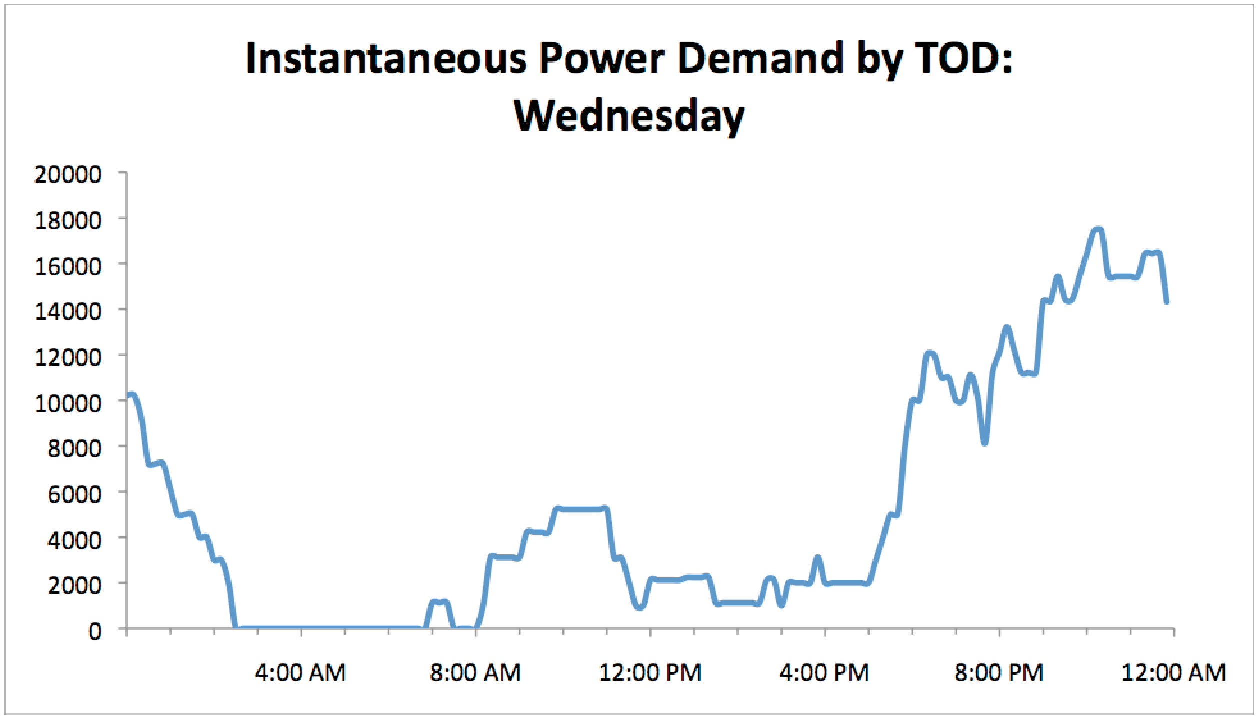

Electricity Availability by TOD: Saturday
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
12:00 AM

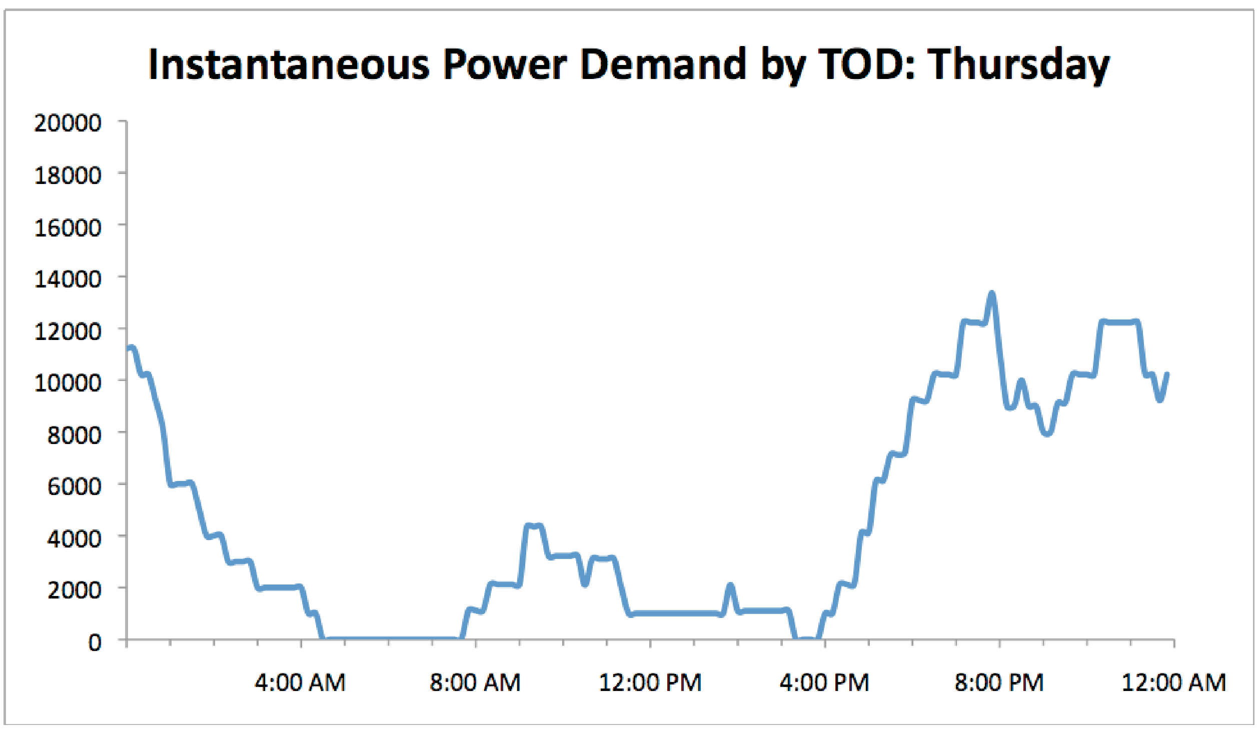

Electricity Availability by TOD: Sunday
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
12:00 AM

**Instantaneous Power Demand Summed for all Households, Watts**




Instantaneous Power Demand by TOD: Wednesday
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
12:00 AM


