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Plug-In Hybrid Electric Vehicle (PHEV) Demonstration and Consumer Education, Outreach, and Market Research Program: Volume II

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DISCLAIMER

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ABSTRACT

We deployed a mixed-method study to engage households in a project of fitting a PHEV into their day-to-day lives, completing PHEV design exercises, and open-ended interviewing to afford them the opportunity to tell their story about their encounter with this new technology. Plug-in conversions of hybrid vehicles were made available to (predominately new-car buying) households throughout the Sacramento region for four to six weeks each. The vehicles were instrumented to report travel and energy; households were interviewed and surveyed. Volume I of this report summarized the 34 households who participated between August 2008 and February 2009; Volume II incorporates an additional 33 households who participated between March 2009 and February 2010. Results from all 67 households—all selected in part because they can recharge a vehicle at home—indicate that while they will recharge a PHEV about once per day o average, there was wide and systematic variation across households. Recharging less than once per day was not necessarily a sign of forgetfulness, lack of engagement, or resistance. Some of the households who did not recharge every day were among the most discerning about how their travel and recharging behaviors interact. The PHEV designs created by the 67 households emphasized increased high (gasoline) fuel economy rather than all-electric operation in charge-depleting mode—as did the designs of prior representative samples of new-car buyers (who had not driven PHEVs) in the US, California, and northern California. Over households' PHEV trials, narratives were written about their encounters with the PHEV-conversions. The primary themes to emerge from comparing these stories are: changing driving behavior, recharging habits and etiquette, confusion about PHEVs and how they work, evaluation frameworks including payback analyses and heuristic assessments of whether PHEVs "save money," how to incorporate environmental (or more generally, pro-societal) costs and benefits into assessments, and the future. The last may concern both a household's considering whether a PHEV is in their future and pondering whether PHEVs point toward the future of all cars. The exploration of the narratives of two households' use of PHEVs equipped with custom-designed real-time energy feedback (REF) instrumentation reveal initial themes that serve as hypotheses for exploration with subsequent households: 1) safety and distraction, 2) motivational

situations, 3) confusion about, or misinterpretation of, the feedback, 4) desire for some feedback, and 5) relationship between self-described competitiveness and driving behavior. Additional narrative assessments and empirical measures of any differences in real-world, on-road energy intensity because of energy feedback information for a larger sample of households will be reported when that analysis is completed. Tracing social interactions by the participants about the PHEVs reveals that complex translation of ideas and information about PHEVs occurred as the PHEV drivers use their trial period to reflexively explore lifestyle and identity possibilities of these new vehicles. We found that interpersonal interactions were among the most important influences on participating households' assessments of PHEVs. The degree of influence was more likely to be greater if the interactions included communication about societal benefits, was with a person regarded as more expert, and was with a person who was socially close or far but not in the middle. The last may be an effect due to distinct types of networks, e.g., among the participating households.

EXECUTIVE SUMMARY

This document addresses four sets of research questions about consumers and plug-in hybrid electric vehicles (PHEVs). The first set asks what might be the driving and recharging behaviors of drivers of PHEVs, as well as the resulting energy impacts. The second places households' experiences with PHEVs within a behavioral framework that takes narrative to be the organizing frame within which people live and construct their lives. The third examines the effect of energy information feedback on the energy outcomes of driving, and does so within an analytical frame that attempts to account for personal, social, and environmental factors. The fourth probes specifically for the role of social interaction—the communication between a participating household and their social network—in the evaluation of PHEVs. These questions can be summarized by this single question, "Why would consumers buy PHEVs?" Elaborations include, "Which PHEVs would they buy?"

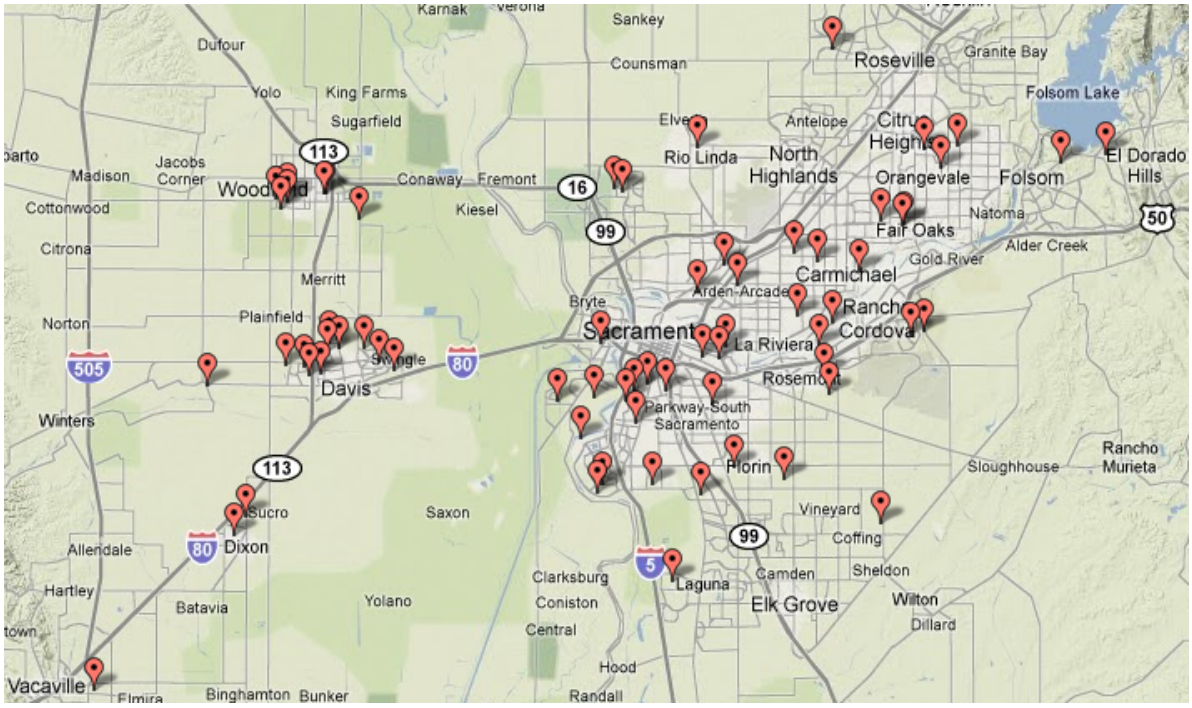
The Plug-in Hybrid & Electric Vehicle Research Center (PH&EV Center) at the University of California, Davis implemented a PHEV Demonstration and Consumer Education, Outreach, and Market Research Project (hereafter referred to as the Project) with funding from the California Air Resource Board's Alternative Fuels Implementation Program (AFIP) and funding and in-kind support from other partners. This report summarizes the findings from 67 households who drove a PHEV-conversion for a period of four to six weeks at some time between August 2008 and February 2010. All households drove a Prius hybrid electric vehicle (HEV) that had been converted to a PHEV. The conversion may be switched off and on. Households either drove the car as a PHEV for four weeks, or as an HEV for two weeks then a PHEV for four weeks.

Participating Households

Participants were recruited through an "illustrative" sampling method (Turrentine and Kurani, 2007.) Such a sample does not attempt to represent a population, but rather to illustrate observed 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 were selected for the Project with the participation of AAA Northern California, Nevada & Utah. Volunteers from the recipients of the invitation letter logged-on to a website hosted on a UC Davis server, where they completed a brief questionnaire soliciting more specifics of the potential participants vehicles, home, travel, household, and contact information. UC Davis researchers reviewed the recruiting questionnaire responses and selected households based on the goal to illustrate the responses of different types of households. The geographic distribution of households is illustrated in Figure ES-1.

Figure ES-1: Geographic Distribution of Project Households

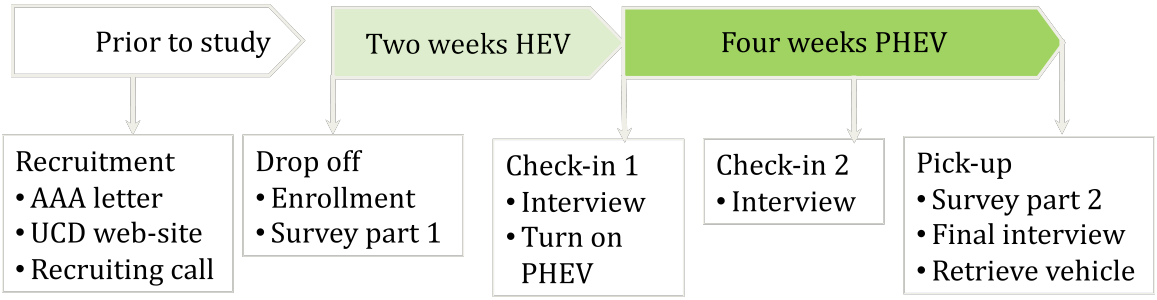


In comparison to samples of the general population and of the population of California and northern California who have previously completed questionnaires for UC Davis regarding PHEVs (Axsen and Kurani, 2008), the Project households differ in that, on average, they have higher income, more years of education, and are more likely to own their home. All three of these differences may be explained by a single Project design

choice: all participating households must have a place to recharge the vehicle at home. Still, the Project participants were similar to other recent samples of new car buyers in terms of concerns with environment and energy, as well as knowledge about electric-drive vehicles.

A basic timeline of the Project households PHEV trial period is illustrated in Figure ES-2. Households participating in the real-time energy feedback and social network research had somewhat different timelines.

Figure ES-2: Generic Household PHEV Trial Timeline



The Vehicles

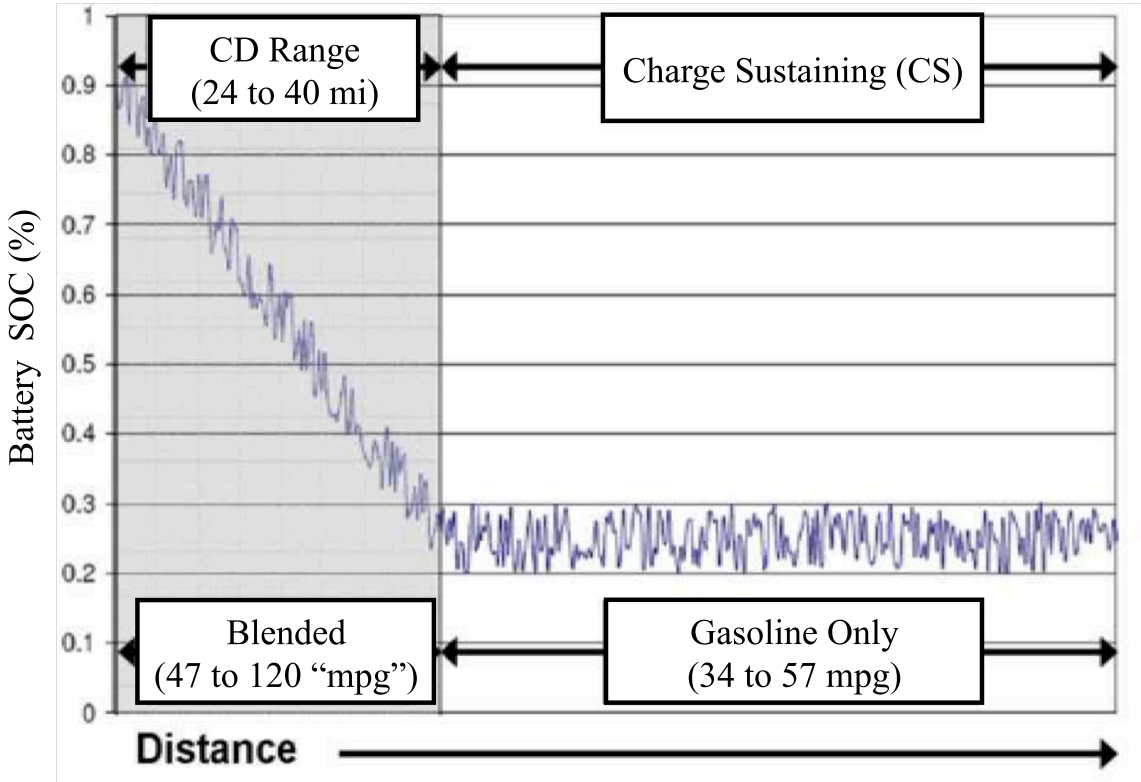
The vehicles driven by Project households were conversions of Toyota's Prius HEV; the vehicles were purchased retail. The conversions packages were purchased from A123System Inc. At the time of conversion, on-board data systems from Gridpoint, Inc. The U.S. Department of Energy's Idaho National Laboratory provided the vehicle data systems to the Project as part of its mission to measure vehicle performance. Additional programming services were contracted directly between the University of California and Gridpoint.

While the PHEV-conversions may be described as a Prius with a nominally 5 kWh grid-rechargeable battery, this technical specification resulted in a wide range of on-road performance in the hands of Project households. This range is summarized in Figure ES-3, drawing on data from the last week only of each household's PHEV trial. We choose the last week because it, with the concurrence of most households, mostly closely

resembles how they think they might recharge the PHEV-conversion if it was their vehicle over the long term. The resulting vehicle description may be stated as the following:

1. A PHEV that operates in blended mode during charge depleting (CD) operation;
2. In exchange for about 4 kWh of grid-electricity, it will achieve (47 to 120) mpg (gasoline-only) during CD operation;
3. CD operation will last for (24 to 40) miles using a definition of CD range that references only when the switch from CD to CS operation occurs;
4. Achieves (34 to 57) mpg in charge sustaining (CS) operation; and further,
5. Changes in total tank/battery-to-wheels energy intensity range from a (7 percent increase to a 32 percent reduction).

Figure ES-3: Range of On-Road Performance of the PHEV-conversions



Citation: Figure adapted from Kroemer and Haywood, 2007

While the actual measures shown in Figure ES-3 are specific to this PHEV-conversion, the range of measures indicates the degree to which the performance of similar PHEVs is subject to the driving and recharging behaviors of different drivers. The 33 households from the second year of the Project extended the variation in measures of CD range, CD (gasoline-only) fuel economy, and CS fuel economy. The biggest change was from the household that achieved 120 "mpg" in CD operation over their last week driving the car.

What PHEVs do Project Participants Design?

At the end of their PHEV trial period, households completed a set of PHEV design games—the same design games completed by prior samples of survey respondents (Axsen and Kurani, 2008). The overwhelming conclusion is that the Project households, like the survey respondents before them, created PHEV designs that emphasized improvements in (both charge-depleting (CD) and charge-sustaining (CS)) gasoline fuel economy; few designed PHEVs that offer all-electric CD operation and none designed a vehicle the combined all-electric CD operation with a 40 mile CD range (the longest CD range offered).

Project participants who had driven a (blended-operation) PHEV for a month were more likely than the previous survey respondents to 1) to state their next new vehicle would likely be an HEV, 2) regardless of their likely next new vehicle, to redesign that vehicle as a PHEV they were interested to buy under a variety of price conditions, and 3) design a PHEV that had better PHEV performance than the starting base PHEV design. The last two effects are illustrated in Figure ES-4 in which the CD type and range are summarized. The size of each data point is proportional to the number of households designing a PHEV with the corresponding CD performance capabilities.

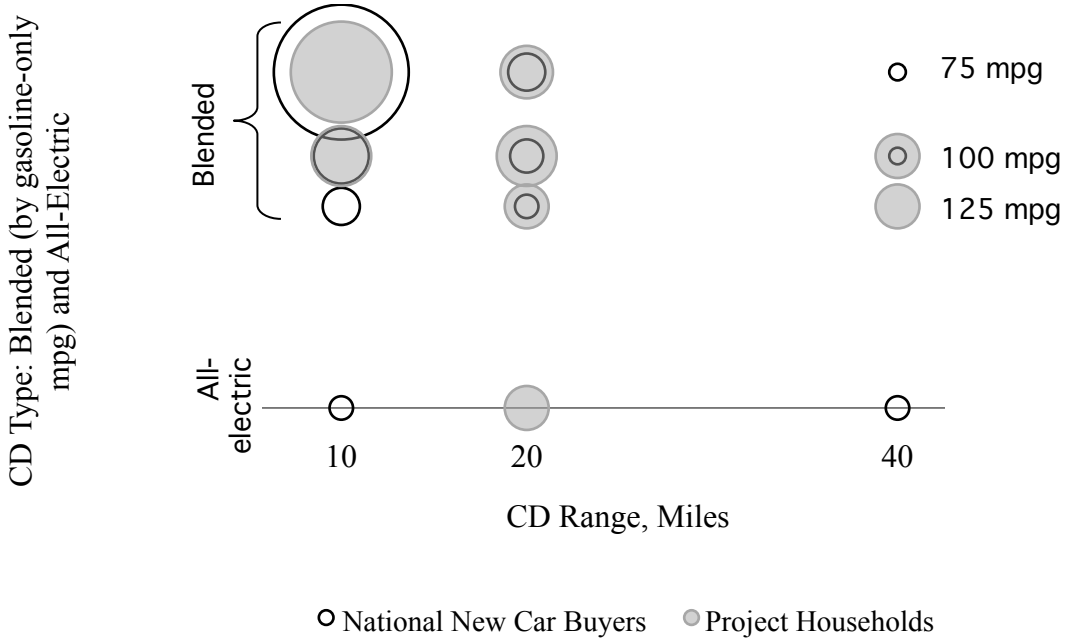
The base PHEV offering was described as taking eight hours to recharge, achieving 75 mpg in blended CD operation for 10 miles, and achieving 10 mpg higher in CS operation than a non-PHEV version of the same car. The Project does appear to have a slightly greater persuasive effect in convincing participants that a PHEV was a worthwhile and desirable vehicle for their household than did the descriptive materials included in the prior survey. (Those materials were also supplied to the Project households at the end of

their PHEV trial and prior to their completing the design games.) Still, these differences were at the margin, and the overall conclusions drawn from the Project participants were similar to those we drew from the survey respondents.

Charging and Refueling Behaviors

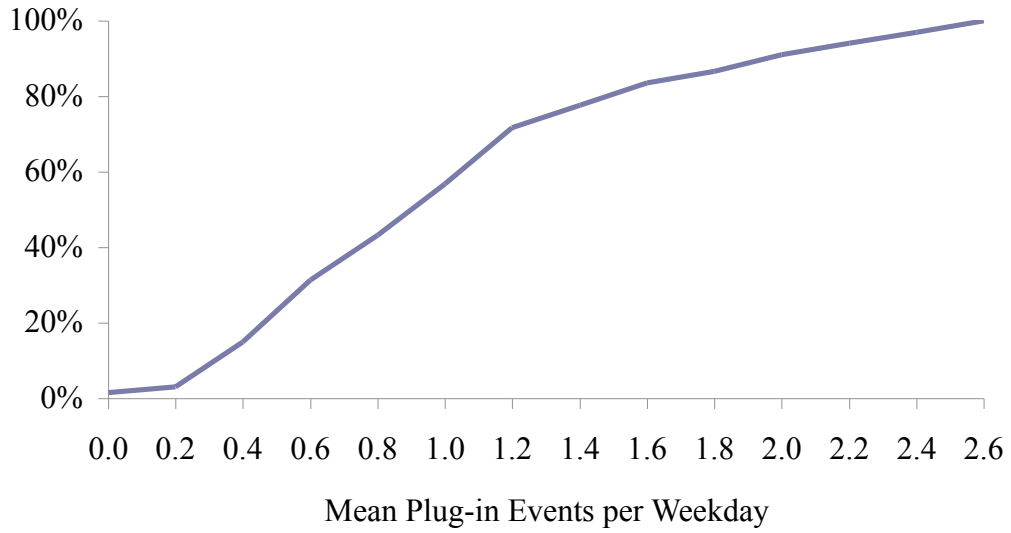
There may be no more fundamental question about PHEVs than whether or not people will plug-in a vehicle that does not have to be plugged-in. The answer from the Project participants to date is, "Yes, we will." During their last week driving the PHEV-conversion, the Project households, on average, plugged-in 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 five times per weekend day. The cumulative distribution of mean plug-in events per weekday is shown in Figure ES-5.