Instantaneous Power Demand by TOD: Thursday
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
4:00 AM
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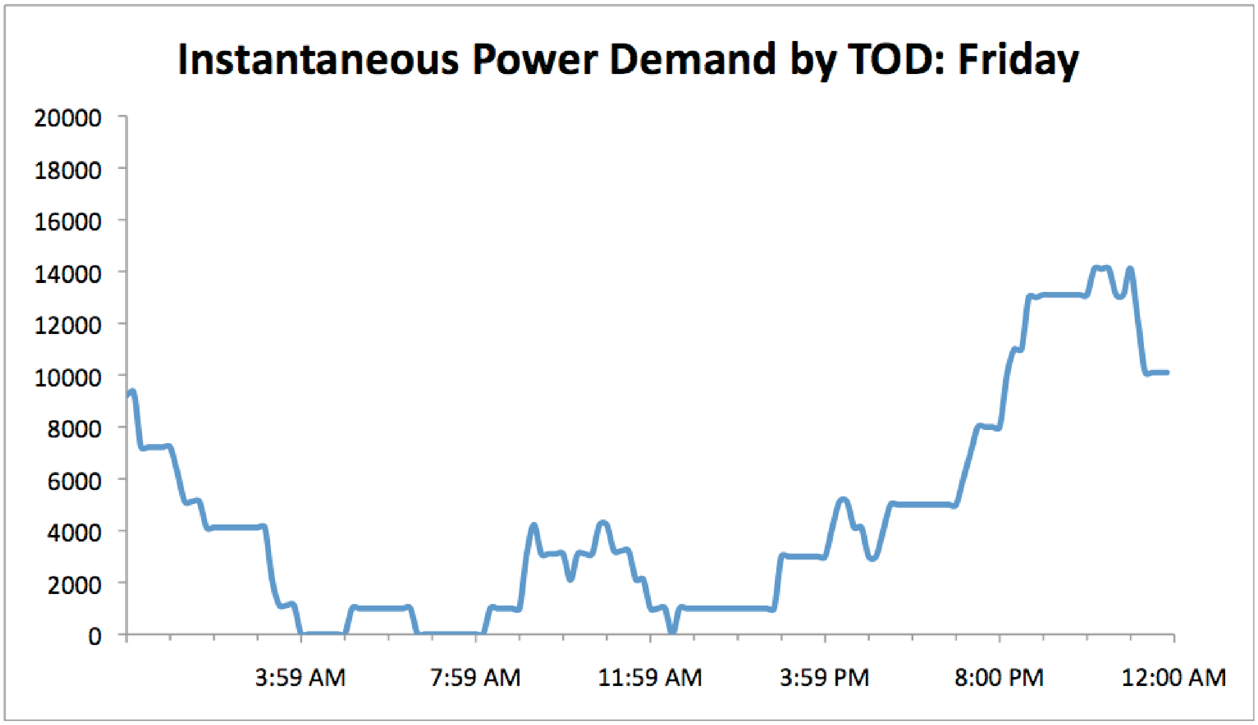
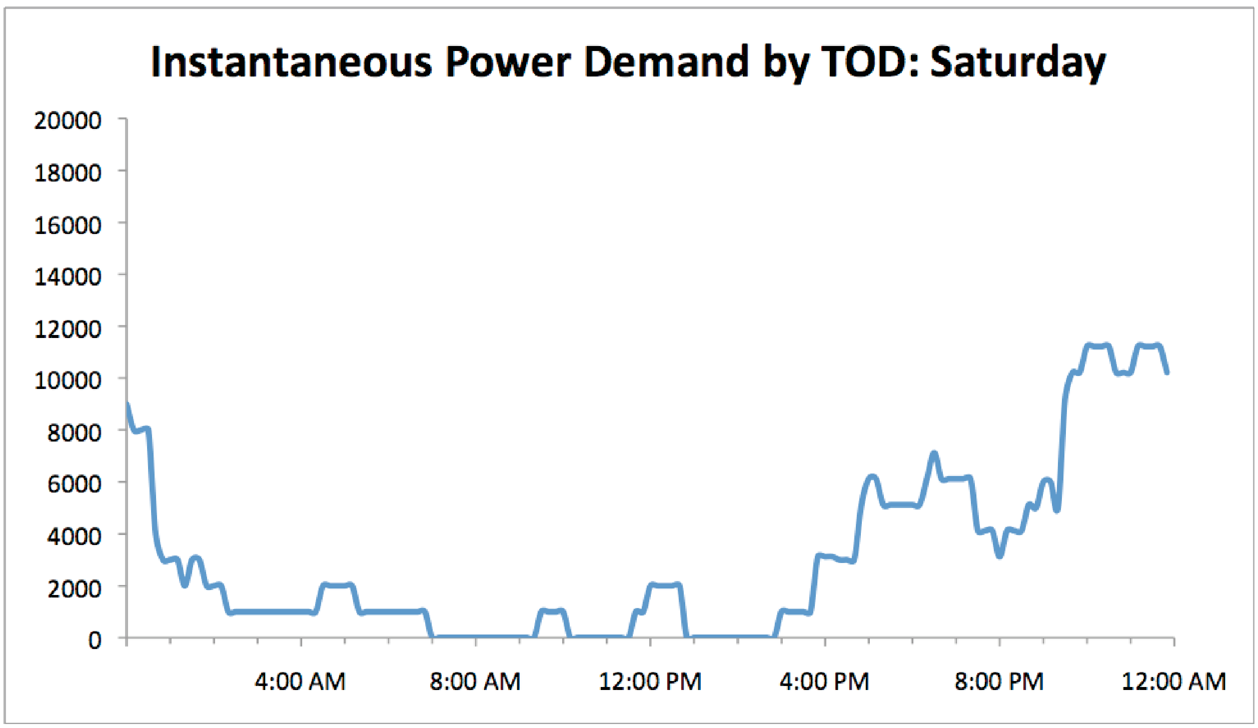
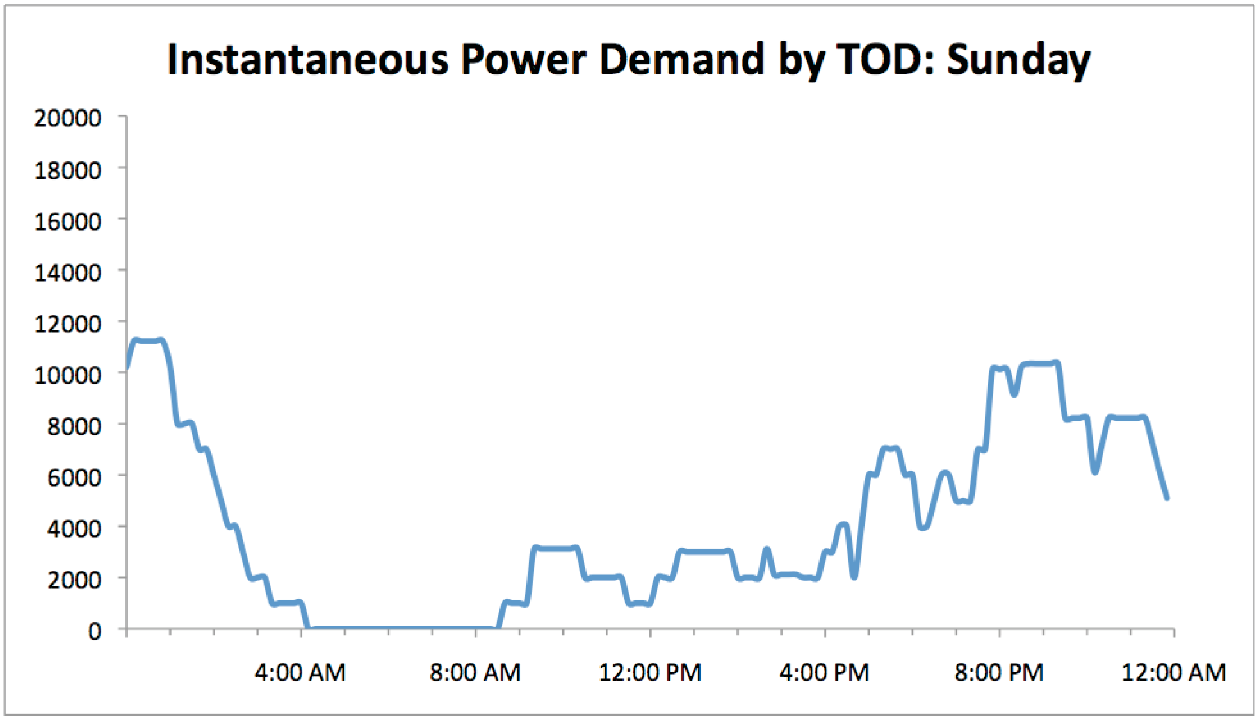
4:00 PM
8:00 PM
12:00 AM


Instantaneous Power Demand by TOD: Friday
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
3:59 AM
7:59 AM
11:59 AM
3:59 PM
8:00 PM
12:00 AM


Instantaneous Power Demand by TOD: Saturday
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
12:00 AM



Instantaneous Power Demand by TOD: Sunday
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
4:00 AM
8:00 AM
12:00 PM
4:00 PM
8:00 PM
12:00 AM

# Appendix F: Three PHEV Project Households' Narratives

## 1. Rick and Samantha Lake

### *Summary Paraphrases:*

Rick: "A PHEV has to payback to be worth it, but I'll kick in an extra 10% premium to do my part—to reduce environmental damage for the next generation. I am most excited about the idea of a PHEV that lets me commute without turning on the engine at all—as little as 10 miles of range would do because I would find a way to plug in at work."