Figure ES-4: Survey Respondent and Demonstration Project Participant PHEV Design Summaries for CD Performance Attributes Only



Though the highest daily frequency of any household plugging in during its last week was greatest on a weekend, across all household-days, 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.

Figure ES-5: Cumulative Distribution of the Mean Number of Plug-in Events per Day per Household



Electricity availability is the time 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. *Instantaneous power demand* is the power drawn from the grid to recharge the supplemental PHEV battery. To compare and summarize across households, instantaneous power demand is standardized (by assumption) to 1.0 kW. Aggregating households' last week of electricity demand to create pseudo-total

demand requires the additional assumption that all households drove and recharged the PHEV during the same calendar week.

Electricity availability is often (at least implicitly) assumed to be 100 percent (at least at night). The red area (left-hand y-axis) Figure ES-6 shows 1) electricity availability to the Project households' vehicles never approaches 100 percent despite the fact all the households an recharge at home, and 2) there is considerable variation across weekdays as shown by the height of the red area. Across the 335 weekdays (67 households times 5 weekdays each), 62 to 75 percent of PHEVs were plugged in between 10:00 pm and 6:00 am. The large number of respondents who had full time jobs and typically left home in the morning to drive the PHEV to work explains the decline by 9:00 am to only 25 to 40 percent of PHEVs connected to the grid. While five households recharged at work during the day, retired individuals, households with flexible work schedules, and those drivers who stayed home during the day drove the other PHEVs plugged-in to the grid during midday. By 4:00pm households started to return home from work and vehicles began to be plugged in. The greatest variability across weekdays—ten to thirteen percentage points—occurred between 10:00pm and 6:00am.

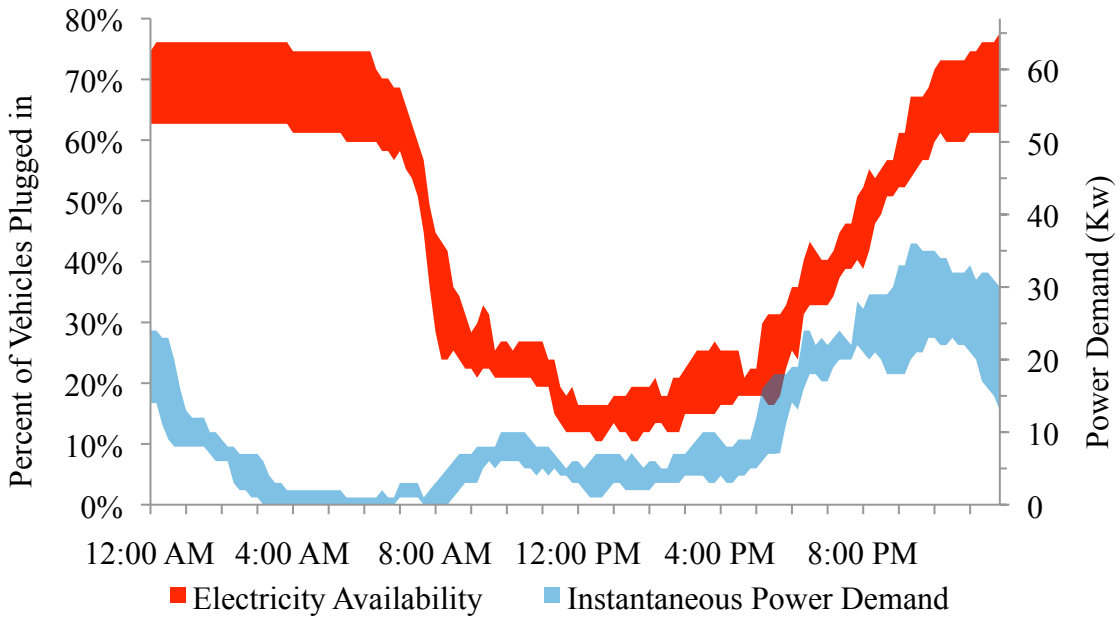
Power demand to recharge the PHEVs is shown by the blue area (right-hand y-axis). While a few households charged during the day, most of the demand to recharge vehicles was between 5:00pm and 4:00am. The most variability in time of day power demand occurred in the evenings between 5:00pm and midnight.

In the absence of any signals, e.g., prices, or supporting systems, e.g., timers, households tended to plug-in their PHEVs in the early evening on weekdays. As described by the household interviews, some households chose to plug-in as soon as they arrived home the first time. Others waited until after the last trip of the day, or until the vehicle was brought into the garage at the end of the day. Regardless of when they plugged in the car in the evening, most households waited to unplug it until they left home in the morning, i.e., only a few came back out late in the evening to unplug the car.

It is clear from Figure ES-6 that there was potential to shift electricity demand from these PHEVs until after 10:00pm, since instantaneous power demand needed to recharge these

vehicles declines rapidly after 10:00pm and most all recharging is completed by 5:00am the following morning. Lastly, the observed peak power demand of 35 kW was about 52 percent of the total maximum power demand of the 67 vehicles. Lastly, at any given time, fewer PHEVs were plugged in on weekend days and power demand was lower. Total power peaked at about one-third the hypothetical 67 kW maximum.

Figure ES-6: 24-hour Variability Electricity Availability (Percent of PHEVs Plugged-in) and Instantaneous Power Demand by Time-of-Day (Watts), Weekday Average, n = 67

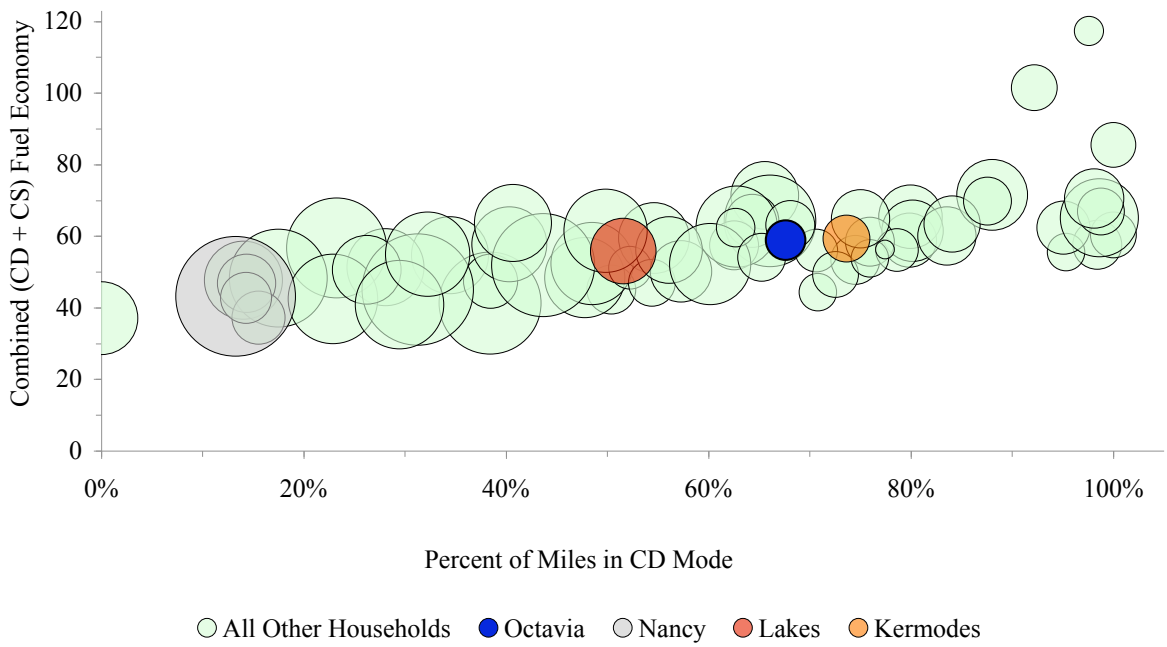


Variation in Vehicle Use, Recharging, and CD-miles Across Households

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. Figure ES-7 illustrates the overall variability in performance of the participants with regard to their combined CD + CS 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.[1] In Figure ES-7, each circle represents one household. The areas of the circles are proportional to the total miles driven by that household in the PHEV over their last week driving the PHEV. For scale, the largest circle ("Nancy," in the lower left) represents 947 miles of driving. That it also depicts one of the lowest percentages of miles in CD mode and nearly the worst gasoline-only fuel economy is due to a long, multi-day tour Nancy took away from home during which she drove the PHEV-conversion many miles without recharging.

Figure ES-7: Gasoline-only Fuel Economy by Percentage of Miles Driven in CD Mode, Weighted by Total Monthly PHEV (CD+CS) Distance



The basic conclusions are that individuals varied greatly in their driving and recharging behaviors and, importantly, in the relationship between these two. A few households

[1] All household names are pseudonyms.

drove only 20 to 30 percent of their miles in CD mode. On the other hand, a few households drove 100 percent of their miles in CD mode and achieved gasoline-only fuel economy measures of 100 or mpg. A linear regression fit to the (distance-weighted) data in Figures ES-6 indicates that each one percent increases in the percent of miles driven in CD operation increases the weeks average total fuel economy by 0.32 mpg, though the R^2 is a modest 0.43.

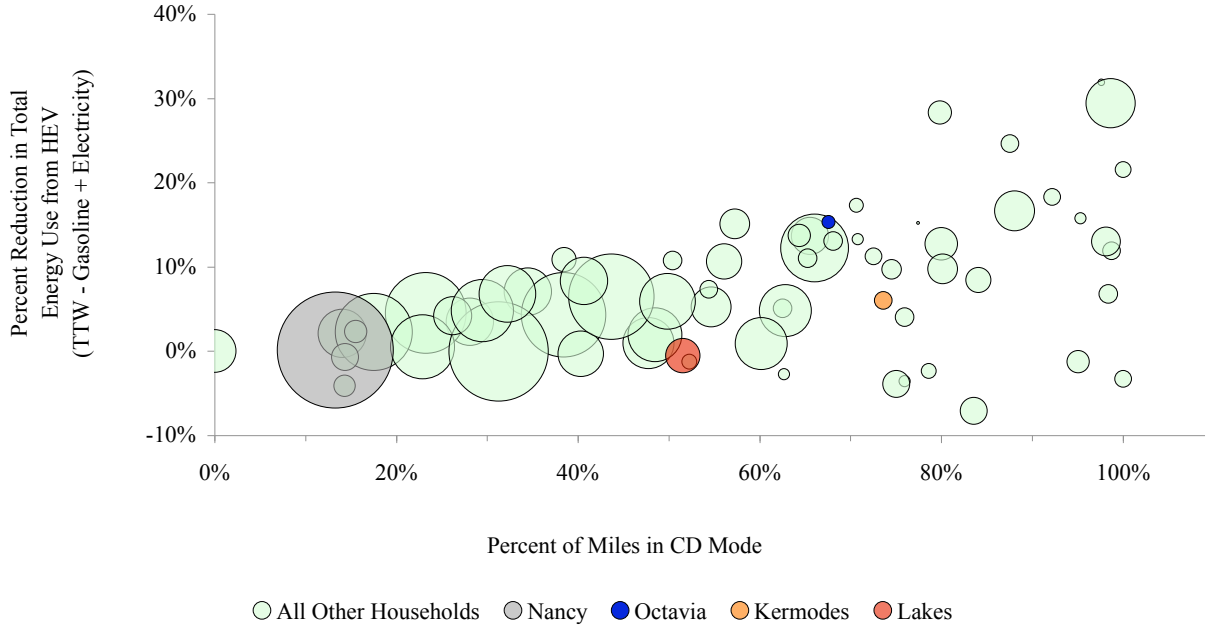
The Overall Effects of Recharging on Energy Use

The analysis of total energy effects presented here is partial for three reasons. First, only one particular PHEV is analyzed. Second, we do not present a life-cycle analysis; here we address only electricity out of the battery and gasoline out of the tank. Third, 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 the last week of their PHEV trial to the amount of gasoline they would have used had they driven that week 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-8. As in Figure ES-7, 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 a comparison of Figures ES-7 and ES-8 shows is that the households' use of the simple measure of (gasoline-only) fuel economy is not qualitatively wrong, i.e., while it is a best a partial measure, it at least does not in general mislead them as to whether they are saving total energy. As the percent of miles driven in CD mode increases, fuel economy and energy savings both increase. Figure ES-8 confirms that most households saved energy 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.

Figure ES-8: 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 -7 to 32 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. While every household reduced their *gasoline* use by recharging the PHEV, the marginal impact of recharging the PHEV on fuel economy varied significantly, with some households only decreasing gasoline use by three percent. In these households, the energy reductions gained through decreasing gasoline consumption were exceeded by the electrical energy from the grid.

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. At its most basic level, each

narrative of a household's encounter with the PHEV-conversion is a story re-told by a researcher. 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 energy reported by the data systems onboard the vehicles. Second, narratives explain, provide coherence, and show causality. A 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).

Second, analysis is accomplished both through the writing and reading of these narratives. A single 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.

Narrative Themes

The ideas that emerge as both important to individual narratives, i.e., what drives the plot of a household's narrative, and as important to multiple narratives are called themes. Four themes were derived from the first 34 households during the first year of the project. Additional themes and refinements of prior themes were identified based on the 33 narratives from the second year. The revised list of themes includes the following:

Changing Driving Behavior: Some participants explained that they changed their driving behavior because information they saw on the Energy Monitor made them aware of how their actions affected their gasoline-only fuel economy or ability to drive using only electricity.

Recharging: Many found recharging to be easy and likened it to a daily chore such as feeding the dog. Most recharged only at home, due to a lack of both perceived recharging locations and etiquette.

Confusion: The theme of confusion was expressed in three different ways: lack of information; incorrect information; and, incomprehension, i.e., they had correct information but did not understand it.

Payback: Some households discussed the idea of payback analysis and if the PHEV was "worth it" comparing the cost of the vehicle and the operational costs. Benefits to the environment were originally subsumed in this theme, but subsequently were separated as explained below in the theme of collective benefits. We still stretch this definition of payback to include related financial accounting practices stated by or inferred from a few households, e.g., net present value and return on investment.

Saving Money: Simple, heuristic evaluations of whether PHEVs "save money." Distinguished from payback in that there is no attempt to balance costs and benefits. Examples include reduced trips to gasoline stations for refueling and actions that highlight the use of electricity such as plugging in the PHEV or driving using only electricity.

Collective Benefits: The most often mentioned collective benefits were environmental impacts; independence from oil was another. These benefits were separated from the payback theme for two reasons. One, the payback concept is likely taken by many readers to be a specific type of private cost analysis. Collective benefits by definition are difficult to incorporate into such an analysis. We heard some households try to do so, for example, the previously cited story of the household identified as "the Lakes" discussing a payback evaluation and saying, "You add ten percent for the environment." Two, some households were considering collective benefits in ways that did not assume a financial calculation, but a moral action.

The next two themes demonstrate how the use of narrative as a framework and the multiple engagements with each household over a period of weeks allows the story told

about each household to reach before and beyond the specific time period of each households PHEV trial.

Prior expectations of the PHEV: This theme includes either the presence or absence of prior expectations of the vehicle the household would be driving and the basis for any prior expectations. Whether the PIEV-conversion met or confounded prior expectations often figured prominently in households' overall assessments.

The Future: The Project introduced households to a new set of possibilities for automobiles. Their speculations generally had to do with the conditions under which either they would own a PHEV or of a future in which all cars are PHEVs.

Understanding and Discernment

One example of the use of the themes is an effort to distinguish those households who expressed an interest in owning a PHEV from those who did not. The theme of confusion is the starting point: it may be assumed that an explanation of how a new technology functions is important, even essential, to its uptake by consumers.

In Volume I, we classified the 34 household narratives according to a typology based on understanding of PHEVs prior to and after each household's PHEV demonstration period. Based on the additional households who completed their PHEV trial during the second year of the Project, we modified our organization of the households' narratives based on whether participants were able to *discern* between a conventional internal combustion engine and a PHEV. The distinction we make between discernment and understanding is as follows: to discern is to comprehend how a PHEV is different from a conventional car depending on how one interacts with it; to understand is to be able to explain the electro-mechanical details of how a PHEV operates. The participants need not understand how the car operates in order to discern how they can engage the PHEV to make it function for them.

Ultimately, neither framework neatly separates those households who express an interest in owning a PHEV from those who don't. It may be important to some households that they understand how PHEVs work before they can form a positive intention, it may be

important to some that they discern how their interaction with the vehicle differs from a conventional vehicle; but this is not universally true within our sample of households.

Energy Interfaces and Instrumentation

There were two main sources of vehicle information available to study all Project participants. First, there was the stock Toyota display console. The two energy related screens were 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). The Energy Monitor schematic includes an approximate battery state-of-charge indicator consisting of a stacked column. In the stock display, when a Prius' own stock battery in near full, the stacked column is green. As the battery is discharged, the stack height diminishes and the color changes to blue. The PHEV-conversion adds a third color: when the vehicle is discharging the PHEV battery, the battery SOC indicator is purple. When the PHEV battery is discharged, the battery SOC indicator returns to its stock operation.

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.

In the second year of the Project a third source of energy feedback was implemented: custom-designed real-time energy feedback (REF) displays were installed in a subset of the PHEV-conversions. The experimental REF interface includes an "energy economy" measure, MPG+ that includes kinetic and potential energy as well as "fuel" energy from both gasoline and electricity. Including all these energy sources is designed to strengthen the driver's perception of behavioral control over energy use. One outcome of this new energy economy metric is that the MPG+ value is usually lower than the fuel economy (MPG) values displayed by the stock Prius display (which includes only gasoline).

MPG+ is calculated over the same distances as MPG, but includes all energy inputs to the motion of the vehicle.

The REF interface was designed to show the driver information that is predicted by behavior change theories to effectively promote behavior change. Energy outcomes were measured via an in-vehicle data-logger for two weeks to create a baseline record of driving behavior and energy use. After two weeks, the drivers were interviewed, and then the REF interface was turned on, and driving and energy were observed for a further two weeks before the final interview. Psychological factors predicted to be important by the TPB were recorded in three associated surveys completed by participants prior to any driving in the PHEV, after two weeks driving (without REF), and at the end of the experiment after they have driven the PHEV with REF. Finally, and most important for this analysis, household interviews provide insight into the thought processes, attitudes, and responses to the REF system.

Data collection is now complete, but analysis—in particular of measurable energy outcomes—is not. Two households' narratives of their encounter with the PHEV and the REF interface were initially compared and themes were identified that serve as hypotheses for the remaining households yet to be analyzed and as illustrations of the type of summary information generated from the interviews. The REF-related themes were the following: distracted driving; motivating situations; confusion about, and misinterpretation of the feedback; a desire to see detailed fuel economy information; and, competitive behavior.

Tension between energy and safety goals may be resolved with refinement of the REF display. Motivational situations suggest there may be differential outcomes of REF for different people in the same situation and the same people in different situations. The new energy metric may display total energy use, thus perhaps providing one thing that no Project household created for themselves—a fully integrated assessment of energy use. But, by accounting for all sources of motive energy, MPG+ tends to display lower "miles per energy" numbers than a simple "miles per gallon (of gasoline)" metric. These lower numbers may be inherently less exciting than the occasionally very large mpg numbers

drivers see. Self-described competitiveness may by linked to a desire to achieve high energy efficiency, but it may also cause competitive people to drop the quest for high energy efficiency if it conflicts with other goals, e.g., speed, time, or safety.

Future work will include the final PHEV+REF sample of approximately forty drivers. The larger sample size will support more extensive analysis of the driving and energy data, questionnaire responses, and interview discussions. Two major questions will be investigated, the first related to behavior change within subjects, and the second related to differences between subjects. In the first case: what attitudes, knowledge, and personality factors lead to behavior change when a driver is presented with REF? In the second case: how much do relatively static personality factors, such as competitiveness, impact overall driving behaviors and fuel use?

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

A sub-sample of ten households participated in an assessment of the role of social influence on their evaluation of PHEVs. A modified research protocol and timeline was implemented, including a mapping of the household members social networks and the sampling from these networks of additional discussants, i.e., additional questionnaires and interviews were administered to members of the Project households' social networks during and after the Project households' PHEV trials.

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 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.

In the context of the PHEV Project households and their social networks, we observed that social proximity (very close, somewhat close, etc.) was a more useful relationship measure than role categories (friend, family, etc.) or an "expert" list of network members who might typically be consulted regarding vehicle purchases. Also, the number of socially close network members does not necessarily correspond to the number of social interactions regarding the PHEV; socially more distant network members, e.g., casual acquaintances and strangers, made up a substantial portion of interactions regarding the PHEV in some participant households. Because social interactions were observed to occur at every level of social proximity, it might be difficult or impossible *a priori* to establish a complete relevant network for any given household.

A second question was whether social interactions were worth studying, i.e., social interactions regarding the PHEV may have occurred, but they may have had no influence. We found that in the context of the Project, social interactions do matter; in most primary households, i.e., households who drove the PHEV-conversion, at least one social interaction was ranked as being highly influential over their assessment of the PHEV technology. Thus, the assessment of PHEV technology did not occur in isolation—participants often consulted others to form their own interpretations about functional, symbolic, and societal benefits.

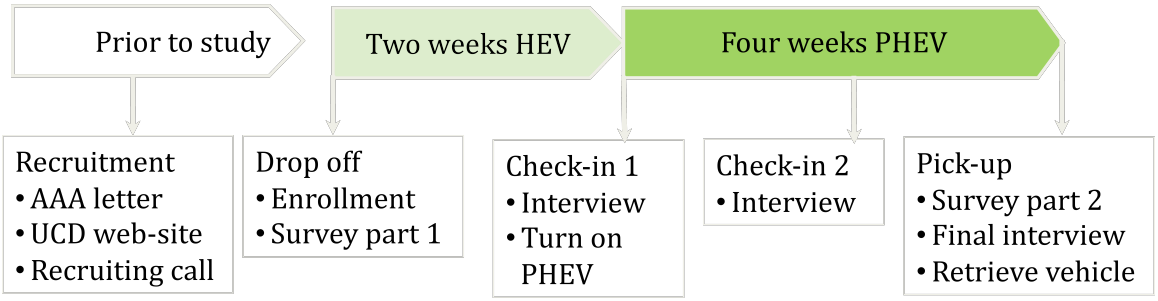
We also looked for patterns to help explain why some social interactions were rated as more influential. In this sub-sample, we found evidence that a social interaction was more likely to be rated as influential if 1) the interaction included communication about societal benefits were discussed; 2) if the participating household regarded the other person as an alternative fuel or electric-drive expert; and 3) if the social proximity of the other network member was near or far, but not in the middle. The first of these three supports the theoretical discussion in Volume I that the adoption of new vehicle technologies is not just driven by the "diffusion" of functional information, but also by the social negotiation of societal benefits. Households that already own an HEV tend to

rank social interactions as less influential than those who don't—likely because they had already formed functional, symbolic and societal perceptions of electric-drive technology prior to their participation in their PHEV trial. On the other hand, primary households rated interactions with network members as more influential if those people had alternative-fuel experience or knowledge. Social proximity may have had a non-linear relationship with social influence. Interactions with very close network members and strangers were more likely to be rated as influential than interactions with people described as somewhat close or as casual acquaintances. One explanation may be that our analysis may confound interactions from at least two different types of social network: those that tend to interact with and draw influence from closer network members, e.g. a tightly-knit family, and those that tend to draw more influence from more socially distant alters, e.g. a single man engaging in multiple recreation activities. The small sample size of the present research makes it difficult to assess consistency of such patterns, but future research may explore how different network types are influenced by social proximity.

1. PHEV Demonstration and Research Plan

Volume I provides complete descriptions of the PHEV Demonstration and Research Project Plan. Only notable differences in the execution of the Plan between the first 34 households detailed in Volume I and the 33 households added to Volume II are discussed here. The basic household timeline that became standardized midway during the first year is shown in Figure 1. Additional activities appear in this timeline for the sub-set of households who took part in the energy instrumentation research reported in Chapter 2D and the social network research reported in Chapter 2E.

Figure 1: Household PHEV Trial Timeline

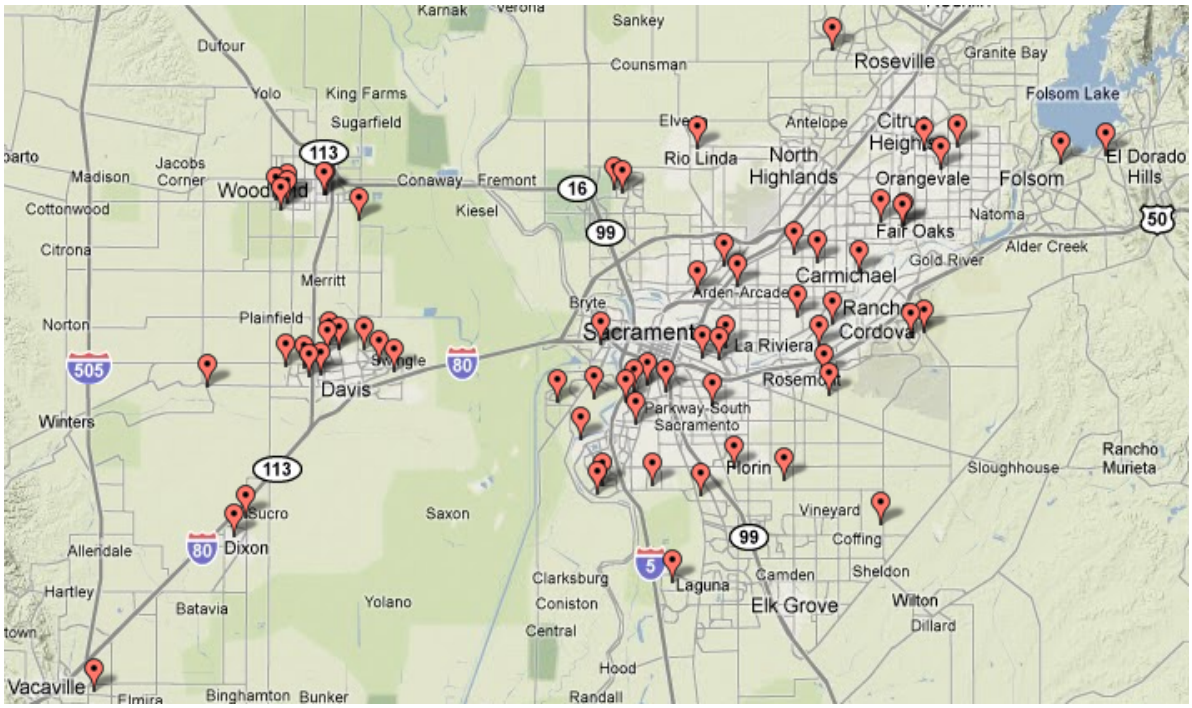


Household PHEV Placements

Sampling

The general sampling criteria remained constant throughout the entire project. To accomplish the original sampling goals, more pre-existing PHEV owners were recruited during the second year. Further, while the geographic sampling frame for the study remained unchanged—the cities and towns along Interstate-80 in north-central California—a much higher percentage of households in the second year were recruited from outside the Davis-Woodland area. Figure 2 illustrates the general location of all 67 households.

Figure 2: Geographic distribution of PHEV Project participants (n=67)



Who are the Project Participants?

Descriptions of the sample of 67 households plus comparative samples are presented in Table 1, including household hybrid vehicle ownership, respondents' gender, education, age, household income, and housing type. One important difference between the Project participants and all comparative 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 1.

The proportion of HEV owners in the sample increased in the second year as we intentionally incorporated a few pre-existing HEV owners. The gender balance is now slightly skewed toward women, but is still close to that of the general population and the 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 themselves 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 Project sample than in the survey over-samples. The most underrepresented age category is 25 to 34 year olds. As with education and age, the 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.

Gasoline Prices Faced by Survey Respondents and Project Participants

One question we are repeatedly asked regarding the prior survey that serve here as a point of comparison for the Project households 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 of new car buyers (including California and northern California over-samples) 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 3.

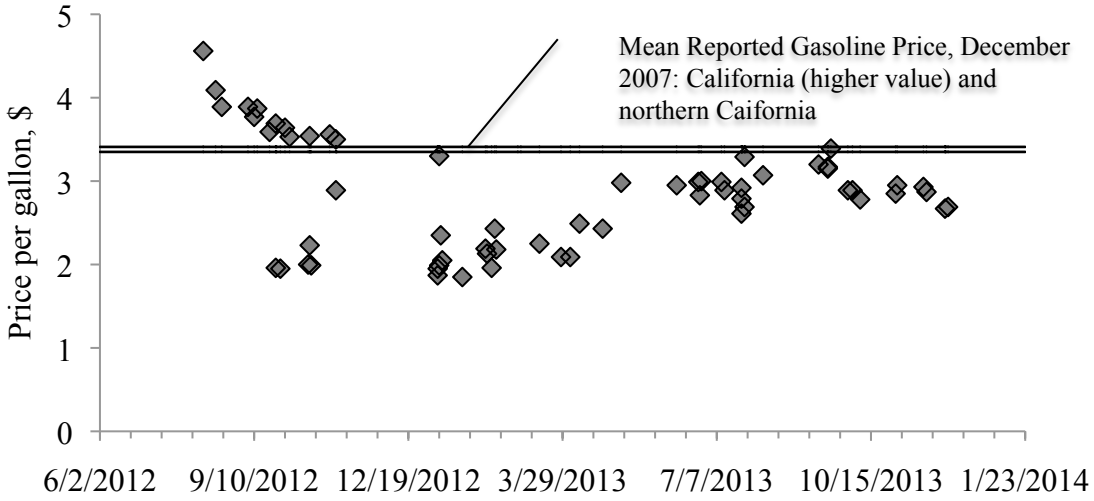
In contrast, the first few Project participants were paying in excess of $4.00 per gallon for gasoline in August 2008. But these are a small minority of Project participants, as gasoline prices quickly declined through September and October 2008 to, and then below, the average of the price faced by the national survey respondents. Prices continued to slowly rise into the summer of 2009 to just below the level reported by our northern California sub-sample from the national survey.

Table 1: Comparing Project participants, survey respondents, and the general population

	Target	AAA members	AAA members	New vehicle buyers			General population	
	Year	2008 – 10	2008-9	2007	2007	2001	2005-7	2000
	Data source	PHEV Demo	PHEV Demo	PHEV Survey (Nor. Cal.)[a]	PHEV Survey (Cal.)[a]	NHTS[b] (Cal.)	ACS[f] (Cal.)	Census[g] (Cal.)
	Sample size	67	34	216	851	389		
Hybrid owner?	Yes	16.4%	11.8%	8.9%	10.6%	-	-	-
Gender[c]	Male	47.5%	49.2%	59.7%	48.5%	44.5%	50.0%	49.7%
	Female	52.5%	50.8%	40.3%	51.5%	55.5%	50.0%	50.3%
Education[d]	High school or lower	4.6%	9.1%	2.6%	8.8%	22.1%	43.0%	43.3%
	Some college	23.0%	21.2%	34.9%	33.9%	22.1%	20.4%	22.9%
	College degree	37.0%	30.3%	32.8%	39.5%	39.9%	26.3%	24.2%
	Graduate degree	35.4%	39.4%	29.7%	17.8%	15.9%	10.4%	9.5%
Age[c]	15 to 24	4.2%	3.2%	4.6%	3.3%	6.5%	19.0%	18.3%
	25 to 34	8.3%	8.1%	21.1%	20.5%	18.0%	18.3%	19.8%
	35 to 44	28.3%	25.8%	27.3%	29.0%	23.5%	19.3%	21.6%
	45 to 54	28.3%	27.4%	29.4%	23.7%	24.8%	17.6%	16.5%
	55 to 64	26.7%	29.0%	10.8%	15.1%	13.3%	12.1%	9.9%
	>64	6.4%	6.5%	6.7%	8.3%	13.8%	13.8%	13.8%
Household income	< 30 k	1.6%	3.1%	1.8%	2.0%	6.3%	25.3%	31.2%
	30 k to 60 k	14.0%	15.6%	11.9%	17.6%	23.4%	25.8%	29.5%
	> 60k to 100k	28.1%	15.6%	35.1%	27.7%	32.3%	23.0%	22.1%
	> 100k	56.3%	65.6%	51.2%	52.7%	38.0%	25.8%	17.3%
	Mean income[e]	$112,031	$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	91.0%	94.1%	71.3%	68.1%	79.4%	58.0%	
	Attached house	7.5%	5.9%	10.3%	11.9%	4.4%	7.0%	
	Apartment	0.0%	0.0%	17.9%	16.7%	13.6%	30.7%	
	Mobile home	1.5%	0.0%	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.

Figure 3: Comparing gasoline prices from survey respondents (lines) and Project participants (diamonds)



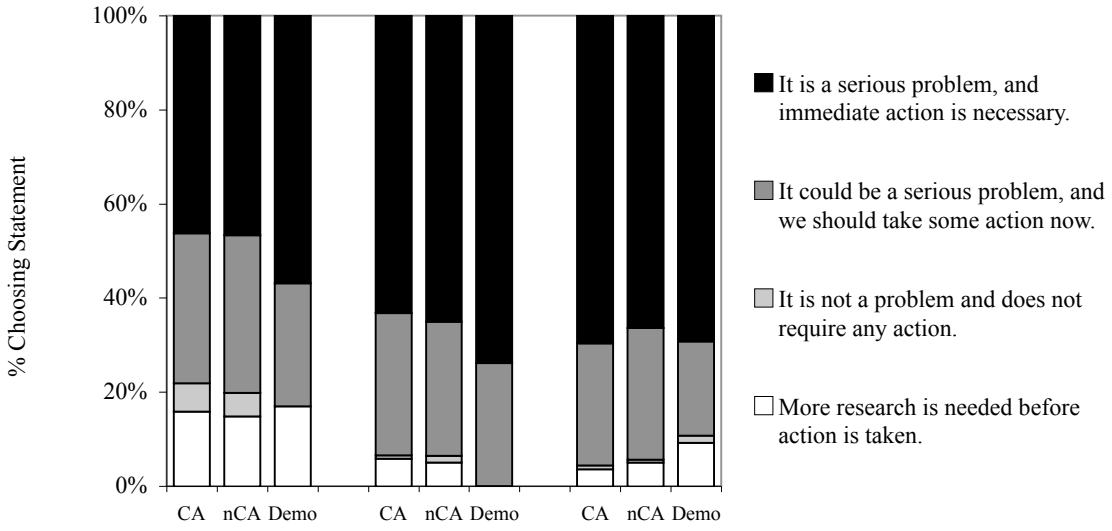
Still, whether they faced higher gasoline prices during their PHEV trial period or whether they simply recall such higher prices from summer 2008, we expect that our all Project participants may now be more sensitive to the uncertainty of gasoline prices than the national survey respondents were at that time. This may make Project participants less like our survey respondents, but 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 to qualifying automotive insurance policy holders did not emphasize motivations to volunteer; still, one might speculate that the households volunteering for a PHEV demonstration project had stronger motivations and knowledge regarding environmental issues, oil dependence, and electric-drive vehicles than households in general. This does not seem to be the case. Responses to three questions regarding these possible motivations are summarized in Figure 4: 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.

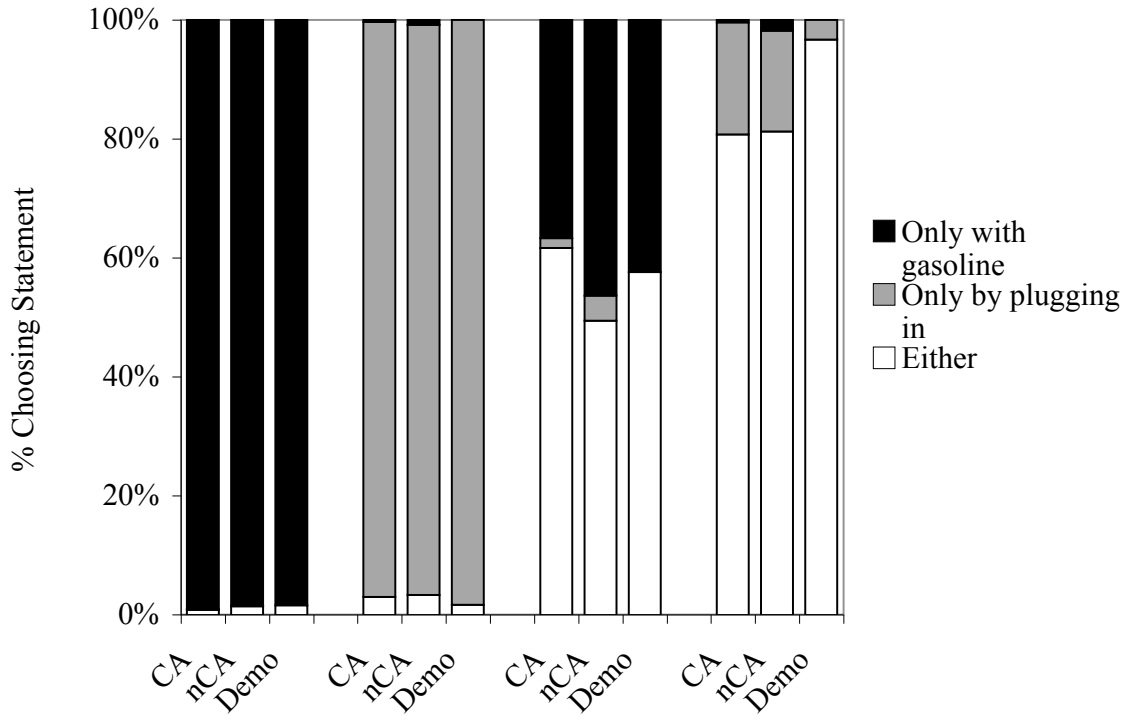
Figure 4: Comparing environmental beliefs among survey respondents (California "CA" n = 1,741; northern California "nCA" n = 464) and Project participants ("Demo" n = 67)



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 (at the start of their PHEV trial but after the vehicle has been delivered) 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 5. 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.[2]

Figure 5: Comparing electric-drive knowledge among survey respondents (California "CA" n = 1,741; northern California "nCA" n = 464) and Project participants ("Demo" n = 67): "From what you understand of these vehicle technologies, which can use fuel, and which can be plugged in?"