Samantha: "The increased fuel economy sounds good—to save money and contribute to the solution of global resource problems. But we are not willing to compromise much on functionality—the vehicle would have to fit into our family's lifestyle, such as storing groceries and allowing long road trips."

Young son: "Will this car save the earth?"

### *The Beginning*

Rick and Samantha Lake are married and in their early 40's. They live in a large house in a gated community and the living room and kitchen are filled with toys for their two boys, aged four and eight (who played video games in the same room as us during all three interviews). Rick works in financial services, while Samantha is currently devoted to looking after the kids and running the household—their reported household income is over $150,000. They own two cars: a 2002 Honda Accord—which they temporarily replaced with the PHEV—and a 2004 Honda Odyssey. Rick primarily uses the Accord for work-related trips, while Samantha uses the Odyssey for running errands with the kids. It is also for family road trips.

Prior to their PHEV trial, Rick and Samantha were fairly familiar with electric-drive vehicles. They knew neighbors that drove neighborhood EVs, such as the GEM, which Rick described as: "like a big golf cart…novel…but it doesn't go very fast, like 35 or 45 miles per hour…they must live near by [their destination]," but overall "not very practical." Samantha perceived that increasingly more neighbors with longer commutes were buying Priuses as commute cars—hybrids were "fairly popular in the gate." Rick had been in a Honda Civic Hybrid before; he laughed about an incident when a co-worker drove him in a company-owned HEV, and the co-worker thought the vehicle had "died" when the engine turned off at a stop light and tried to "start cranking it." Although they were initially unclear about the functions and abilities of PHEV technology, Rick had seen a news clip highlighting the UC Davis PHEV Center on the local cable channel, where Center Director Tom Turrentine showed off the battery of a PHEV conversion. Rick recalled the statement that a driver could get 100 mpg for the first 40 miles—so he was "shooting for 100 mpg" during the trial.

Rick recalled being excited when he received the invitation letter for the PHEV study. He noted that it coincided with a project he was engaged in at work—a training program on "going green," where he was focusing on green buildings, and he looked forward to sharing insights with his group (during the trial, he repeatedly asked for PHEV pamphlets, and tried to arrange a photo opportunity with the PHEV Center's vehicle that prominently displays that it is a PHEV). They anticipated Rick would do most of the driving because they were replacing his car—which he stored at his mother's house for the duration of their trial. The Lakes did not ask very many technical questions at the drop-off meeting, but they were curious about how often they should plug the vehicle in. All four family members took part in the test drive, during which the eight-year old boy asked: "will this car save the earth?" (Samantha noted that he was in an environmental club or program at his school.)

### *The Overall Driving Experience*

Overall, the Lakes enjoyed driving the PHEV. Rick was the main driver, using it for his 19-mile roundtrip commute and other work-related trips. Rick stated that it "took a day or two to get used to," but after that it proved to be a "nice, smooth little car" that was "very practical" and "handled pretty well." He said that "for a day-to-day commute, its great" and it fit into their lifestyle "fairly seamlessly." He "was expecting high mileage, and it delivered." Rick's assessment of the PHEV was at least partially related to his perceptions of pure EVs: “for me it was the combination of having the gas and electric assist—it made it easier to integrate into our life than pure electric, because it had that gas component you never really worried. If it was just electric...you’d have to plan out your route more, make sure there is a cord somewhere to charge it…but because it had that gas component it was fairly seamless, aside from plugging-in at night.” Rick was critical of certain specific features: he found the provided 50 foot electrical cord to be awkwardly long (he just kept it in his garage), and immediately removed the spare tire to maximize their cargo space. He was also frustrated that the engine would come on even during short trips: when “its burning gas, and I don’t need it…just half a mile…why doesn’t it just run on electricity?”

Samantha drove at most once per week, running errands such as taking the kids to school—no more than 5 or 6 days during the trial. Like Rick, she took some time to get used to the PHEV; she attributed initial awkwardness to the general differences between Toyotas and Hondas (“all Hondas are the same”), as well as getting used to the keyless system. Overall, she also liked her experience with the vehicle, noting that it was “peppy.” She also compared it to a pure EV, noting that she liked “knowing that I have a full tank there…I know I’m not going to run out…(with an EV) I’d be looking to see how far I can go…and if can I plug in once I’m there…with this (PHEV) we think we can go pretty much anywhere and be okay.” She stated that the kids were also happy with it—“maybe the novelty of a new thing”—and would often say “let’s take the electric car today” instead of the minivan. Samantha noted that the PHEV would not likely work for the longer distance road trips they normally took every couple of months (but not during the trial), such as trips to LA, during which they would “pile in a week or 10 days worth of stuff,” summarizing that “a road trip is easier with a bigger car.”

The Lakes agreed that, in general, their driving behavior during the trial was fairly representative of their typical patterns. After several minutes of discussion between them, they concluded that the first two weeks were more typical of the distance and types of trips they would make, as well as the split between Rick and Samantha as driver, while the latter two weeks were more representative of the fuel economy they would likely achieve in the long run (where Rick paid less attention to the energy instrumentation, etc.—more on this below).

### *Recharging*

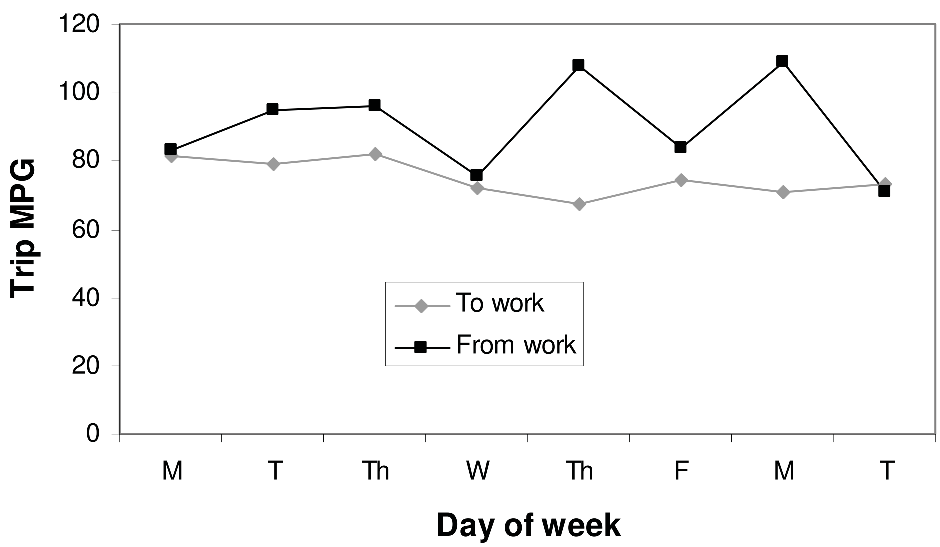
Rick recharged the PHEV at home very regularly, plugging it in every night and unplugging it every morning, and sometimes plugging it in again during the afternoon between trips. Samantha stated that recharging took a little getting used to, where on the first day she noticed that Rick almost drove away without unplugging the cord ("…after that we always remembered"). In the interest of further simplifying the recharge process, they both envisioned a vehicle with a retractable cord. For home recharging, they had a general idea that electricity would be cheaper at night, but were not sure when or how much, and did not plan around this. Rick simply recalled reading about rate differences on a website, and Samantha thought the difference might start at 8 or 9pm (she recalled a suggestion that laundry loads would be cheaper after this time).

The Lakes did not recharge at another location during the trial. Rick described why his workplace wouldn't work: "I started looking for plugs everywhere…where [the electrical outlet] was situated it would be a hazard…between two banks of elevators…that's not going to work…to make it more viable to plug in the employers would have to get in on the act…to have outlets." He felt he might get sued if someone tripped over it, so the risk was not worth it. Rick did notice "EV-only" parking spots at some locations, such as the library and mall, but he wasn't sure if he was allowed to use it. Samantha added that it was just easier to plug-in at home anyway.

### *Energy Use and Instrumentation*

Rick described a shift in his use of the PHEV over the course of the trial: "it was a novelty at the beginning…I was babying it a lot…now I just drive it normal." At first he liked to monitor how he as "doing" by watching his mpg as well as the Energy Monitor diagram to see if the battery was being used. He would experiment with different behaviors: "I'd gas it and watch it…put my foot of the throttle and watch it…I'm probably a dangerous driver…out of curiosity to see how my actions affected things…air conditioner, not air conditioner." He said it was this "curiosity" that led him to watch the instruments "more than [he] should." Rick was also motivated by his goal of achieving 100 mpg or higher: "…but I didn't quite get there…for a trip I never got close…oh no, I take that back, I did hit it once. If I look at the travel log (V2Green website) there are actually a few days where I hit 100…I was coasting a lot." (Indeed, according to V2Green, about two weeks into the trial he did achieve ~108 mpg during two 9.8 mile trips from work to home. Otherwise, his to-work mileage ranged from 68 to 82 mpg—generally decreasing over the trial—and his from-work mileage was typically higher for a given day by 2 to 15 mpg. Figure 1 illustrates these patterns.)

**Figure 1: Rick Lake's ~10 mile (one-way) commute (gasoline-only) mpg over their PHEV trial**




In contrast to Rick's initial focus on the energy-use instrumentation, Samantha stated: "I'm the opposite: oblivious…just driving…I pay attention to the road mainly." She reasons that because she is driving fast she has "got to pay attention," and thinks that Rick looks at the screen too much. She figures that, after all, the PHEV "was gonna do what it was gonna do." As Rick talked about trying to achieve 99.9 mpg on the highway, Samantha added, "People are honking at you."

Once the Lakes were given access to V2Green, Rick made regular use of the website, and seemed to integrate the provided information into his assessment of the vehicle. At the midterm interview, prior to access to V2Green, he was highly uncertain about his overall fuel economy—he guessed somewhere between 50 and 100 mpg ("99.9 half the time, and 50 otherwise"). However, he noted he had not yet had the chance to make a more precise estimate because he hadn't refueled the PHEV, and he normally calculated fuel economy when he fuels up his cars ("just out of general interest," according to the survey). After getting V2Green access, he would regularly scan the website at work (the kids were too distracting at home). He says he looked at everything, but found the mpg most useful—the rest was "gee-whiz" information, such as the duration of recharge episodes, distances driven, and kWh used. While he claims not to have used the website to change his driving habits, he feels he would use the website at least weekly in the long-term.

Because of his continued monitoring, Rick was more knowledgeable about his fuel economy for the final interview. He knew his overall mileage was around 60 for the month [our calculation is 62.8 mpg], and noticed that his fuel economy dropped dramatically during the latter half of the month, which he observed was largely due to longer trips out of town. During one longer trip he recalled that he achieved about 75 mpg on his way to the meeting, but only 58 or 59 on way back. He estimated he was averaging around 75 mpg for the first half of the month, but his overall average dropped due to these longer trips [our calculation is 70.4 mpg for the first two weeks, and 58.6 for the latter two]. He also admits that in the latter half he had been driving "more normally, more aggressively…instead of coasting I was accelerating to make freeway speed." Rick also used the information to (playfully) compare his fuel economy with Samantha's:

*Rick:* *"when I drive its about 75, when you (Samantha) drives its about 50…I looked on the internet (laughs)"*

*Samantha: "…what does that mean—highway vs. city?"*

*Rick: “…could be…or more aggressive accelerations…I coast a lot”*

*Samantha: “…I’m in a rush to get somewhere…”*

*Rick: “…right, nobody passes mommy (laughs)…”*

Over the month, Rick estimates they spent about $26 on gasoline for the PHEV-conversion. Although they acknowledged driving the PHEV a little more than they would drive the Accord (they took the PHEV on some weekend trips that the minivan would normally be used for), Rick estimated they saved about 30% on fuel costs over their Accord. He considered electricity in this estimate, but admitted he couldn’t precisely estimate the electricity costs until he saw their next bill.

### *Talking to Others*

Samantha noted that a couple of neighbors asked about the PHEV during the trial. She didn’t recall any in-depth questions, just a few questions about “what’s that plug in the back?” and little bit of follow up discussion. Rick added that, at home, they didn’t park the PHEV outside, so there was little opportunity for others to see it. The few neighbors he talked to were interested in what fuel mileage the vehicle could get, how they could get in the study, if they could buy one, and if Rick would buy one after the trial. Rick’s coworkers were also curious, particularly those involved in the “going green” training program. Some had already looked into PHEV conversions and were aware of the $12,000 price tag for A123System’s retrofit. Rick told neighbors and coworkers that he would not be willing to pay so much for such a retrofit, though he might pay a smaller, “reasonable” premium—$12,000 would require too long a payback period.

### *One Motive for Purchase: Payback*

At the midterm interview, Rick pointed out that he might be a “bad person” for this study because he is the type who will “always try to do the cost-benefit analysis” [likely rooted in his educational background and present employment]. He says: “I try to capitalize everything—I would take the present value of my costs and all that, and ooh, right now it doesn’t pencil out…for the (Lexus Hybrid) you’re going to pay an extra 10 grand—to me it doesn't pencil out." He further illustrates the importance of this financial motive with a story of his brother-in-law's (who is also a coworker) purchase of a low-energy water heater:

> *"His water heater just went out and they got a tankless water heater (for $3000)…and I said it will never pay back… you can get one for $700. Did you discount the cash flows…the difference? And he says (he) did '…on a pure economic basis it is not worth it…but we're doing our part….' His thought is you lower your carbon footprint or something like that…I said 'okay, as long as we're clear.' Once this (PHEV) study is done I'll do the same…I'll run the numbers to see the payback period for the difference in savings. I like the fact that it's green…I haven't seen An Inconvenient Truth, but I'd like to…but I think that for a lot of consumers it will be dollars and cents…but then you'll have some pure guys that are saying its better for the environment, I'll pay the premium to do my part."*

During this midterm interview, Rick described his tendency to favor the financial perspective, but neither Rick nor Samantha appeared to clearly support or reject the pro-societal motive of "doing your part"—Rick merely noted it as a possible perspective. Interestingly, Rick also stated that high gas prices were not a serious problem for their household: "it was more of an irritant…it didn't really affect our life at all." [This interesting contrast—where the idea of payback is very important but money itself is less so—indicates that for Rick, payback is tied into something else. Maybe he feels some dedication to making smart decisions, and not getting duped into paying too much for environmental purchases?]

### *Another Motive: "Doing our Part"*

In the final interview, Rick and Samantha further elaborated on the pro-societal perspective hinted at during the midterm—this time describing how such non-financial motives were also important to them. When asked what specifically he liked about the PHEV, Rick included the potential to reduce $CO_2$ emissions through reduced gas use, at least "in theory." He further states: "I don't know whether or not it really reduces pollution…but its nice to think it does…nice to have the perception that you are doing something to help out." Rick's uncertainty seems to stem from both the nature of electricity generation and battery production. He figures that "in theory" using electricity "reduces the dependency on fossil fuels, petroleum products…here we do hydro, and back east they do what, coal? ...And nuclear …here, maybe some wind farms and solar farms …so you reduce your dependency on fuel." After "poking around on the internet," Rick also thinks it might be "really expensive to build the batteries…lithium-ion batteries…so I don't know economically how much it makes sense…but I guess it would definitely reduce your dependency on gas…but I don't know what the reality is." Despite this uncertainty, Rick highlights the importance of "doing our part" in regards to "not using more (resources) than you need to" and not adding "more pollutants out there than you have to."