[2] That 50 to 60 percent of respondents in all samples indicate they believe HEVs can be refueled by either gasoline or electricity is surprising. It has been more than ten years since HEVs were introduced. It is possible that these results were shaped by the specific language used in the questionnaire, which rather than using the acronym or the shortened "hybrid," spelled out the full label as "hybrid electric vehicle."

2A. PROJECT RESULTS: CONSUMERS' 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.

Whose PHEVs? Plausible early markets

This section compares the PHEV designs elicited from the 67 households who completed their Project participation between August 2008 and January 2010 with those elicited from respondents in the California (CA) and northern California (nCA) over-samples of the national survey in December 2007. As with these results reported in Volume I, 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 whether the household designs a PHEV in the "higher" price condition of the *Purchase Design* game. The first is measured as parking a car at home within 25 feet of an electrical outlet. The plausible early market segments estimates for the comparative survey samples and the Project households are summarized in Table 2.

Table 2: Plausible Early PHEV Market Segments

		Home Recharging,[1] Percent	PHEV Design,[2] Percent	Plausible Early Market Segment Size, Percent
New Car Buyers	U.S.	52	64	34
	California	46	74	34
	Northern California	46	71	34
PHEV Demonstration	Northern California	100	78	78

1. Car parked at home within 25 feet of an electrical outlet.

2. Designs a PHEV in the medium price version of the Purchase Design game if a car or high price version if a truck. Purchase Design game explained further in the text.

All Project participants have access to home recharging because it is a requirement for participation. Among these 67 households, 52 (78 percent) indicate a PHEV purchase intention in the higher price scenario and thus these 78 percent are included as the *plausible early market* Project participants. This represents a ten-percentage point drop from the original sample of 34 households, of which 30 were included as the *plausible early market*. Thus, while 88 percent of the initial 34 households were in this market, only 65 percent of the subsequent 33 households were. Still, as with the first 34 participants, in total all Project participants are more likely to design their next new car as a PHEV than are the national survey participants.[3] 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 believed they were most likely to buy as their next new vehicle.[4] Figure 6 compares these base vehicles selected by the survey respondents to those selected Project participants. While the percentage of Project participants that stated their next new vehicle would be an HEV dropped from 67 percent to 59 percent, they are still more than twice as likely to do so as the comparative samples from the California and northern California survey 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 prior HEV ownership or self-selection of Project participants. As shown in Table 1, only 17 percent of Project participants had owned an HEV. Recall from their previous description that Project participants do not possess more knowledge about electric drive vehicles or 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

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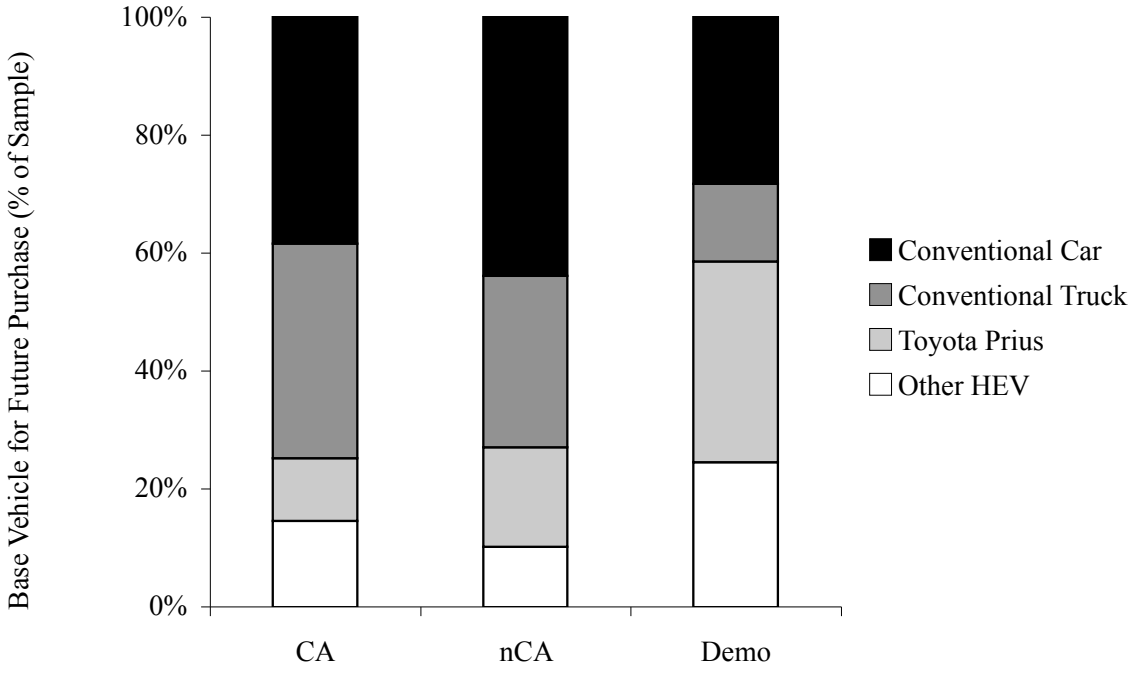
[3] At these small sample sizes, this drop may only be "apparent," i.e., the change could simply be due in part to expected variability. Reasons for an actual drop may include receding memories of gasoline prices higher than $3.50 per gallon that many of the earlier participants experienced.

[4] The two PHEV design games are described more fully in Volume 1 and in Jaxsen and Kurani (2008). In particular, to see the PHEV design space used in both games, see Tables 1 and 2 in Volume I.

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.

Figure 6: Comparing base vehicles for PHEV Purchase Design Game (*plausible early market* only: CA, n=286; NCA, n=63; Project, n=52

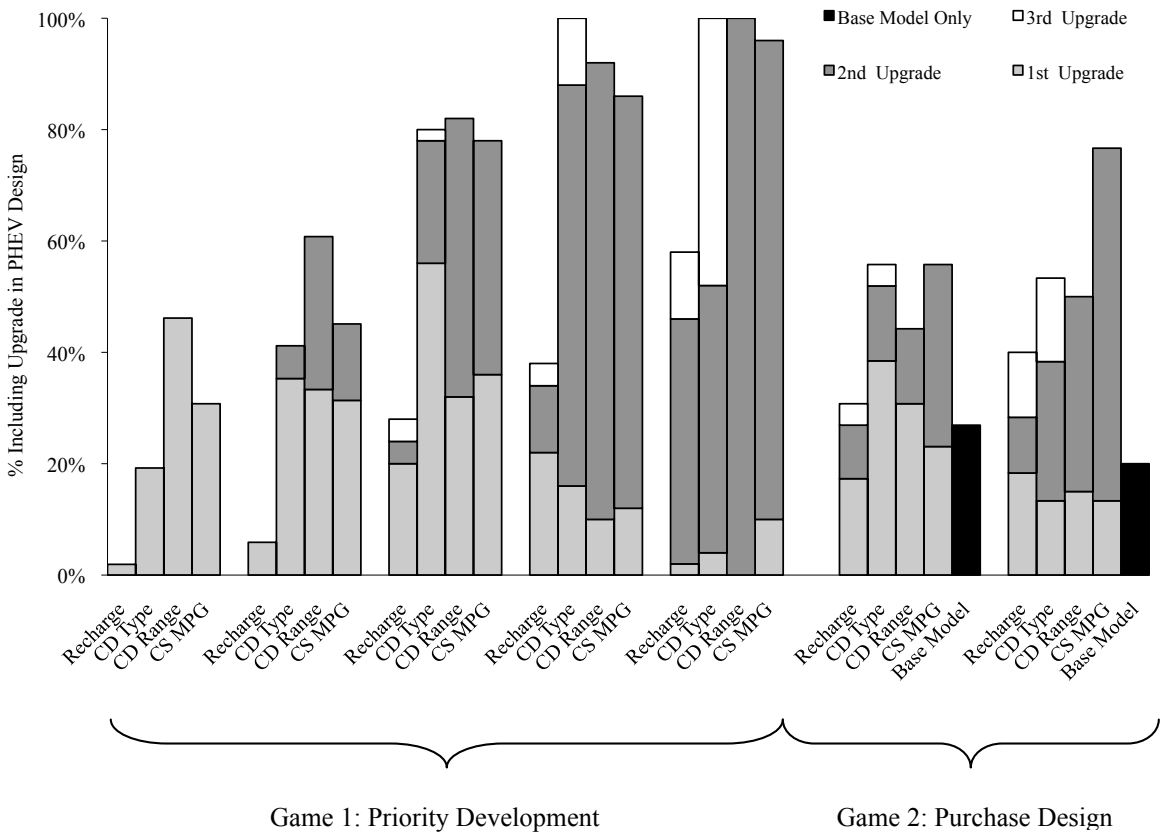


Focusing on the interests of these *plausible early market* Project participants, results of the two PHEV design games are summarized in Figure 7. In Round One of the *Development Priority* game, respondents were given one point to allocate towards one upgrade to the base PHEV model.[5] One of four upgrades was available in this first round: recharge time (from 8 to 4 hours), gasoline-fuel economy during (blended) 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). The general ranking of attribute upgrades in Round One

[5] The Development Priority game starts with the premise that the household is redesigning one of their household vehicles to be a PHEV. See Volume 1 and Jaxsen and Kurani (2008) for details.

continues through later rounds: a higher percentage of potential early market respondents designed PHEVs with CD range upgrades and CS fuel economy upgrade. Few respondents designed PHEVs with faster recharge times than the base 8 hours.

Figure 7: Upgrades selected in PHEV design games by Project participants (*plausible early market* Project participants only, n = 50)



All-electric operation (in CD mode) was first offered to respondents in Round Three of the *Development Priority* game; only one household incorporated this upgrade into their PHEV, which came at the expense of all other upgrades available in prior rounds. By the final round, the proportion of *plausible early market* Project participants designing a PHEV with all-electric operation rose to nearly half—but only after nearly every respondent had already selected the maximum CD range and CS fuel economy upgrades.

Figure 8 portrays the 23 different possible PHEV designs possible in Round Four of Game 1: *Development Priority*. This is the first round in which the design envelope allows a PHEV with 40 miles of all-electric range. Three of *plausible early market* Project participants (6 percent) created this specific design. Overall, all-electric operation was not incorporated into participants PHEV designs, especially when resources (points) were relatively scarce, i.e., all-electric operation "cost" most of the available points and alternative designs were available, i.e. in Rounds Three and Four of the *Design Priority* game. Resulting PHEV designs, and thus performance priorities varied widely across Project participants—though it is now true of the 67 total respondents that a single PHEV design emerged as a slim majority favorite—8 hours recharging, 125 mpg in blended CD operation for 40 miles, and a +30 mpg increase in CS operation compared to their base vehicle. (Recall that in this game, one of the households existing vehicles is the base vehicle.) This result accentuates the results of the designs created by the California and northern California survey samples—for whom, despite the apparent concentration on the same design—it is the case that 1) most do no incorporate all-electric operation in their design and 2) there is no single majority design. There is an emphasis on increasing fuel economy. (Compare to Figures 11 and 12).

Results of the *Purchase Design* game suggest the majority of Project participants would value PHEV capabilities in their next vehicle. Figure 7 also depicts the proportion of upgrades incorporated into PHEV designs under the price conditions of this second PHEV design game. 14 *plausible early market* Project participants (27percent) chose the base PHEV models in the "high" price conditions, and ten (20 percent) in the "low."[6] Among those who created PHEVs in the higher cost rounds, overall priorities are similar to those in the *Development Priority* game: CS fuel economy upgrades were incorporated more often than other upgrades, and there is no evidence of strong interest in all-electric operation: two and four households upgraded to AE operation in the higher and lower price conditions, respectively.

[6] "High" price means the high price for trucks and medium price for cars; "low" is medium prices for trucks and low for cars. We did this to impose a greater cost penalty on creating PHEV versions of larger, heavier, less aerodynamic vehicles, i.e., trucks.

Figure 8: Distribution of selected PHEV designs in Round Four of Development game (*plausible early market* only: Demo, n=50)

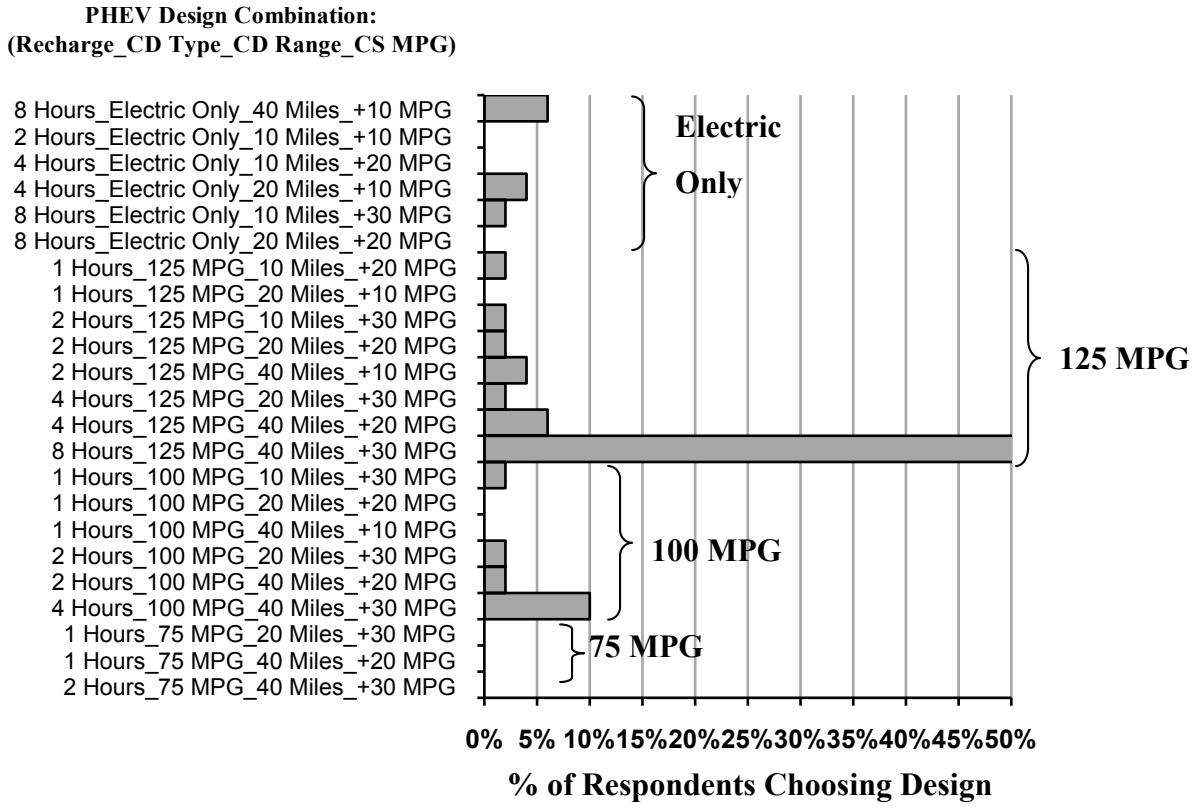
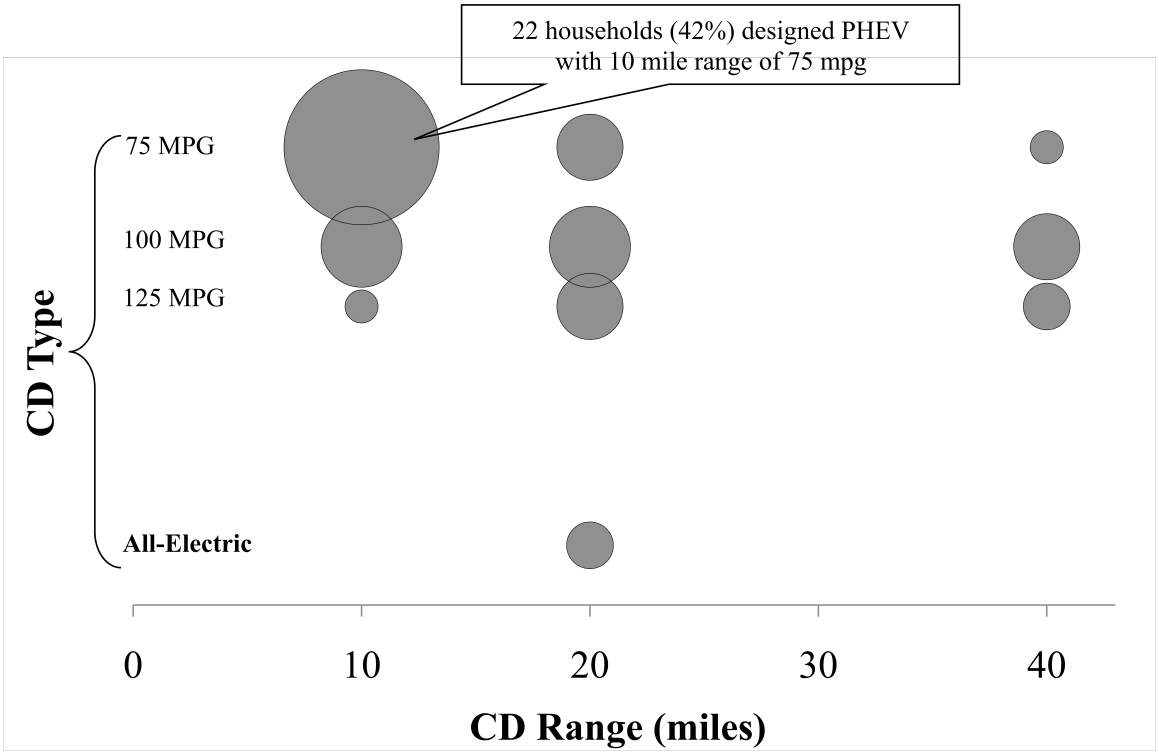


Figure 9 depicts the proportion of the cross-classified CD type and CD ranges incorporated by Project participants into their PHEV designs. Note that 22 households (42 percent) designed a PHEV with blended CD operation capable of 75 mpg for 10 miles. Further, 46 households (88 percent) designed a blended CD design (as opposed to all-electric) with a range of 20 miles or less. These percentages are nearly identical to those reported in Volume I for the first 34 households. Such PHEV designs have far lower battery energy and power requirements than the all-electric, longer-range designs assumed by various battery experts (Axsen et al., 2008).