Samantha described how, when gas prices recently went up, they saw more shows talking about natural resources: "how much we have and why, and the other developing countries like India and China who are now playing a bigger role in wanting the resources… now the US is competing more…there is only a finite amount…I think we need to figure out ways to make sure that globally everyone gets what they need…we can't always say that whatever we need we should be able to get…so I think we can all work at that, whatever it is…we've got to pass on the world to the next generation." At this point Rick related this issue to his children's future: "we'll probably be okay in our generation, but their generation (points at kids) is going to suffer unless we do something…use renewable resources...like solar, or hydrogen I guess."

Rick and Samantha agree that the world is generally moving in a better direction. Rick thinks it is good that there is more public education about global warming, and Samantha added that she sees more people willing to ride the bus. Rick described how he learned to take the bus to work about once per week (at first it took 50 minutes one way—"that's not going to happen"—but he found a faster express route). He also explained how some people just don't seem to get the "doing your part" idea, such as a neighbor that saw him walking home from the bus on day:

*"'Oh, [Rick], what are you doing?' I said, 'Coming home from work.' She said, 'You taking the bus?...I'd never do that, why are you taking the bus?' I replied, 'I felt like doing my part, I try to take it once or twice per week.' She says: 'Oh, I'd never do that…but kudos to you!' And turned around and walked away!"*

### *Future Car Purchase*

The Lakes were very interested in the idea of purchasing a PHEV, but they had specific needs they wanted it to meet. Rick noted that while the PHEV-conversion they had been driving was a good "day to day" commute vehicle, they would want to keep a second vehicle for the family—something that seated 7 or 8. He also wants the purchase to make economic sense: "I would do a little cost-benefit analysis…you can kick in a little premium, maybe a 10% premium just to go green or do your part for the environment to be a good citizen…but beyond that I don't know, I'd have to wait for (the price) to come down." Rick was clear he would not want to pay the 50% premium currently required for the A123Systems conversions. Samantha agreed that cost would play a part in their decision, but she felt that while Rick "wants to crunch it out," she is "more the gut-feel type." She might be willing to pay 24 or 28 thousand for PHEV Prius, but wants to consider other things like "reliability, size" and for the environment she "doesn't know where [her] cut off is." She says she certainly wouldn't want anything smaller than the Prius. [I think Samantha noted that she also has a quantitative background like Rick, but she was just not as likely to use it at home.]

For the design games, Rick seemed most excited about the idea of all-electric operation for his hypothetical Lexus RX 330 (see results in Table 1). In Game 1 (Priority Development), he chose the all-electric upgrade as soon as it became available in Round 3—which means at the expense of any other upgrades [note: not many respondents choose this]. When he originally completed Game 2 (Purchase Intention) online (without much input from Samantha), he only chose the PHEV upgrade in the lowest price scenario, in which he selected 10 miles of all-electric range, and maximized the CS fuel economy [We don't have direct corroboration from Rick, but we suspect that he was not as excited about the PHEV upgrades that were too expensive to justify his vision of an all-electric commute]. When asked, he explained he only needed 10 miles of range to get to work, and once there "tripping or not, I'd find a plug…if it meant that I could make it there and come back without having to gas up, I'd hit up somebody to build me a plug…(or) I would show up so early to park next to that plug, to save 5 bucks (laughs)." [Note that in the midterm interview, workplace recharging sounded infeasible—by the final interview he was fired up about making it happen]. This enthusiasm for all-electric driving links to his assessment of the PHEV trial: "I wish it had a pure electric mode, I wish I could just flick a switch and say: run on electricity as long as you can…because I think I could make it to work and back without having to use the gas…but with this one when you fire it up, the engine runs." He also heard that driving with electricity was equivalent to $0.75/gallon gas, which would save money, plus he wouldn't have to stop at a gas station—"who knows if some goofy guy is going to jump you."

**Table 1: The Lake's PHEV design game results (moderate and high price scenarios include adjustments from consultation with Samantha)**

| | Low Price (Shown first) | | Moderate Price (Shown second) | | High Price (Shown last) | |
|---|---|---|---|---|---|---|
| | Lexus RX 330 | PHEV Lexus RX 330 | Lexus RX 330 | PHEV Lexus RX 330 | Lexus RX 330 | PHEV Lexus RX 330 |
| Recharge hours | | 8 | | 8 | | 8 |
| CD mpg | | AE (+$2k) | | 75 | | 75 |
| CD miles | | 10 | | 10 | | 10 |
| CS mpg | | 56 (+$500) | | 56 (+$1k) | | 56 (+$2k) |
| Regular mpg | 26 | | 26 | | 26 | |
| Base Price | $22,000 | $24,000 | $22,000 | $25,000 | $22,000 | $26,000 |
| Upgrades | | $2,500 | | $1,000 | | $2,000 |
| **Total Price** | **$22,000** | **$26,500** | **$22,000** | **$26,000** | **$22,000** | **$28,000** |
| Bought | | Yes | | Yes | | Yes |

Samantha was unsure about her husband's initial selections. (Rick was responsive to her concerns: "I don't buy anything unless momma approves (laughs).") At first, she didn't understand his focus on 10 miles of all-electric range [I don't think she saw his vision of an all-electric commute, and she was also confused about whether all-electric meant a pure EV]. Samantha also disagreed with Rick's selections in the higher price games—she thought that the PHEV with CS upgrade could be worth the extra money. They discussed these options for several minutes—at one point Rick decided he needed to do a payback calculation and got up to get his business calculator. He sat down, pressed buttons for less than a minute, and then concluded, "Yeah I would by it" (agreeing with Samantha's selections). When asked to explain his calculation, he said: "I took my average miles per month, and the difference in gas, at two bucks per gallon, then I discounted it at a safe rate (5%) for 10 years…took a present value." He also figured that gasoline prices would likely go up again, so the net present value would be even more compelling. In summary, the Lakes both felt that faster recharge times were not necessary—they would mainly recharge at home. They would be willing to pay extra for PHEV upgrades with maximized CS fuel economy in all price scenarios. Only in the low-price scenario would they also upgrade to all-electric range for the 10 miles of CD range—thus achieving Rick's initial vision of an all-electric commute.

Rick and Samantha Lake were both interested and motivated to explore the PHEV technology for economic and environmental reasons. They were willing to pay a premium to do their part for the environment, while at the same time were concerned with fuel savings and conversion costs.

### 2. Nancy

#### *Summary Paraphrase*

"I don't plan on just sitting around a lot. I want to be able to drive when I can, and I want to be able to afford the gas. I never would have picked that car, but, after driving it for a month, it just feels right. I really would like to buy one with a plug if I could afford it, because I really feel like I am getting the most for my money when I use the electricity.

But I really don’t know what the regular Prius is like. I might be OK with one of those … does it feel the same?”

### *Who is Nancy?*

Nancy is a single retired grandmother who lives in an older, modestly sized, detached home. She spends a considerable amount of time caring for her granddaughter, and she is the primary caregiver for her 8-year old grandson. As a caregiver with a single income, Nancy admittedly watches her money closely, and is always looking to get the most for it. While participating, she substituted the PHEV completely for her only vehicle, a 1991 Toyota Camry with 253,000 miles.

Nancy was drawn to participating for two main reasons: partly because she had never before taken part in a research study, and partly because she thought that it would be worthwhile to try out a new car, since she would have to replace her 1991 Toyota Camry within the next 6 to 12 months and thought that this would be a good opportunity for an extended test drive. [We feel as though the latter was the predominant reason.] She mentioned several times that she enjoys the feel of Toyotas, and that Toyota and Lexus were the only cars that she liked when she had to “downgrade” from her big Cadillac in the early 90s. [This might be indicative of status or class, since Cadillac represents success and accomplishment to older individuals. It is particularly interesting that she mentioned her Cadillac several times without prompting. It would seem that the feel and comfort of the Prius invoked feelings of nostalgia for the comfort Nancy had enjoyed in her previous Cadillac.]

Nancy was very eager to take part in the study, greeting us outside as we pulled up to her home. She also made multiple attempts to find a suitable plug for us to test when we the first plug that we tested didn’t work. When we suggested we may have to leave without placing the vehicle, she hurriedly (almost frantically) searched for another plug and even offered to have it fixed as soon as possible, saying, “My guy can be out here tomorrow!” [Her eagerness may be attributed to the fact that she was planning to go to Southern California, and had anticipated that she was going to take the much newer PHEV. Also, it is a new car that she could show off to her friends in Southern California. [We feel that how other people perceived the vehicle had a lot to do with why Nancy enjoyed it so much. We also feel that demonstrating the vehicle to her friends and showing the plug (something different from a regular Prius) also made the car more valuable to her.]

### *The Beginning*

Nancy didn't quite know what to expect from a PHEV when she signed up to take part in our vehicle demonstration. Having no experience with any hybrid vehicle, she seemed to struggle with the concept of how the car worked, and how it was different from a regular Prius. [When questioned at the final interview, she stated that she had expected to get good fuel economy, or, at least, better than with her own car. She assumed that the PHEV used less gas, but still wasn't sure how it compared to a normal Prius, asking: "How does the regular one feel? Does it feel the same?"]

After taking a brief test drive, she had many questions about the car such as: "How often do other people plug-in...Why would I use the screen?" [Referring to the Prius' built-in Energy Monitor] and "What kind of fuel economy do other people get?" She was, however, quick to understand that using electricity could save her money on gasoline, and she exclaimed: "I am gonna plug this sucker in all the time!"

As a single grandparent/caregiver living on a fixed income, Nancy feels as if costly gasoline expenditures limit her mobility. She has spent so much time at home raising her children and taking care of her grandchildren that she sometimes wants to be able to "just get up and go" on trips. This can prove challenging with her limited budget, or "one income," as opposed to the two household incomes when she was married [and had a Cadillac]. Nancy doesn't mind driving [as demonstrated by the 3000+ miles she put on the car during her trial month—she even laughed with joy when she was told how far she had driven], and, when asked, she took pleasure in listing off numerous places she had visited with the car on her trip to Southern California. Nancy admitted that the trip to Southern California was something she did only about twice a year, and it so happened that we had caught her at "just the right time." She also noted that, if this had not been the case, she probably would have taken her own car on the trip, because she had her granddaughter with her and it would have been too expensive to purchase airplane tickets for the two of them. [Overall though, we feel that the mileage of this month's driving was much higher than her standard month, especially since her usual driving is limited by the age of her vehicle, a 1991 Camry with 253,000 miles. Further evidence that this month was unrepresentative of her normal driving is that in the intervening week between relinquishing the PHEV and her final interview, Nancy reported that she had barely driven her Camry and referred to driving 30 miles to a large town in daunting terms as "a good drive." Yet while she had the PHEV, she had driven almost every day, and within 2 weeks, (when not driving to Southern California) had accumulated over 1,000 miles.]

Nancy feels that that if she had a more reliable car, she would probably make similar trips more often. She is looking to move back to Southern California and believes that a good car would allow her to drive back up to visit her children and grandchildren. [This indicates that the extra driving isn't so much because of better fuel economy—which she reported to be 37 mpg—but more because she had a new car for a short period of time and wanted to take advantage of it as much as possible. The gas savings were probably an added bonus for her.]

### *Driving the vehicle*

Nancy told us that when driving the vehicle, she couldn't feel or notice a difference between CD or CS operation. Nor was she aware of where the energy to move the vehicle was coming from. She repeatedly told us: "I am not sure when I'm using the gas or the battery." However, she knew that by using the electricity or battery [this is how she referred to CD operation] she got "good mileage," or boosted her fuel economy. She told us: "I'd rather use the battery, then you don't have to fill up as much. The gas will last longer." When asked how she knew this, she responded that she had a feeling that she was getting good mileage, based on how far she could go on $20.00 worth of gasoline. As a consumer, she feels she generally has an instinct for good value. For example, when she goes out to eat or purchases something from a store, she just knows when she is getting her money's worth or a good deal. She did notice, or feel (on her trip to Southern California) that when in CS mode, the car still did "pretty good," on fuel economy.

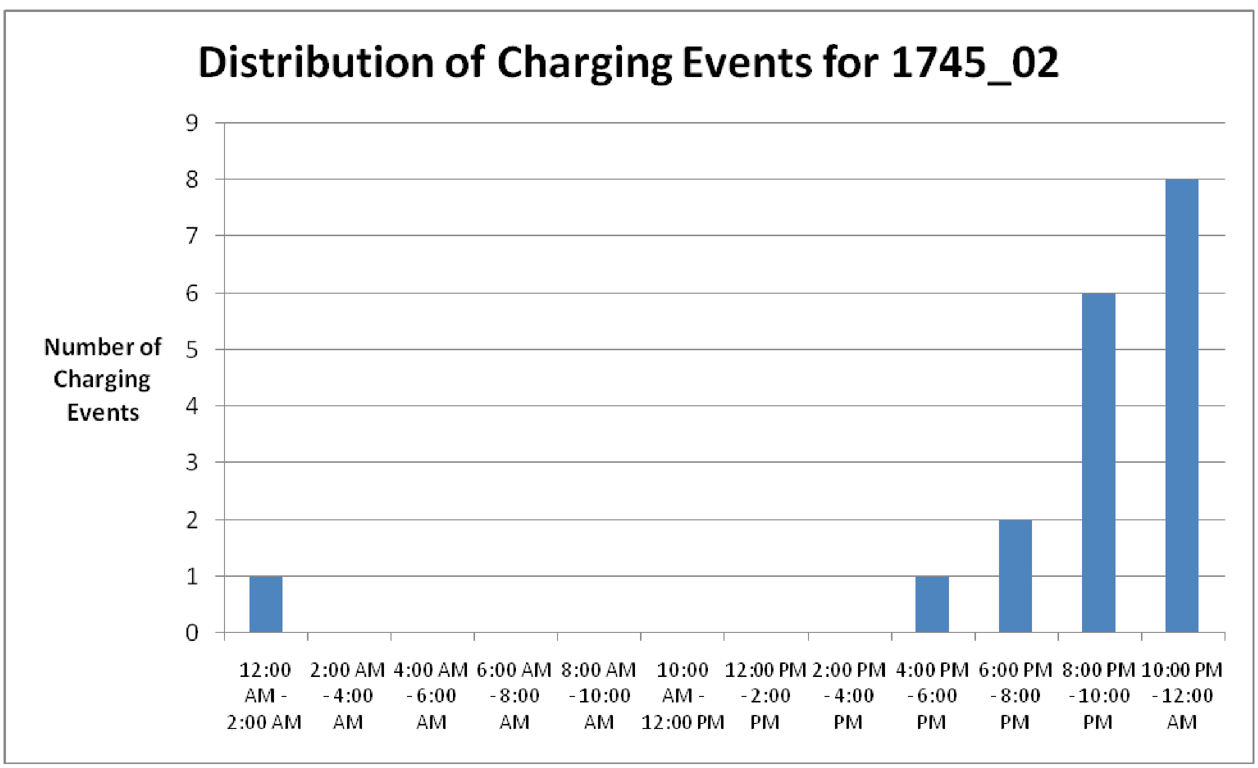
While Nancy looked at the Energy Monitor, it didn't really influence her driving. She saw the instantaneous mpg reading, but the numbers kept changing, anywhere from 17 mpg to 99 mpg, and she found it too much to process. She was also confused about what the arrows meant, or what the display was telling her. She told us: "I watch [the screen], I try to watch [the screen]. I thought that I was getting it…but I think I am just confused." Nevertheless, when asked if she would have altered her driving had she known what the display was telling her, she enthusiastically agreed, again saying that she would rather use electricity than gas because electricity is cheaper. The screen reminded Nancy of one of her former Cadillacs, which was able to change from 8 cylinders to 6 or 4 cylinders. She recounted how she would play with the accelerator to get the car to decrease the number of cylinders it was using. [We feel Nancy would have responded to very simple display, or if she was coached how she should drive the car to maximize fuel economy. During the first test drive we noticed that she accelerated quickly, did not coast, and drove rather fast—habits that are not conducive to good fuel economy.]