Figure 10 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 11 and 12 show the distribution of PHEV designs in Round Four in the CA and NCA samples, respectively for comparison to Figure 8.

Figure 9: Distribution of selected PHEV designs CD attributes in high price scenario of Purchase Design Game (*plausible early market* Project participants only, n=52)



All figures indicate a wide variety of PHEV design interests across households, without any particular draw to the all-electric 40-mile design. Figure 13 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 than any of the samples of survey respondents. Several differences among samples could contribute to this result. Project participants have higher household income (as portrayed in Table 1) 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 survey samples.

Figure 10: Comparing upgrades selected in Round 4 of Development Priority game, (*plausible early market* only: CA, n=286; NCA, n=63; Project, n=28

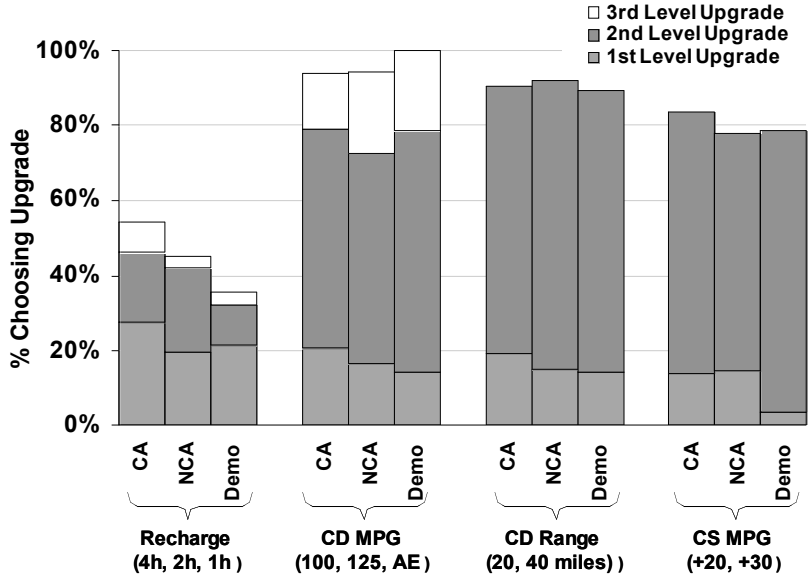


Figure 11: California Distribution of selected PHEV designs in Round Four of Development game (*plausible early market* only: CA, n=286)

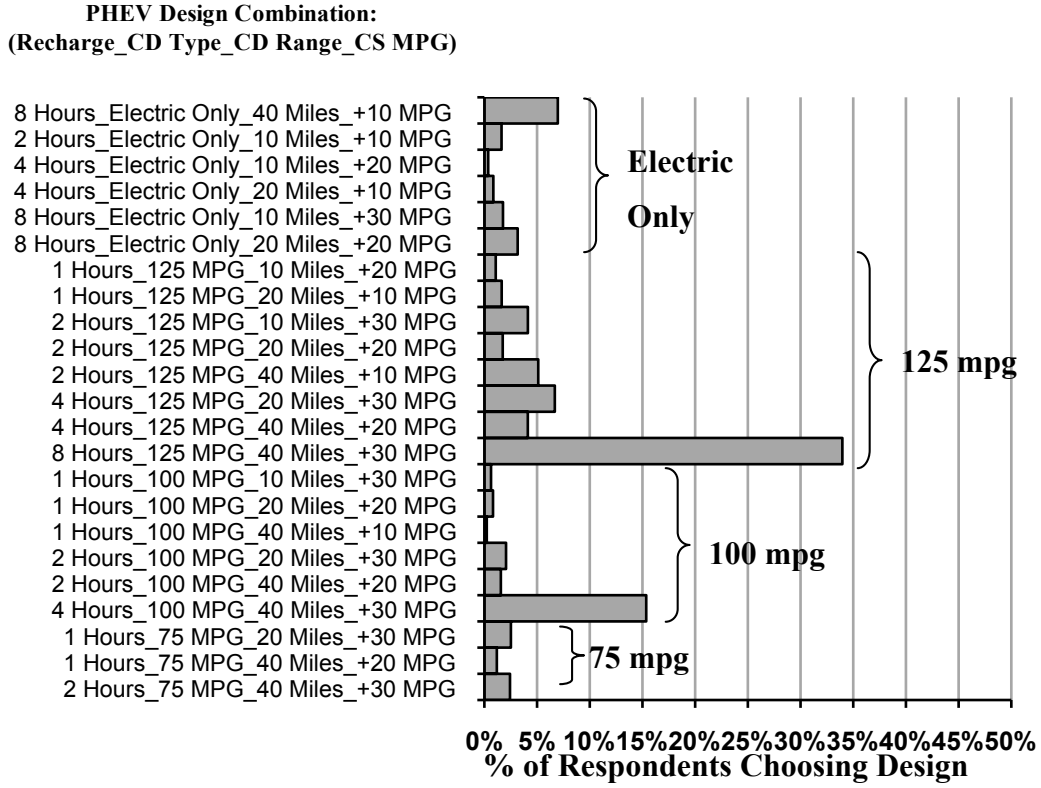


Figure 12: Northern California Distribution of selected PHEV designs in Round Four of Development game (*plausible early market* only: NCA, n=63)

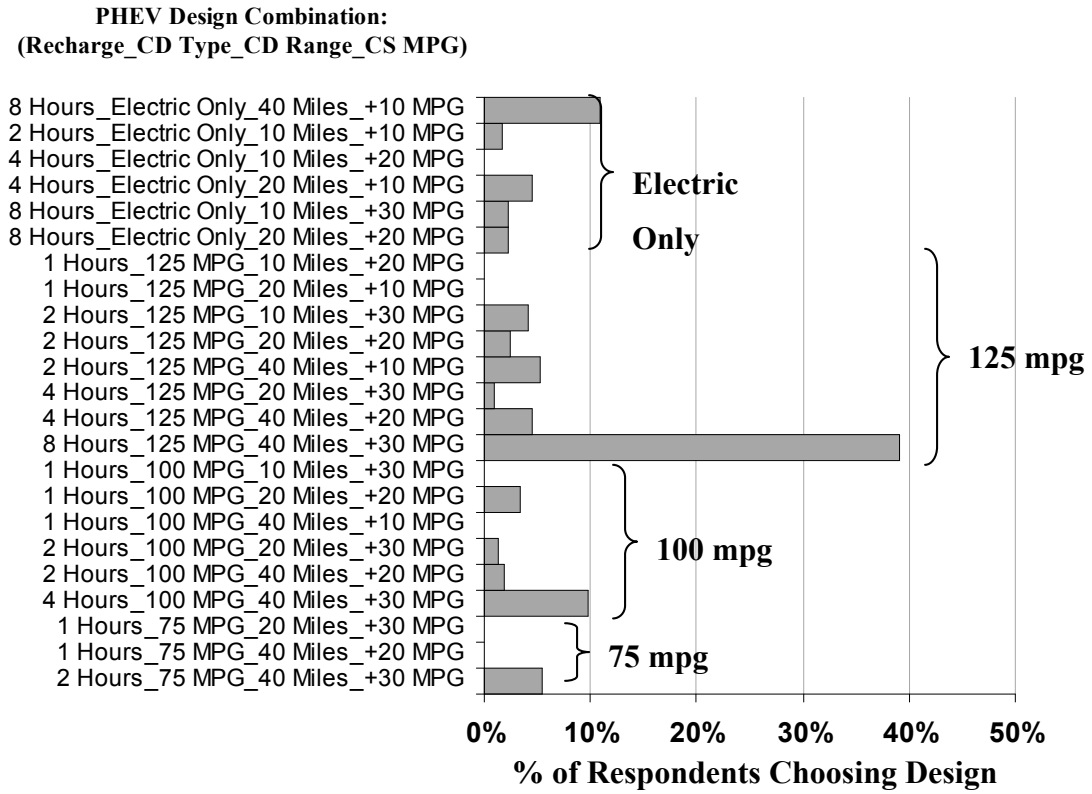
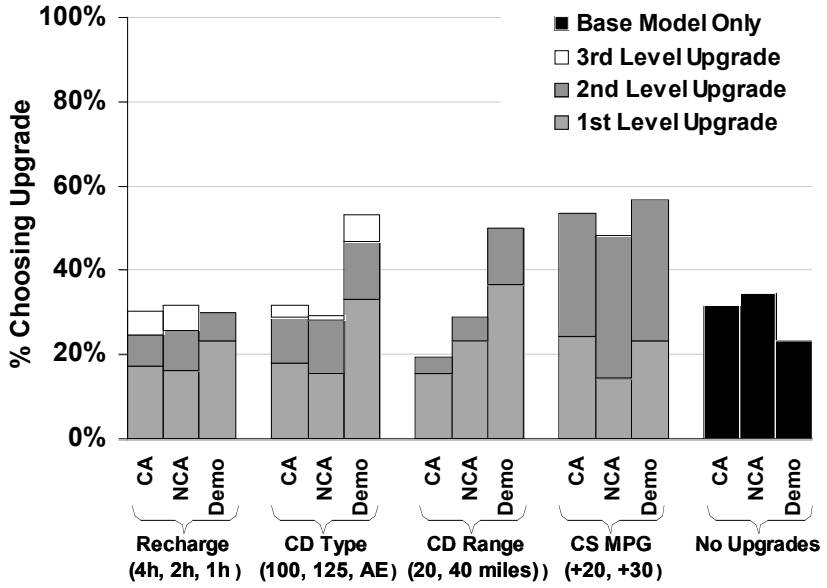


Figure 13: Three-Sample Comparison of upgrades selected in higher price scenario of Purchase Design game (*plausible early market* only: CA, n=286; NCA, n=63; Project, n=30)



2B. PROJECT RESULTS: RECHARGING

PHEVs provide consumers the option of using gasoline and grid-generated electricity to power their personal vehicles. As the effects of PHEVs on lifestyles, energy use, the environment, and the electricity grid depend on driving and recharging behaviors, there is interest in how often, and at what time of day PHEV owners will recharge. One goal of presenting information about the recharging behavior of drivers in this demonstration project is to compare those observed behaviors to assumptions about such behaviors. From the 67 households-to-date, we have recorded 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 during their PHEV trial.

We emphasize that households were not coached, encouraged, or cajoled to recharge. We clearly delivered a car to them that *could* be plugged in to the electrical grid. Almost the first thing we did upon arriving at each participating household was to verify where they *would* park and *could* plug in the vehicle. In this sense, the entire experience compels at least the idea of plugging in the car. If we are trying to address the most conservative assumption about recharging PHEVs, i.e., that people will not conscientiously plug-in a car that does not have to be plugged-in to be driven, it is almost impossible to imagine how this experiment could be run at all. On the other hand, advocates will be disappointed that we did not probe for the maximum possible benefits that could be wrung from these vehicles by plugging them in at every available opportunity.

The answers to whether we have unavoidably over-estimated the minimum and under-estimated the maximum possible recharging lies in the observed behaviors of our households. By conducting the experiment as we did, we were able to observe people who did not recharge, people who made concerted efforts over periods of weeks to maximize their CD driving by recharging frequently, and the range of behaviors in between.

All figures presented in this section are based on the last week of each household's trial with the PHEV conversion so that we can compare the same number of days and days of the

week. 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. Further, based on the structuring of daily life provided by the unit of a week, we have assumed Mondays are more like Mondays and that all households Mondays occurred on the same hypothetical Monday, and so forth for every day of the week.

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 strongly believe that for some households, 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 their PHEV slightly more than once per day in an unconstrained world (as will be detailed next), we do not dismiss the argument that if these households had been given PHEVs with a different CD range, recharging frequency would be different than we observed.

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

How often 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) between recharge opportunities 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, only households who could recharge a PHEV at their home participated in

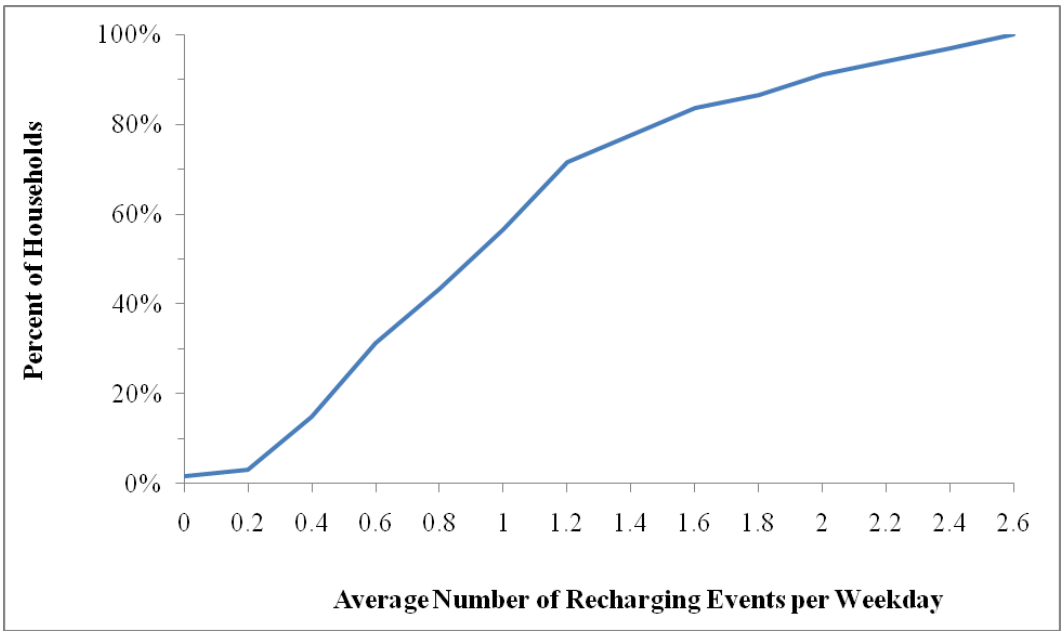
the Project. Second, as most households lacked a sense of the etiquette that would shape recharging at away-from-home locations, less away-from- home recharging was observed than may otherwise occur in a world where the rules and conventions are known. Households who noticed "EV" parking and recharging spaces often asked us whether they could park and charge their PHEVs in such spaces. The few bolder people 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. Fourth, when away-from-home recharging opportunities were discovered, they often were a source of free (to the PHEV driver) electricity. 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 and in some cases unconstrained by prices at all.

We calculate the mean number of times per day each household plugged-in their PHEV on weekdays and weekend days of their last week driving the PHEV and plot the resulting cumulative distributions in Figures 14 and 16. Since plug-in events are the number of times households physically plugged-in the vehicle to an outlet, plug-in events vary in their duration and energy taken from the grid. The weekday distribution ranges from a mean of zero to 2.6 plug-in events 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 median and mean of the weekday distribution are 1.0 and 1.1 plug-in events per day, respectively; 29 households (43 percent) plugged in their PHEV more than once per day on average on weekdays. The mean number

of weekday charging events and the proportion of the sample plugging in more often are unchanged between the initial sample of households reported in Volume I and the 67 households (which include the 34 original households) reported here.

In contrast to those households with a daily recharging routine, 20 households (30 percent) plugged-in an average of 0.5 times per day on weekdays. While sometimes households forgot to plug-in a car, some of these households averaging less than one plug-in event per day were among the most sophisticated participants, cognizant of the state of charge of the vehicle as well as their upcoming travel. Thus, even if it is true that some households who did not charge every weekday might learn to charge more, it is not safe to assume that additional experience (beyond approximately one month) will necessarily increase the frequency of charging as measured across a population of PHEV drivers.

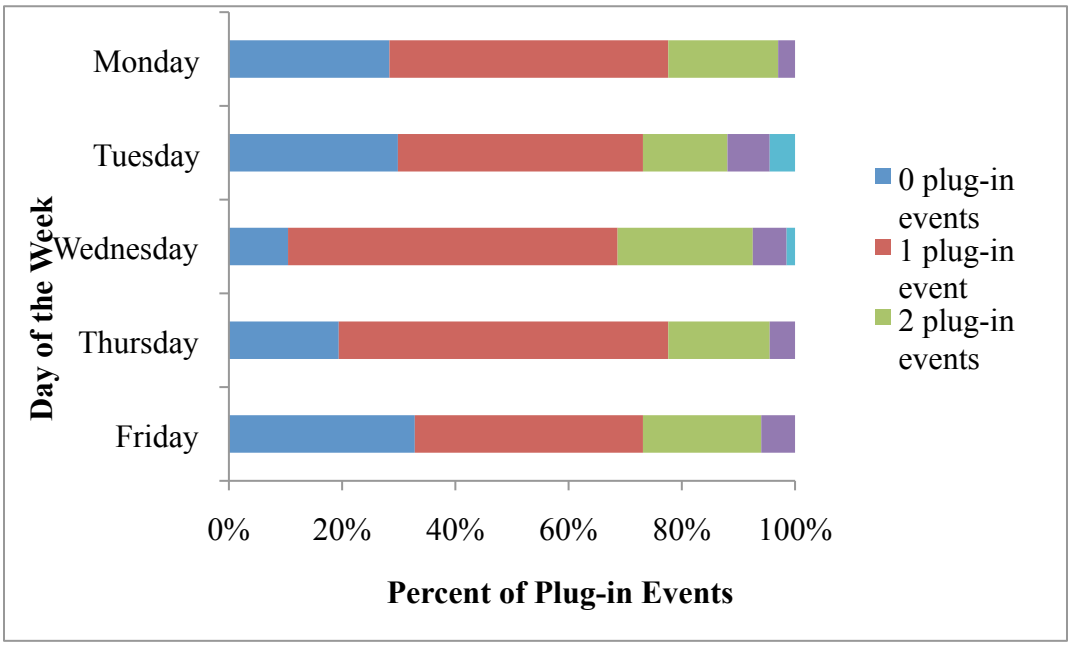
Figure 14: Weekday Cumulative Distribution of Mean Daily Plug-in Events



While Figure 14 shows the cumulative distribution of the average number of plug-in events for each household's last week, Figure 15 shows the variation across weekdays in the number of plug-in events. We observed a difference of 0.33 ($\rho = 0.017$) in the mean number of plug-in events by day of the week between a high of 1.3 average events per household on

Wednesday to a low of 0.97 on Monday. The difference between Monday and Wednesday was mostly due to the differences in plug-in behavior for those households who recharged on average every other day. Of the 19 households who plugged-in about every other day, more twice as many (12 households) did not plug-in on Monday as did not plug-in on Wednesday (five). Overall, Figures 14 and 15 show that on every weekday there was a variety of recharging behaviors across households, resulting in zero to four plug-in events per vehicle (household) per day. Further, while half the households plugged-in at least once a day on average, 10 to 30 percent of households did not plug-in at all on weekdays.