Nancy understood that running the car on electricity wasn't free, but she assumed that the cost wouldn't be very high. When asked what she thought the cost was to charge the vehicle, she recalled that when she was given the PHEV, it was explained that the car, when charging, would use a similar amount of power as a toaster. She then paused and thought out loud saying: "Well I don't know how much it would cost to run a toaster for 8 hours; I hardly ever use a toaster." However, despite her apparent lack of any frame of reference, she repeated that she didn't think that it would be a lot, and she would be checking her electricity bill to make sure. [It would appear that the explanation that the researchers provided influenced her response.] Nancy usually compares her monthly PG&E bill to the bill from the corresponding month in the previous year. While this helps her budget, she also uses it to make sure everything in the house is working well. She recounted a story about one month when the current bill was much higher and her efforts to figure out what had happened to cause the increase.

When asked about the vehicle, Nancy spoke mostly about the feel of car, and how it was different from her Camry. She mentioned that it was more comfortable and fit her better, was higher off the ground, quiet, had good air conditioning and a good stereo, was more reliable, and how "everyone liked [her *new*] car."

### *Charging*

Nancy found charging the PHEV to be very easy, both at home and on her trip to Southern California. While Nancy never encountered a problem charging, she really only looked for opportunities at the houses of friends and relatives where she was spending the night. At her own home she only charged at night. [Despite her flexible schedule, and the fact that she was at home during the day.] She was adamant that charging at night was the best way to go, calling herself a "nighttime charging gal." [She seemed to be worried that if she plugged in during the day someone might unplug the car, or interfere with it, saying she was very cautious not to draw attention to the car.] Of the 18 times that Nancy charged the vehicle, she consistently did so after 5:00 pm, and usually between 8:00pm and 12:00am. The following is a time of day distribution of the start of recharging events for Nancy's PHEV.



There was one instance where plugging in was difficult because the outlet was far from the vehicle, but it worked because the 50ft cord just reached. She figured that there would have been more problems charging if the cord wasn't so long, especially when she had to park on the street at night while staying in Lancaster.

While looking for a place to charge, Nancy triggered an interesting social interaction. At a party hosted by her sister's ex–sister-in-law (whom she hadn't seen for 20 years), she asked to plug in. Despite not seeing her for 20 years, Nancy figured that the host wouldn't mind her pulling in to the driveway and plugging in to the outlet in the garage. [We feel as though the party setting provided a platform for Nancy to "show off" her car and draw attention to the novelty of plugging-in.]

Nancy seems to have fallen into a charging routing with the vehicle over the course of the month. However, it would appear that she couldn't tell when the battery was depleted, telling us at the midterm and again at the final interview that she couldn't tell when the car switched from CD to CS. [This is substantiated by the fact that she only charged 18 times despite her wanting to run on electricity instead of gasoline.]

However, at the final interview she was adamant that she only got her best mileage when the car was charged, and felt like on the long trip to Southern California she wasn't doing as well because of how far she went without charging. [When asked, at the final interview, why she charged the car, she also noted that she had the impression that she was supposed to charge the car, otherwise what "would you [as researchers] have to study?"]

When asked how often she charged the PHEV, Nancy responded that she charged it every day she used it except for two days, on one of which she simply just forgot. Later, she remembered and asked herself, "Why didn't I charge?" But, she recalls that the car did "all right on gas" especially for driving through the hills.

### *V2Green*

During the midterm, Nancy seemed to be very excited about the prospect of using the V2Green website to track her expenditures, in a similar way to her routine comparison of her electricity bills. However when asked at the final interview, Nancy hadn't looked at the website. This despite the fact that she remembered that she had the tool and recounted how she had told people that she could go online and look at how the car was performing. Nancy believed that she was just too busy the last two weeks of the trial to look at site. When asked, she agreed that it would be nice to have similar information in the car. She explained that her grandson "bothers" her when she is at the computer, and makes it hard for her to concentrate, so an online system isn't good for her. [A monthly paper report, like an addition to the electricity bill, would probably be more suitable and useful.]

### *Designing a PHEV*

In the design games Nancy choose a Toyota Prius as the base vehicle, which she then modified to a PHEV with a charge depleting range of 20 miles for the low cost, and 10 miles, high cost scenarios. She chose to stick with a CD fuel economy of 75 mpg because it appeared to be in the middle range between what she was achieving and the highest mileage of 125 mpg. [Again, her experience and instincts as a bargain shopper may have taught her this philosophy.]

While making the choices, Nancy says she was mainly looking to get the best for her money and was buying on a budget. She figured that a charge-sustaining fuel economy of 75 mpg was pretty good. She did, however, choose to upgrade the charging time in every scenario to four hours. When asked why she chose this upgrade, she mentioned that it would be nice to be able to charge during the day. [This seems odd since she never charged the vehicle during the day, and identified herself as a nighttime charger.] When asked when she would picture herself charging during the day, she said that although she hadn't previously done so [because she was worried about drawing attention to it], she would probably charge her car during the day if it only took four hours. Nancy felt that faster charging would have been helpful in her trip to Southern California, where she could have easily stopped for a couple of hours along the way to recharge the car. She went on to explain she would have chosen a period of 1 hour charging, but that it would have cost her too much more. [Based on how she used the vehicle, the extra money might have been better spent increasing CD range or CD/CS fuel economy.] When asked to compare the PHEV-conversion she drove to the vehicle she had built in the game, Nancy said she wasn't sure which car was better. [This underscores a level of confusion about the vehicle on her part.]

Several times throughout the interviews Nancy asked if she could purchase the PHEV she had used during the trial. She repeatedly said how much she liked the PHEV-conversion and that if she could afford it she would buy one immediately. It is unclear if Nancy was enamored with the PHEV being a new car, since her current car is an older model that she says has lost its comfort, or if she likes the technology and function of the PHEV.

### 3. Octavia

#### *Summary Paraphrase*

"It is a great car that does everything I need, with no change in my driving. I was unsure at first how it worked—especially recharging. The more I learned, the more I felt I knew how to get the most out of it—recharge every day to reduce our dependence on oil."

#### *The Start*

Octavia is a middle-aged woman who lives with her retired mother in an attached home and works as a librarian. She drives a Honda Civic, which she purchased a few months ago. She generally makes shorter trips (<20 miles). She was first attracted to AAA Northern California, Nevada & Utah's recruitment letter because its sounded like a fun way to help researchers explore an important technology that held important implications for the environment and fuel use—what she considered to be a "worthy" cause—without requiring too much of her to participate. At first, she thought the study involved pure EVs, like the small, short-range EV owned by her neighbor across the street. Later, when she was told by phone that the vehicle would be a modified Prius, she was "intrigued" and anticipated that it would be more functional than the small EV she had in mind.