Figure 15: Household Weekday Distribution of Plug-in Events by Day of the Week, Percent



In light of the possible differences in routines and vehicle use between weekday and weekends, Figures 16 and 17 plot cumulative frequency distributions and daily distributions of plug-in events for weekend days. Comparing Figures 14 and 16 shows that plug-in events are less frequent on weekend days than on weekdays. Notably, one fifth of the sample did not plug-in their PHEV on either weekend day. The mean number of plug-in events per household was 0.9 per weekend day; the median value was 0.75. In contrast to weekdays on which 43 percent of households plugged-in the PHEV more than once, on weekend days only

30 percent did so. The biggest cause of the lower mean incidence of plug-in events on weekends was the PHEV being used for a trip away from home, which was most households' primary or sole recharging location. When taken out of town on trips that tended to be long (compared to weekday households' weekday travel and to the CD range of the PHEV) and overnight, the PHEVs were rarely or never charged. Conversely, PHEVs were plugged-in less frequently because the household was away for the weekend in one of their own vehicles. This was often the case when one of the households' own vehicles better accommodated passenger and luggage requirements.

Figure 17 shows the distribution of plug-in events across weekend days. The differences in recharging behavior between Saturday and Sunday are mostly due to the differences in the vehicle's location. In particular, on Saturdays, more households don't plug-in because more vehicles are away from home (or more households are away from home but the PHEV is at home) and their primary recharging location. As household's return home on Sunday, some plug-in the PHEV in preparation for Monday.

Figure 16: Weekend Cumulative Distribution of Mean Daily Plug-in Events

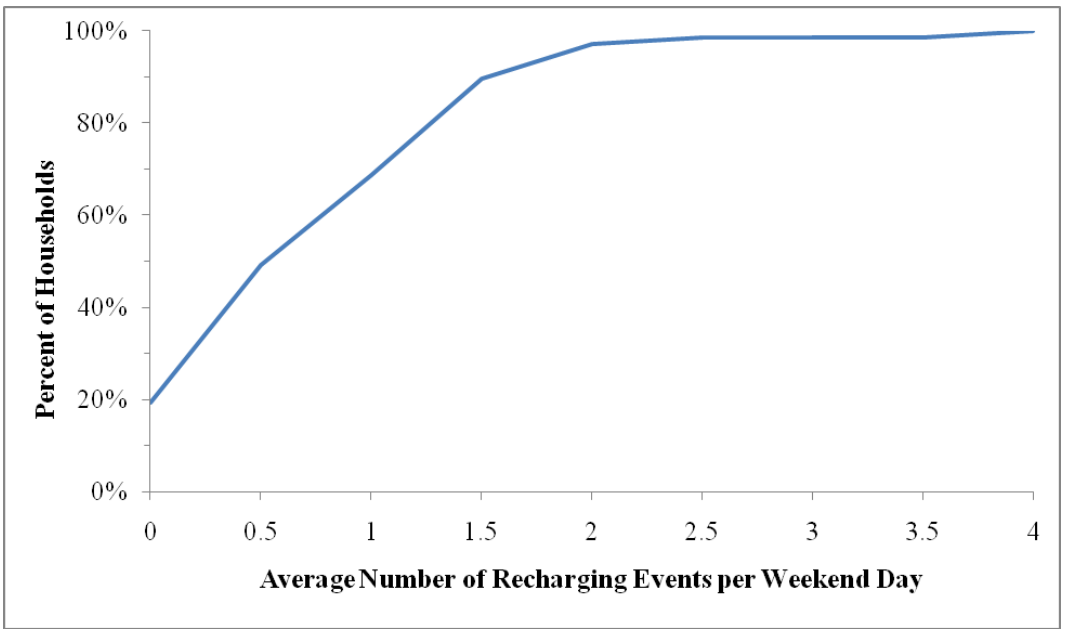
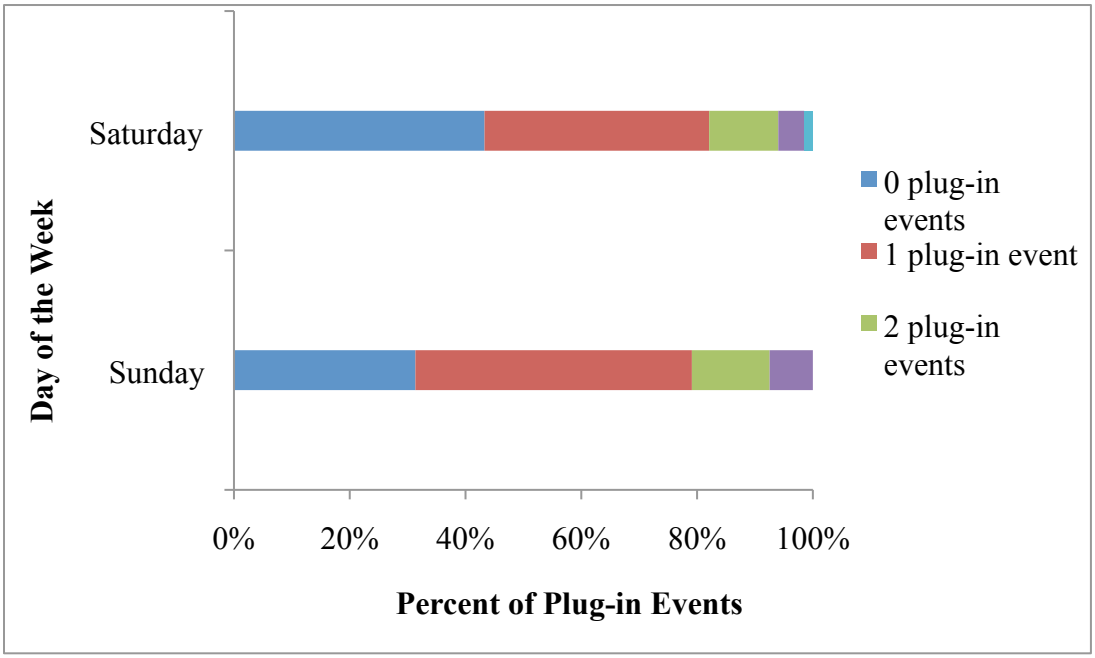


Figure 17: Weekend Distribution of Plug-in Events by Day per Household

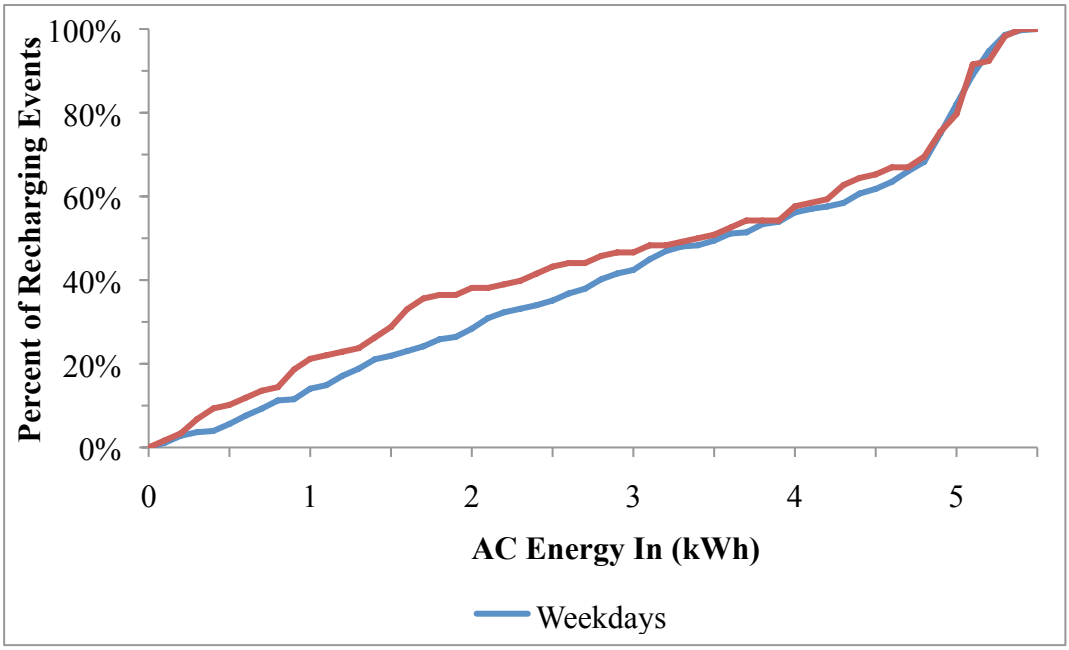


Plug-in Events and Energy Use

Plug-in events vary widely as to amount of energy transferred to recharge the battery. As such, "recharging behavior" varied across households with respect to plug-in events, the time of day households plugged-in, and the energy taken from the grid for any given plug-in event. Figure 18, shows the observed distribution of the AC energy per plug-in event for all households last week, for weekdays and weekends.

For weekdays and weekends, about 40 percent of all plug-in events were full charges of the battery, defined as returning the battery from "empty" (approximately 10 percent SOC) to full (100 percent SOC), and requiring over 4.4 kWh of energy. The other 60 percent of plug-in events were partial recharges of the battery. On weekdays, about 40 percent of all plug-in events required less than 3kWh as compared to 2.25 kWh on Weekends. The difference in AC energy per plug-in event between weekdays and weekends is due primarily to differences in driving between the two days. Those households that drove the PHEV and plugged it in on the weekends tended to drive less on weekends than on weekdays, and thus plugged-in on weekend days at a higher starting SOC. The cumulative distribution of AC energy in for all 67 households is almost identical in to that of the first 34 households.

Figure 18: Distribution of AC Energy Use per Plug-in Event



Electricity Availability And Instantaneous Power Demand

To describe the time of day recharging behavior observed during each household's demonstration, we have summarized information in two additional measures: electricity availability and instantaneous power demand. *Electricity availability* is the time 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. *Instantaneous power demand* is the power drawn from the grid to recharge the supplemental PHEV battery. The observed average recharging rates for these PHEV conversions varied across households and vehicles—generally falling between 0.9 and 1.2 kW. To compare and summarize across households, instantaneous power demand is standardized (by assumption) to 1.0 kW. Additional parasitic loads from the battery cooling system, in the range of 5 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.

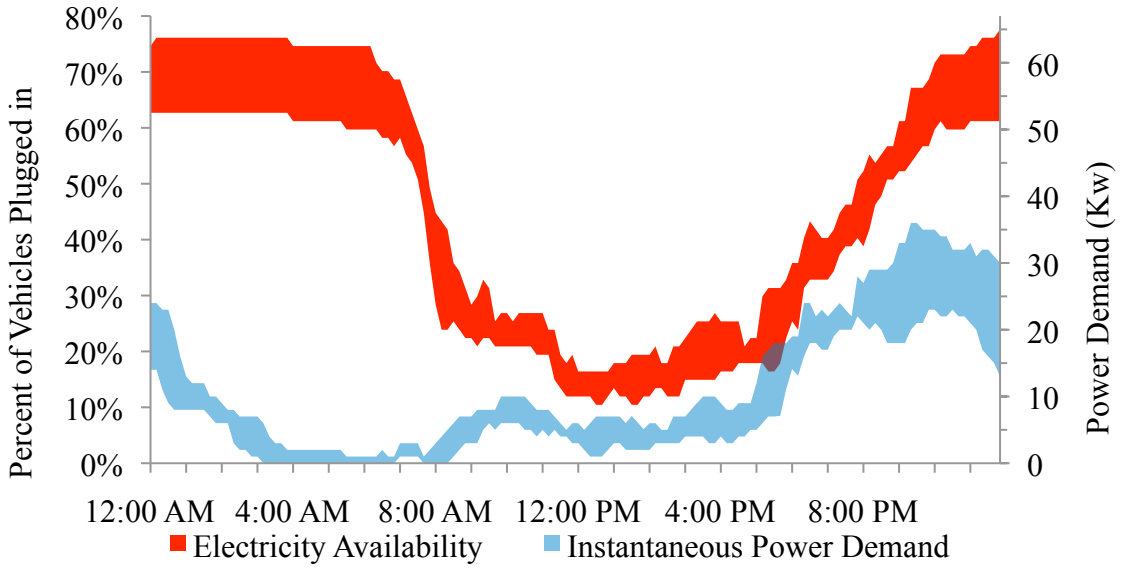
Aggregating households' last week of electricity demand to create pseudo-total demand requires the additional assumption that all households drove and recharged the PHEV during the same calendar week. Given the variation in time of day of electricity availability and power demand across households and days of the week, average values are poor representations of the observed behaviors. As such, the range of the observed values of electricity availability and power demand are reported.

Electricity Availability & Instantaneous Power Demand: Weekdays

Weekday electricity availability is presented in Figure 19 as the range across weekdays in the percent of vehicles that were plugged in at a specific time of day. Electricity availability is often (at least implicitly) assumed to be 100 percent (at least at night). Figure 19 shows 1) electricity availability never approaches 100 percent and 2) there is considerable variation throughout the day across weekdays as shown by the height of the red area. Across the 335 weekdays (67 households times 5 weekdays each), 62 to 75 percent of PHEVs were plugged in between 10:00 pm and 6:00 am. The large number of respondents who had full time jobs and typically left home in the morning to drive the PHEV to work explains the decline by 9:00 am to only 25 to 40 percent of PHEVs connected to the grid. At noon, 12 to 18 percent of vehicles were connected to the grid. While five households recharged at work during the day, the other PHEVs plugged-in to the grid during midday were retired individuals, households with flexible work schedules, and those drivers who stayed home during the day. By 4:00pm households started to return home from work and vehicles began to be plugged in. The percentage of PHEVs to which electricity was available steadily increased until 10:00 pm at which time the percentage stabilizes. The greatest variability—ten to thirteen percentage points—occurred between 10:00pm and 6:00am.

While the electricity availability tells us when the vehicles were connected to the grid and could recharge from (or discharge to) the grid it does not specify when power is being demanded; we discuss instantaneous power demand for recharging next. The blue area in Figure 19 shows the variation across weekdays of the total instantaneous power demand by time of day for all 67 Project households, again aggregated into a single pseudo-week.

Figure 19: Weekday Electricity Availability and Peak Power Demand



Power demand to recharge vehicles ramped up after 5:00pm and peaked just after 9:00pm. It declined steadily through the rest of the night and into the morning, and practically reached zero by 4:00am, and stayed there until 7:00am. While a few households charged during the day, most of the demand to recharge vehicles was between 5:00pm and 4:00am. The most variability in time of day power demand occurred in the evenings between 5:00pm and midnight. The lower boundary of the power demand between 4:00pm and 8:00pm was primarily a result of the increased probability of households not plugging in the PHEV on Friday evenings. The upper evening boundary was shaped by a higher percentage of people who plugged-in on Wednesday night. Regardless of the absolute power level at 5:00pm, there was a rapid increase in the instantaneous power demanded between 5:00pm and 6:00pm. Compared to the first 34 households, the minimum observed electricity availability increased slightly, by approximately 3 percentage points. The increase in the observed minimum also effectively decreased the variation in the percent of vehicles plugged-in between 10:00 pm and 6:00am.

In the absence of any signals, e.g., prices, or supporting systems, e.g., timers, households tended to plug-in their PHEVs in the early evening on weekdays. As described by the household interviews, some households chose to plug-in as soon as they arrived home the

first time. Others waited until after the last trip of the day, or until the vehicle was brought into the garage at the end of the day. Regardless of when they plugged in the car in the evening, most households waited to unplug it until they left home in the morning, i.e., only a few came back out late in the evening to unplug the car. Instantaneous power demand increased rapidly starting at 5:00pm, as more vehicles with depleted batteries were plugged-in. Power demand peaked around 10:00pm.

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 that there was potential to shift electricity demand from these PHEVs until after 10:00pm, since instantaneous power demand needed to recharge these vehicles declines rapidly after 10:00pm and most all recharging is completed by 5:00am the following morning. Lastly, the observed peak power demand of 35 kW was about 52 percent of the total possible power demand of the 67 vehicles.[7] As such, it would appear as though the variation in the frequency of plug-in events, the energy per recharging event, and the time of day in which people choose to plug-in, reduced evening peak power demand well below this hypothetical maximum. This percentage of the possible peak power demand was nearly identical to that observed in the first 34 households, where 55 percent of the total possible power demand was observed at the 10:00pm peak.

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 a 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, and the time of day power demand may differ from weekdays. To explore these differences, we provide next an analysis of weekend days that parallels the analysis for weekdays just presented.

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[7] Using the assumed 1.0kWh recharging rate, the maximum possible demand if all 67 households had been recharging at once would be 67kWh.

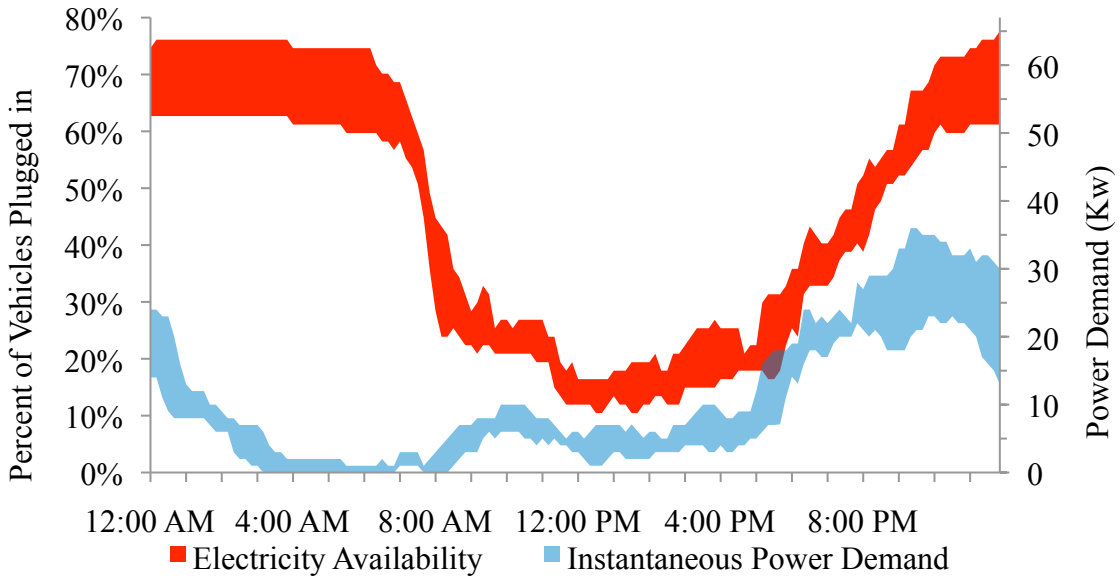
For weekend days, Figure 20 shows the variation in the percent of vehicles with electricity available to them at a given time of day (in red, on the left axis) and the instantaneous power demand (in blue, on the right). Fewer PHEVs were plugged in during the weekend high availability period than during 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 started an hour later on weekend days than on weekdays. While electricity availability decreased toward and into the morning, it does so more gradually than on weekdays and did not decline below 15 percent for the entire 24-hour period. The incidence of vehicles being plugged-in between 2:00pm and midnight increased less rapidly than on weekdays. Compared to weekday recharging, it appears that some households, if they had access to an outlet, plugged-in the PHEV for longer on the weekend than on weekdays.