In Part 1 of the questionnaire completed at the start of her PHEV trial, Octavia reported that she was not familiar with HEV, EV, or PHEV technologies and thought that a "hybrid-electric vehicle" could be plugged in to an electrical outlet. After further explanation of electric-drive technologies, she concluded that most current HEV buyers were driven by financial motives, whereas if she were to buy an HEV, it would be for environmental reasons. She believed that climate change is a real, human-caused problem that, along with air pollution and the nation's dependence on foreign oil, requires urgent action.

She was very eager when the PHEV was delivered; during the initial test drive she was very pleased with the amenities including the coldness of the air conditioning (she felt Honda wasn't very good with climate controls). After the first lap around the block, she commented on the fuel economy, stating that she had "never gotten 70 mpg before." However, she did seem unsure of the PHEV technology, and in particular wanted to know when to charge the vehicle and for how long.

### *The Driving Experience*

During the study Octavia completely substituted the PHEV for her Honda Civic. Relative to her normal driving patterns, she felt that she did not change the frequency, distance, or destinations of her trips. She stayed within her "predictable" driving radius, and didn't feel any need to modify her speed or driving routes. She was surprised the car performed "great" without any "compromise" for the added benefits of fuel economy. She felt the PHEV was quiet and smooth, although she did occasionally feel a "lurch" when the engine kicked in. When driving, Octavia focused on the mpg portion of the gauges, and found the indicators of electricity usage and battery state of charge to be more confusing. Octavia was surprised by the "phenomenal" increase in gas mileage relative to her Honda Civic—as well as the accompanying reductions in carbon emissions, which were "even better." She said it was "fun to watch the thing," seeing that she could drive 65 mph while getting 75 mpg.

She filled up the PHEV only once during the month, whereas she believes she has to refill the Civic every ten days to 2 weeks. She was impressed that the PHEV fuel-level (gasoline) gauge "didn't move" very much. Although Octavia acknowledged that she didn't track or calculate fuel expenditures ("I don't do that"), she believed that the $31 she spent on gasoline for the month she had the PHEV was substantially less than the

$100-125 she would normally budget ("in my head") per month for gasoline costs. Although she did not know how much her electric bill would increase due to the vehicle, she reasoned that it could not be significant relative to the $75-100 she estimated for gasoline savings. (Note: In part 1 of the questionnaire, Octavia reported her monthly electric bill ranges from ~$60 to $110 dollars, and she consulted her bill to find that her per kWh rate is variable (12 to 23 cents) depending on the amount of electricity used.)

For Octavia, using less gas "was a great feeling" because it "has got be a good thing." She linked gas savings with energy independence and reducing environmental impacts. She said that in the world today "we have people dying…corruption and big business…due to the whole dependence on oil…we are in trouble…" creating "untenable situations for our country"; "we can't keep going this way." She felt that the PHEV gauges would help people make a stronger connection between their personal actions and such global problems.

### *Learning Recharge Behavior*

Octavia only recharged at her home, parked in her driveway; she didn't seek additional recharging locations. She didn't feel a need for alternative locations because of the short distances of her trips (which never exceeded 20 miles). She also felt that home was a safer spot for recharging because she "[didn't] want someone to take the cord."

Other than the location, Octavia did significantly adapt her recharge behavior over the course of the trial. During the first two weeks, she was unsure how to judge the battery's state of charge and would plug-in for 3-5 hours every other day or couple of days. She was just "guessing" and didn't follow a consistent pattern. She thought of recharging the vehicle as if it were a "cell phone." [We did not probe further what this meant. I took it to mean that she thought of the car as providing whatever benefit it provided so long as the battery had some charge in it, much the same way you can place a phone call using your cell phone whether it is fully charged or half charged.] After being introduced to the V2Green website at the midterm interview she immediately saw that there was large potential for her to improve her gasoline mileage—that she "could do more." She commented on how website information was something she hadn't before "paid attention to," and that she hadn't been "scheduling [her] plug-in time based on that." Although she stated that she was not a "numbers person" and was resistant to having to do any "math," she was excited about the possibility for the website to help her improve gas savings. Over the last two weeks of the trial she logged in to the website every few days.

She felt her understanding of the battery was further boosted a week later when she was instructed to read the PHEV "buyer's guide" in preparation for the design exercises in the final questionnaire. She considers herself to be a "reader," and felt that the handout and exercises helped her to finally "solidify" how to recharge the PHEV. With this information she said, "Now I get it...and I'm not charging it enough…I'm [switching] to gasoline half way through my day…I'm not utilizing the battery component…I need to start at 100% every day." The handout helped her to pull together the information of how long it took to recharge the vehicle to maximize her gasoline savings.

Octavia's explanation of her learning process was corroborated by our records of her gasoline and electricity use (although she did not specifically describe her change in terms of mpg or electricity use over the month). She drove 280 miles over the first two weeks, averaging 50 mpg, with 32% of her miles in CD operation. At the mid-term interview, she estimated attaining at least 60 mpg, explaining that she would get over 40 mpg in town, and between 65 and 90 mpg on the highway (she noted that these estimates are rough and that she "will never do anything mathematical to figure it out"). After receiving access to the V2Green website, she drove over 214 miles in the second two weeks and increased her average (gasoline-only) fuel economy to 60 mpg, and the proportion of CD miles doubled to 65%. In particular, over the last 6 days (70 miles) of her trial—after she had read through the PHEV buyer's guide—she began to recharge almost every evening and achieved an average of 79 mpg with 100% CD driving. At the final interview she wished she could have had access the V2Green and buyers guide information from the very start of the trial. Given the big changes in recharging over her month, she agreed that her last week looked more like her prediction of her longer term driving and recharging than did her earlier weeks.

### *Talking to People*

Over the course of her PHEV trial, many people interested in the vehicle approached Octavia. At work she was approached by security people and teachers that noticed the PHEV was not her normal car. Once Octavia explained the intent of the study to explore technology use, people were "really excited" particularly when she mentioned how many mpg she could get, such as 99.9 mpg going down a hill. People would ask if they could get in the study. A few people also noticed the car plugged in at her driveway, which initiated further conversations. She also took some friends for a test ride, at that the experience left most people "intrigued."

### *Future Vehicle Purchases*

In PHEV design games at the end of the trial, Octavia chose a Toyota Prius as her next likely vehicle purchase. In designing her own PHEV upgrades, she was not interested in improving recharge time lower than 8 hours because she could plug in at night (at home) most of the time. She also liked the idea of achieving 100 mpg in CD operation (particularly if it was "only $1000" more than the base 75 mpg option), as well as a 20 mile CD range that would cover her roundtrip commute. In higher price scenarios Octavia was willing to reduce such upgrades in order to keep the "total price" down, although she feels she would need more time to fully contemplate such tradeoffs.

In discussing the PHEV design exercise, Octavia admitted she didn't understand some concepts. In particular, she was under the impression that all-electric operation meant the vehicle "won't revert to the gasoline and you are more limited," although she later pointed out the explanation in the PHEV guide that specifically said that AE operation did not mean the car was an electric vehicle. Octavia stated that clearer information was important to explain AE operation, where the researchers needed to reinforce that the vehicle is capable of accommodating everyday driving needs. Her "experience has not been with a [electric] vehicle like that in my entire life" and such a change would be a "leap." Thus, she didn't "have enough" information to understand that AER would be safe and reliable for her.

At the close of the study, Octavia "really like[d] the Prius" and regretted having just bought a new Honda Civic a few months before without at least test driving a hybrid. She did consider a hybrid at the time, but due to cost issues and worries about the battery and how to dispose if it, she did not seriously pursue this option. In the future she would consider PHEV options, but she would have to further "ponder" about the specific attributes she would like, such AE vs. blended operation. She also noted that for a longer-term scenario, e.g., if she purchased a PHEV, she would likely seek out additional recharge opportunities beyond home, and potentially modify her driving behavior as required to further reduce gasoline usage.