Fewer households plugged-in their vehicles on weekend nights compared to weekday nights; the highest percentage of vehicles plugged-in on weekend nights (Sunday) was about the same as the lowest percentage on weekday nights. While there appears to have been little difference between Saturday and Sunday in the percentage of vehicles plugged in during the morning and afternoon, there was 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 made 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 20 also shows the variation in power demand on 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 were significant differences in the total power required from weekdays. 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 SOC 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 vehicles plugged-in earlier have already finished recharging, although they remained plugged-in to an outlet.

Figure 20: Electricity Availability (Percent of PHEVs Plugged-in) and Instantaneous Power Demand by Time-of-Day (kW), Weekend Day



Unlike weekdays, the greatest difference in power demand was in the early afternoon and early evening. The upper boundary for the evening electricity demand is due to the demand observed on Saturdays, when people generally charged later than on Sunday. As with the case of weekday instantaneous power demand, it appears as though there was an opportunity to shift recharging of these PHEV-conversions by these households to off-peak electricity demand periods.

Comparing weekend electricity availability and demand between all 67 households and the first 34, there were only slight differences in the percent of vehicles plugged-in, with an increase in the low and high values between Saturday and Sunday of about five percentage points. Electricity demand increased almost proportionately between the two periods of analysis, with approximately 31 percent of total possible power being consumed at peak for the first 34 vehicles, and 33 percent for all 67 vehicles.

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

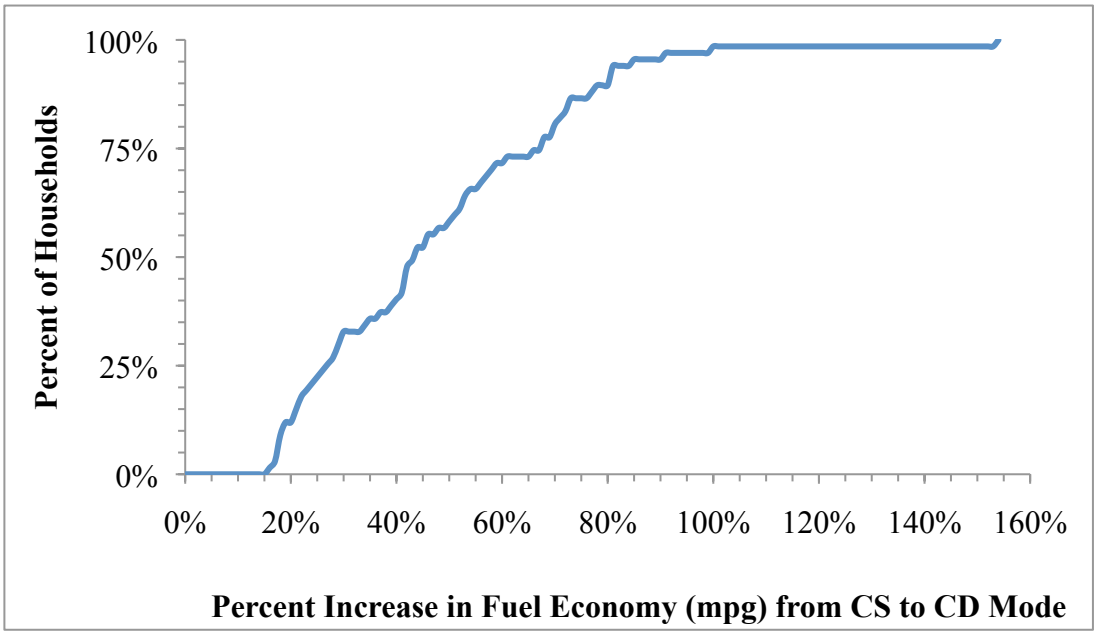
The recharging results presented so far focus on the recharging behavior across households, without any indication as to the impacts of these varied behaviors on CD operation or our household's abilities to reduce fuel or energy consumption. One measure of the differences between households is the difference in gasoline-only fuel economy (miles per gallon) between CS and CD operation. We describe these results first as it is the measure used by most participants to judge what recharging means to each of them. The discussion of gasoline-only fuel economy 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 they could travel on a tank of gasoline, cost per tank, or frequency of gasoline refueling.

Across the group's last week with the PHEV, the mean CS fuel economy was 44.3mpg and the mean CD fuel economy was 65.5mpg. Thus, the group mean increase in CD vs. CS fuel economy was 49 percent. These group measures mask tremendous variation across households. The cumulative distribution of households' mean fuel economy improvements between CS and CD operation is shown in Figure 21. The range is from 16 to 154 percent, however, improvements over 80 percent are exceptions. Ninety percent of households had improvements in gasoline-only fuel economy between CS and CD driving of less than 80 percent; the median improvement was 43.5 percent.

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 sanction. The analysis presented next combining gasoline and electricity is still preliminary and partial. It is preliminary because only one particular PHEV design is analyzed. It is partial because it is not a life-cycle analysis—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 ever recharging, i.e., entirely in CS operation.

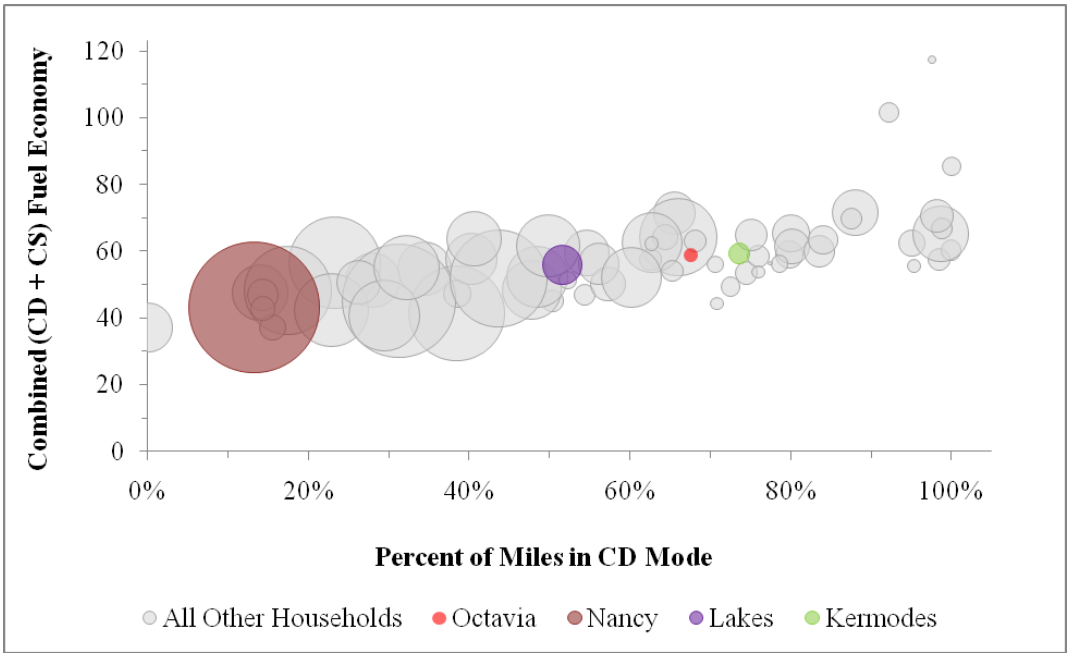
Figure 21: Improvement in Gasoline-only Fuel Economy from CS to CD Operation



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 vehicles are similar to each other, differences across households are due to differences in driving and recharging behaviors. Figure 22 illustrates the overall variation in performance of the participants with regard to their last week of driving and recharging the PHEV conversion. Figure 22 plots each households average (gasoline-only) fuel economy by the percentage of miles they drove in CD mode. Each circle represents one household; the diameter of each circle is proportional to the overall distance they drove in the PHEV during the their

respective vehicle trials. Four households identified (by pseudonym); they will be discussed in further detail throughout this and following sections.[8]

Figure 22: Gasoline-only Fuel Economy by Percentage of Miles Driven in CD Mode, Weighted by Last Week (CD+CS) Distance Driven



Households 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. (However, on average, these households always outperformed their own driving of the PHEV-conversion in CS operation.) On the other hand, 18 households (27 percent) drove 80 to 100 percent of their miles in CD mode and achieved weekly average

[8] Figures 22 through 26 in Volume II are not comparable to their counterparts for the first 34 households in Volume I. The figures in Volume II are based on the last week of driving the PHEV; those in Volume 1 are based on the entire month of PHEV driving.

gasoline-only fuel economy of 70 to 117mpg during their final week driving the PHEV-conversion.

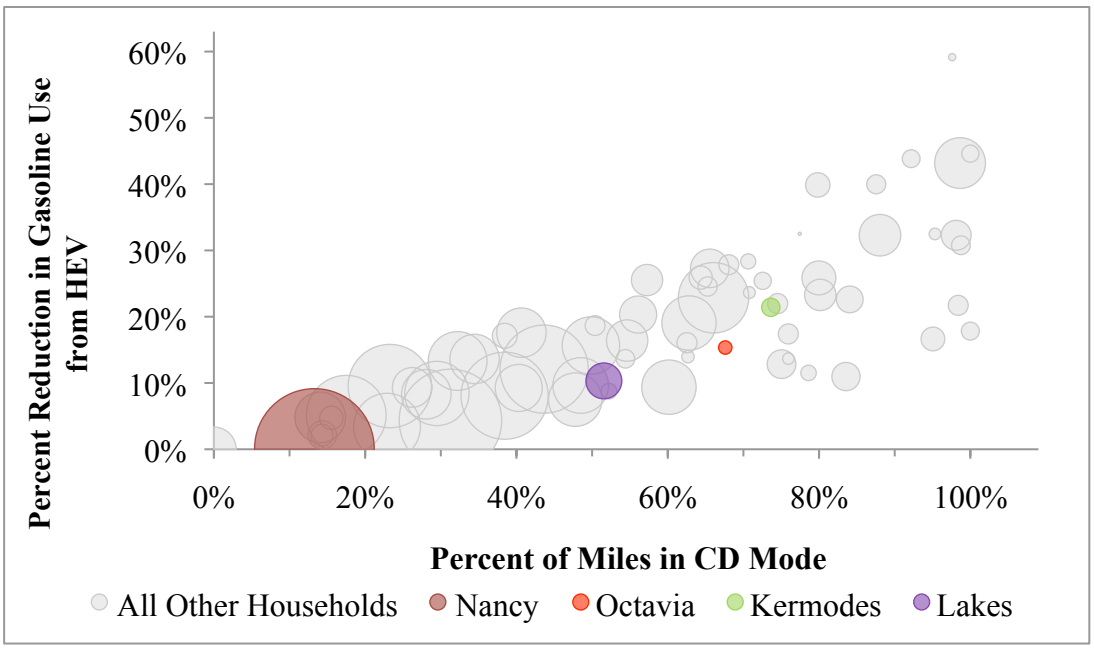
A simple linear regression fit to the (distance-weighted) data in Figure 22 is statistically better than fitting the mean of the mean average fuel economies (at $\alpha < 0.01$), but returns a modest adjusted $R^2 = 0.43$ (lower than the 0.55 for the first 34 households, indicating increased variation in later households). 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 0.321 (not substantively different from the 0.346 estimated for the first 34 households): each percentage point increase in miles driven in CD mode leads to, on average, an increase of about one-third mile per gallon in the weekly average CD+CD fuel economy. This result is specific to this PHEV-conversion—the increase would differ for any other PHEV for behavioral reasons, e.g., travel and recharging, as well as technical.

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 22 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 22. While our households varied in their marginal increase in gasoline-fuel economy provided by the PHEV conversion, i.e., HEV compared to PHEV for their last week with the car, every household who plugged-in was able to increase their fuel economy during their PHEV trial, compared to what they would have gotten driving an HEV.

Figure 23 shows each households reduction in gasoline use in driving the PHEV-conversion vs. the underlying HEV. Again, each household is also represented by a single bubble whose diameter is proportional to the total miles driven for that household's last week of their PHEV trial. Households varied widely in their overall gasoline use. Gasoline consumption tended to be lower in households with higher percent of miles driven in CD mode; however,

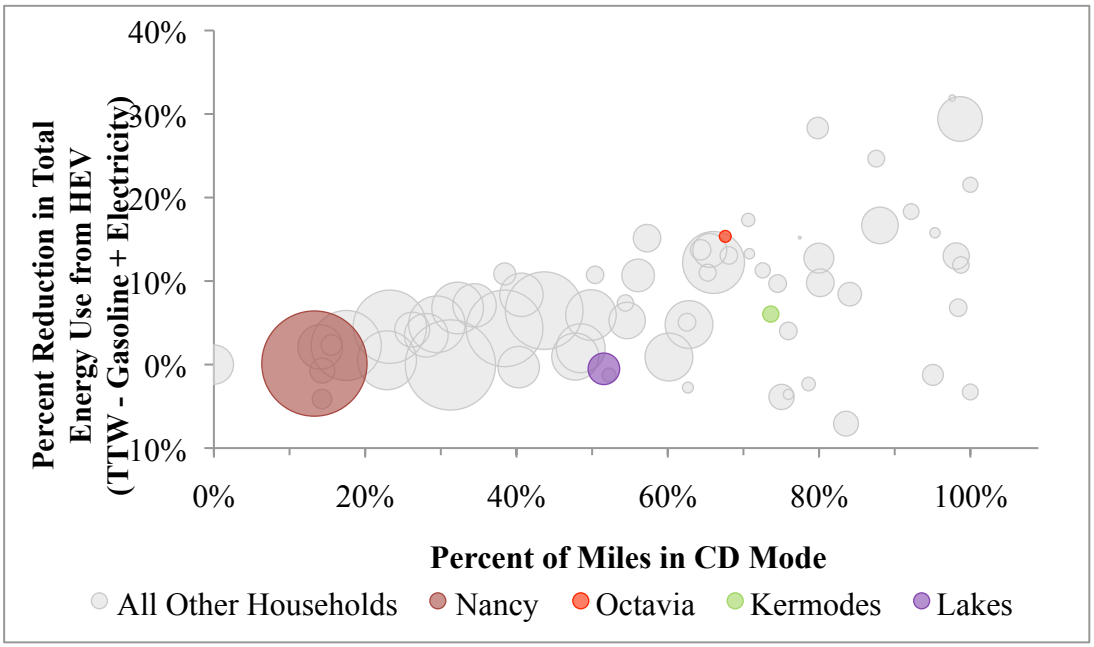
it would appear that gasoline consumption (at least for these vehicles) includes factors beyond the relationship between recharging behavior and driving distance. These could include top speeds, accelerations, and the distribution of trip length and type. However, a handful of households were able to decrease their gasoline use between 40 and 60 percent; others decreased their fuel use as little as three percent.

Figure 23: Reduction in Gasoline Use Compared to Driving an HEV, Percent



In addition to gasoline consumption, ideally PHEVs decrease total energy demand. To illustrate relationships between driving, recharging, and total energy use we plot the marginal percentage decrease in total energy (gasoline (tank to wheels) plus electricity (battery to wheels)) by the percent of households' miles driven in CD mode for each households' last week of their PHEV trial in Figure 24. As in Figure 23, the diameter of each data point in Figure 24 is proportional to the total miles driven during the last week of each household's trial.

Figure 24: Reduction in Total Energy Use Compared to Driving an HEV, Percent



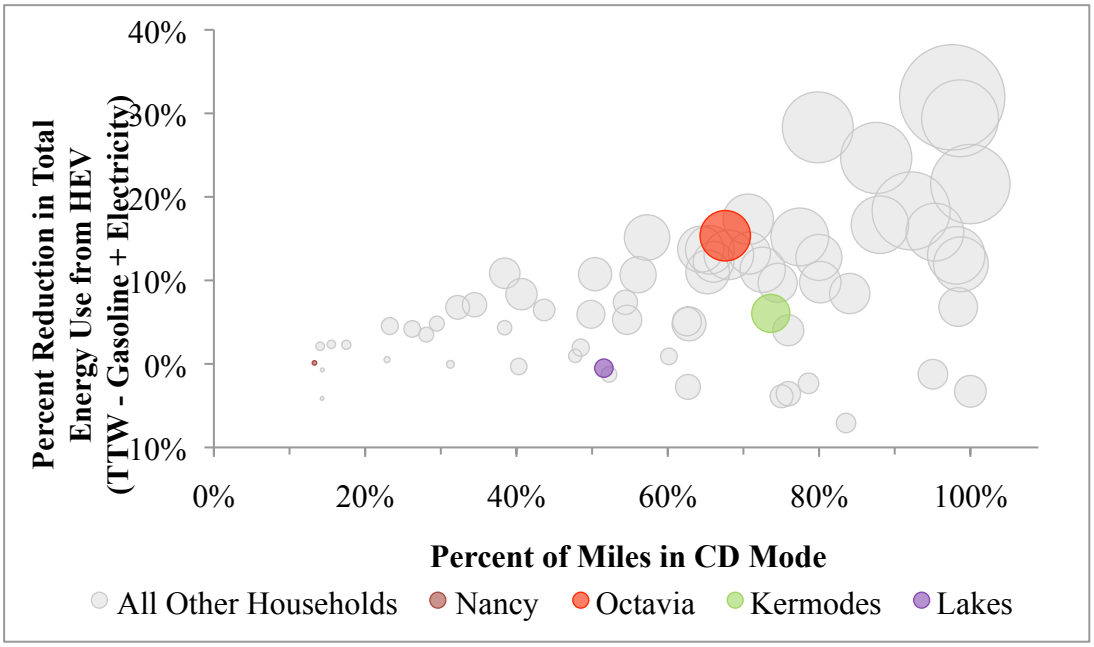
Comparing Figures 23 and 24 shows that the households' use of the simple measure of (gasoline-only) fuel economy is not qualitatively wrong. As the percent of miles driven in CD mode increases, both fuel economy and total energy savings increase. Whatever changes to travel or recharging that would have 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 23 confirms that across most 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.

Looking at the household identified as "Nancy," her low percentage of CD driving yields low percentage energy savings from a large (compared to the other households) base. In comparison, Octavia achieved much higher percent energy reductions but across much less travel, and thus a smaller energy base. She did so in part because of the much higher percentage of travel accomplished in CD mode—because she both recharged more often and traveled fewer miles than Nancy and the household identified as the "Kermodes."

Overall, households reduced total "tank-and-battery to wheel" energy from -7 to 32 percent. While every household reduced their gasoline use in the PHEV, the marginal impact of the PHEV on fuel economy varied significantly, with some households only decreasing gasoline use by three percent. In these cases the energy reductions gained through decreasing gasoline consumption were exceeded by the electrical energy from the grid.

The effect of the marginal increase in gasoline-only fuel economy on total energy reductions between the households driving a hypothetical HEV and the PHEV is illustrated in Figure 25; in this case, the diameter of the circles are proportional to the percentage difference in the average fuel economy each household accomplished in CD and CS operation.[9] Those households that had small percentage increases in fuel economy between CS and CD operation tended to increase their total energy use or decrease it very slightly, i.e., the small circles plot at or below 0 percent reduction in total energy use.

Figure 25: Reduction in Total Energy Use Compared to Driving an HEV, Percent (weighted by difference between each households achieved CD and CS gasoline-only fuel economy)

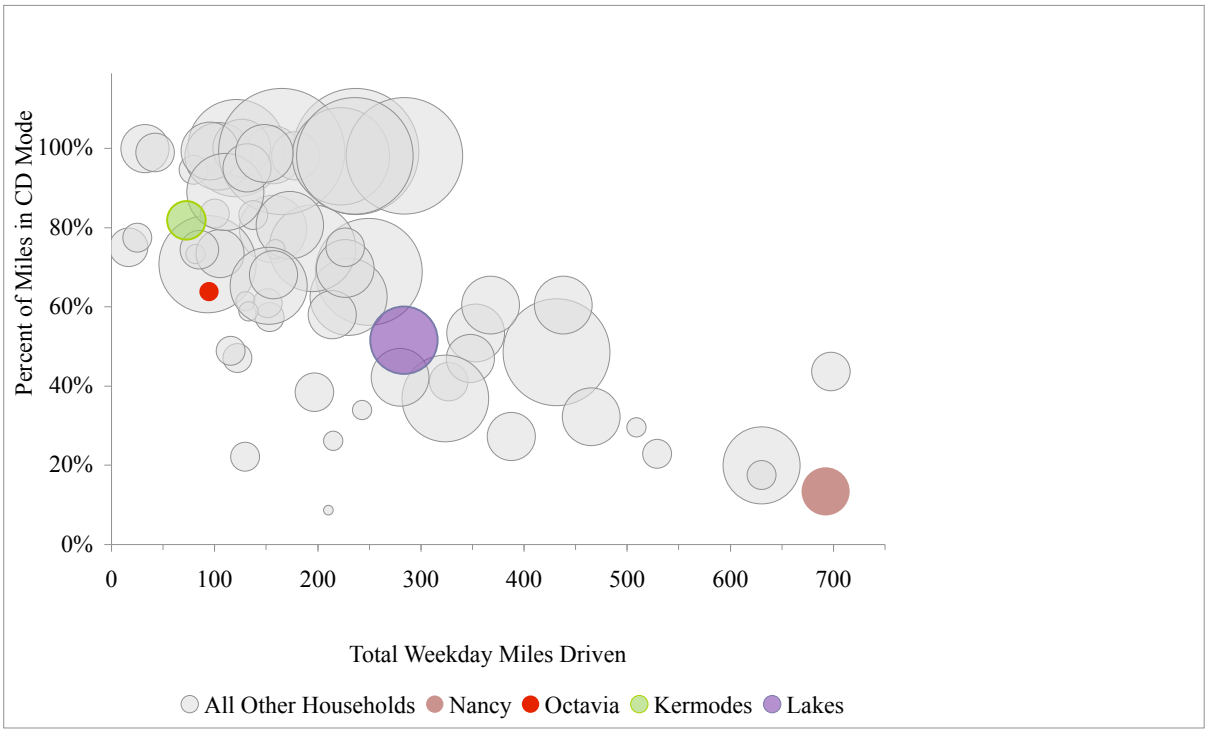


[9] The hypothetical HEV is the PHEV in CS operation.

Impact of Recharging Behavior on CD Travel

Up to this point the effects of recharging behavior and household travel on CD driving have been examined separately. Figure 26 illustrates the combined effect of households' recharging behavior and travel on the percent of miles driven in CD mode. The diameter of each household's data circle is proportional to their mean number of weekday plug-in events. The relationship between recharging, travel and CD operation is not simple. A linear regression fit to the data in Figure 26 shows that on average an increase of 100 miles of driving per week is correlated with a decrease of the observed percent of miles in CD mode of 10 percent. Still at the any given total miles driven, households differed by up to 60 percent in their observed CD driving. The distribution of the observed percent of CD driving for any given driving distance supports the assertion that for PHEVs users' driving and charging behaviors can be just as important as the technical specifications of the vehicle.

Figure 26: Distance Driven in CD Operation by Total Weekday Miles, Percent (weighted by household mean weekday plug-in events during their last PHEV week)



2C. Project Results: Narratives of Households' Encounters with a PHEV

Recap of Narratives: What and Why?

As used in this research, a narrative is a description of a household's encounter with a PHEV as written by a researcher. Narratives of each household's encounter with PHEVs allowed researchers to both analyze and synthesize the vast amounts of different types of data collected from participants. Participants' interview and survey data provided insight into their motivations and thoughts as they interacted with the PHEV. The interpretive nature of narratives allowed researchers to convey a participant's individual meaning as well as what their culture (as shared with the researchers) prescribes.

A New Typology of Household Narratives: Discernment

In the first volume, we classified narratives according to a typology structured by the level of understanding of PHEVs prior to and after each household's PHEV demonstration period. For example, the narrative of Rick and Samantha Lake typified people who understood the PHEV technology before they started their demonstration (and therefore at the end, too). Nancy represented those households who did not understand the technology either initially or after their experience. Finally, Octavia illustrated those households who started their trial not understanding the PHEV technology but developed a better understanding over the course of their PHEV trial.

For this second volume, we have modified our organization of the households' narratives. The new typology is based on whether participants were able to *discern* between a conventional internal combustion engine and a PHEV. The distinction we make between discernment and understanding is as follows. To discern is to comprehend how a PHEV is different from a conventional car depending on how one interacts with it; to understand is to be able to explain the electro-mechanical details of how a PHEV operates. The participants need not understand how the car operates in order to discern how they can engage the PHEV to make it function for them. Table 3 organizes some example households according to

whether they had discernment between PHEVs and conventional vehicles prior to their participation in the study and whether they ended their PHEV trial able to discern between the two. As with the prior typology—in which no household started with understanding and ended not understanding—no household started with discernment and ended without it. Further, the Table identifies households within each category of prior-post discernment as to whether in the end they expressed an interest in buying a PHEV.

Ultimately, neither understanding nor discernment neatly classifies which households were interested in a PHEV for their next car and which were not. The implications of this for policy and marketing are introduced in the discussion at the end of the chapter. The next step in the analysis will be to compare the two types of household narratives—those that are interpreted as interested in a PHEV and those that are not—and search again for explanation.

Table 3: Examples of Households Organized by PHEV Discernment and Interest

Prior Discernment	Ending Discernment	PHEV Interest	Example Households
No	No	No	Polluck
No	No	Yes	Nancy[a]
No	Yes	No	Fort[b]
No	Yes	Yes	Octavia[a], Kermode[b]
Yes	Yes	No	Bluth
Yes	Yes	Yes	Lake[a]

a. Narrative in Volume I, Chapter 3c and Appendix F.
b. Narrative told below.

Narratives' Themes

While the typology above is important because it allows researchers to organize narratives according to arcs of varying discernment between conventional vehicles and PHEVs, another important way to organize the narratives is according to the themes that arise from the narratives themselves. Themes are storylines or motivations that appear to be particularly

important to the arc of a household's narrative. A theme may be a description of the arc; it may also be what compels the arc, i.e., what moves the story of the household's encounter with a PHEV along. The categorization of households according to their beginning and ending discernment is one use of themes; in the case of discernment, the theme is confusion.

Recapping Themes from the First Thirty-four Households

As detailed in Volume I, researchers elicited these four themes from the narratives of the first 34 households (though no single narrative revealed all of them): changing driving behavior, recharging habits and etiquette, confusion, and payback. These themes are recapped with these brief examples.

Driving Behavior: Some participants explained that they changed their driving behavior because information they saw on the Energy Monitor made them aware of how their actions impacted the performance of the car and their gasoline-only fuel economy. Some used the Energy Monitor to play a game of who in the household can achieve the highest fuel economy or keep the battery engaged the longest distance or time. Others, mostly women, drove the car like their normal vehicle and did not watch the Energy Monitor.

Recharging: Many found recharging to be easy and likened it to a daily chore such as feeding the dog. Most recharged only at home, primarily due to a lack of other perceived recharging locations, hesitance to ask if they could recharge due to a lack of etiquette around recharging and fear of the cord being stolen or a tripping hazard.

Confusion: Confusion plagued many participants; some were confused about the technology and many were confused about the state of charge of the battery. The theme of confusion was expressed in three different ways: lack of information; incorrect information; and, incomprehension, i.e., they had correct information but did not understand it.

Payback: Some households discussed the idea of payback analysis and if the PHEV was "worth it" comparing the cost of the vehicle and the operational costs. Benefits to the environment were put into the category of payback because households decided if the cost of the PHEV outweighed the benefits to the environment, the same "calculation" used for buying a car, either in the design games or in life.

New Themes from the Second Thirty-two Households

While the four themes elicited from the first set of households were also elicited from the narratives of the second group of 32 households, new themes were also elicited and the theme of payback was redefined. Payback is now distinguished from two themes that had previously been subsumed within it. One is simple, heuristic evaluations of whether PHEVs "save money"; another is valuation of "collective benefits."[10] The most often mentioned collective benefits were environmental impacts; independence from oil was another. This refinement of the payback theme was done for two reasons. One, the payback concept is likely taken by many readers to include a specific type of private cost analysis. We still stretch this definition of payback to include related financial accounting practices stated by some households, e.g., net present value and return on investment. Two, it became apparent that some households were considering environmental benefits in ways that did not assume a financial calculation, but a moral action. Two newly identified themes are prior expectations of the PHEV and the future—of either all cars or cars for a given household.

Saving Money

Those who spoke about saving money were talking specifically about spending less money on gasoline per month; they made no attempt to compare these operating cost savings to the initial price of the vehicle and cost of upkeep as one would in a payback analysis. Further, that they would save money with a PHEV was typically assumed based on the further assumption that electricity is priced less than gasoline.

Many households believed the PHEV saved them money. Edgar explained, "[Recharging the PHEV with electricity] is a heck of a lot cheaper than buying gasoline." For him, the price of electricity was less than the price of gasoline and because of this he saw value in using electricity as a fuel source to replace gasoline. Shannon was convinced the PHEV saved her money because of a conversation she had with a friend who owns a Prius. According to Shannon, this friend said, "her savings on gas make her car payment." This was influential

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[10] Collective benefits are similar to the pro-societal benefits introduced in Chapter 2E.

for Shannon and helped form her opinion of the PHEV as a cost efficient vehicle because if the standard Prius saved money then the PHEV version must too.

Other households described the PHEV as saving them money by comparing the cost of filling up the fuel tank on their regular vehicle to the cost of filling up the fuel tank on the PHEV. Ed said, "Definitely we save money, about half of what we spend in [gasoline for] my truck." In even more detail, Betty compared the cost of buying gasoline for her car and the PHEV, "I would have filled mine at least two times per week, if not more. It would have cost me, easy, $100 at gas prices right now. I spent half that, less than half of that with the Prius within a week. So, I know overall for the entire month I saved probably $200 in gas."

Collective Benefits

Collective, or pro-societal, benefits are those from which no one can be excluded and generally require collective payment. Another way to state the latter is that in most instances, no single person can create collective benefits. The example most often discussed by Project households was a vague call "to do something for the environment." We distinguish discussions of collective benefits from payback because of the wide variety of ways that households talked about how to incorporate these into their assessments. The Lakes talked about "throwing in an extra 10 percent" to pay for environmental benefits. But many households did not articulate a tradeoff or extra cost, so much as the opening of a new way for their car to achieve and express moral values and links to another new theme, the future.

For example, Penny and Devon did not mention the environment in their initial interview or list the environment as a reason that they believed they, or other people in general buy or might buy a HEV. But their conversation in their final interview foreshadows the upcoming chapter on social interactions. In their final interview the benefit to the environment came up a number of times, and seemed important to the couple. Devon talked about conversations he had had at work; "People at work thought it was pretty cool...use a vehicle that doesn't solely use gas, help out the environment a little bit."

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,

"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 instrumentation would help people make a stronger connection between their personal actions and such global problems.

Edgar, one of our most elderly participants, articulated perhaps the broadest range of collective benefits. Edgar notes that while fuel [cost] savings were important, they were not as important as "the overall effects on the atmosphere—we really do have to be concerned about the environment and the global warming." He was pretty sure that the PHEV would leave a "smaller footprint." Edgar believed that gasoline was "less clean than electricity" and he had "all sorts of negative connotations about the oil people, the way they manipulate the market, the games they play in the Middle East and Texas and even in Alaska." He stated, electricity "is going to have to play a bigger role in how we live." He feels that cutting back on petroleum is a good idea "if it's done right"—he is not a fan of using corn because it raises the price of food and is thus not a particularly efficient solution. But, "things are gonna have to change" and "we know that the US can never be self sufficient in petroleum."

Prior Expectations of PHEVs

Participants had a variety of expectations prior to driving the PHEV. Some of these expectations may have arisen from the recruitment call to participate in the research. Researchers attempted to provide uniform explanations; they explained that households would be receiving a modified Toyota Prius that uses gasoline mixed with electricity and they will not get stuck (unless they run out of gas). During that call, most participants did not ask any further questions about the PHEV; if they had further questions, they tended to be about insurance requirements.

Despite the brief and limited discussion of the Prius PHEV-conversion, participants still had an assortment of expectations. Stephanie said, "I thought it was going to be one of those little Smart cars or those things that look like golf carts." Several people made comments like this because they had seen Smart cars on the road or a neighbor had a GEM neighborhood electric vehicle. Others formed a preliminary opinion based on the fuel source being part electricity and not solely gasoline. "I thought it would be slow, I was just expecting

something really dinky and kind of tinny and chug chug, but I was very impressed," said Ethel. Another participant, Ursula, who was familiar with Prius said, "My expectation was that the car would be more economical [than her mid-size sedan]…and I think I did also expect it to be quieter and maybe have less power." Ray was one of the participants already familiar with hybrid cars and in particular the Prius: "I imagined it would be just like a Prius…I had an open mind…I wasn't sure if it would be a few MPG different or if it would be a lot different."

Many participants also had prior expectations about the PHEV battery. Heidi said, "I'm surprised at how quickly the initial battery actually runs out." This was a frequent comment from households. Norman explained, "I was a bit disappointed when I realized that the battery only would give us, what, twenty miles, and then it would be done. I wanted it to be longer than that just because it took trunk space, and it was just like, for all that, is it worth it?" Similarly, Billy said, "Even a flashlight battery should last longer than 25 minutes." The participants who were able to tell when the battery was discharged were disappointed with the length of time and/or distance the battery lasted.

The Future

Participants spoke about their time with the PHEV as a glimpse into the future: some saw the future of all cars; some saw their future with cars. When describing the PHEV Shannon said, "I mean we're talking Jetsons here."[11] Edgar explained a benefit of PHEVs, "People are looking toward how they can save money and maybe this [PHEV] is something they want to do in the future." There seemed to be a clear separation for some participants regarding the cars of today and the cars of the future; they saw the PHEV as the potential car of tomorrow, not something realistic for their current lives. Billy said, "This [PHEVs] could be the thing of the future," inferring that PHEVs may be commonplace in the future but they were not a part of his life today. This line of thinking may be in part because participants are aware PHEVs

[11] The Jetsons© was a American television cartoon show that first aired in the early 1960s depicting a world of cities elevated into the sky, robot maids, flying "cars," and other early space age imaginings.

are not currently for sale in the United States and therefore participants do not view them as an option for present purchase.

Other participants spoke about the future of cars on an individual basis, that is, not how all cars might be different, but how they as individuals will interact with PHEVs. Several participants wondered aloud about public recharging in the future. Shannon said, "I wonder if they charge you like a meter would, you know, you have to put in 50 cents for the charge while you're [parked] there." Similarly, Cindy spoke of public recharging, "I imagine that is going to be more of a thing I think in the future." Some participants were able to make a mental leap and imagine PHEVs as a realistic car option. Katrina said, "My future car will be a [plug-in] hybrid." Likewise, Michael said, "I think it's a car I'll be interested in buying eventually." For some participants PHEVs seemed like a car of the future, but the near future, and something they would experience in their lifetime.

Two Household Narratives

The following two household narratives highlight the themes elicited from the narratives constructed by researchers of each of the household's encounters with PHEVs. These two narratives have been selected to compare and contrast two households who moved in an arc from a prior inability to discern between a conventional vehicle and a PHEV to an ending discernment. Both the Forts and the Kermodes began their PHEV trials unable to explain how a PHEV might differ—to them—from one of their own conventional vehicles. More than simply being unable to explain the electro-mechanical workings of a PHEV (and notably, most members of both families would be unable to explain the electro-mechanical workings of their conventional ICEVs), neither the Forts nor the Kermodes had well articulated ideas about what a PHEV might do for them that their conventional cars don't. By the end of their PHEV trials the Forts and Kermodes had developed this discernment.

A single narrative allows understanding of a particular household; additional understanding is found in the comparison across households. Even if quantitative measures, e.g., recharging frequency and vehicle miles traveled, appear similar across households, their narratives of their encounters with a PHEV may differ. The Kermodes drove a similar percentage of their

miles in CD operation as the Forts, but their encounters with and ending evaluation of PHEVs are markedly different.

In an effort to have the narratives speak "for" rather than "about" the participants, researchers write each narrative according to their encounters with each household: a single structure has not been imposed on the narratives. To emphasize this change in authorial voice from that of the researchers' as analysts to that of researchers as story-tellers of the households' narratives, we set the narratives apart from the rest of the text by enclosing them in their own boxes. We footnote and italicize narrative text that illustrates themes, as well as footnote points of analysis, comments, and descriptions that are in the researchers' analytical voice.

Meet the Forts: More mass always wins

Brett and Selena Fort are forty-somethings who live with their college-aged daughter, Julie, and their teenage son, Rex. Only Brett and Julie participated in the PHEV trial because Selena was out of town for the first week. Their annual household income is between $100,000 and 124,000. They live in a large, 7 year-old detached home. Because the Forts park all their vehicles out front, the sheer mass of their fleet is immediately apparent to any visitor.[12] Selena drives a 2002 Chevy Suburban (full size SUV) for running errands and shuttling her son twenty miles round trip to and from school twice a day. Julie drives a 2006 Dodge Ram (full size pickup truck) to attend university in the same nearby town as her brother's school. The Forts also own a 2004 Chevy Silverado (full size pickup truck) that they use to haul their camper, dirt bikes, and ATV for weekend camping trips. Brett drives the smallest vehicle: a 1994 Honda Accord "commuter car" used for his 60 mile roundtrip commute to his job as a computer engineer.

Brett Fort links their fleet of large vehicles to concerns about safety: "My wife's been hit twice in small cars by full size trucks…she doesn't drive anything small anymore." In the first collision she was pregnant with Julie; in the second both young children were in the car with her. Brett tells us, "That's when she said, 'No more small cars.'" He concludes, "Mass always wins." Julie elaborates on her safety concerns about small vehicles, "What's scary is when people drive big things…if everyone drove a Prius, I'd be good driving one, but…you know, I drive big cars because people drive things like [large trucks]…and if you're in a little car, it's scary."[13]

The Forts bought the Suburban for Selena because of "mass…that's all it was." The purchase was prompted when their (prior) 1998 Suburban was bought back by the manufacturer under the lemon law, and though they were unsure about buying another one, "it just came down to, it was

[12] The researchers' first encounter with the Forts is pulling up to their house to deliver the PHEV and seeing the Forts' three large trucks parked in front of their home.

[13] Here the Forts elaborate on the first of what will be four different ways they arrive at vehicle purchases. In this first, they use a strict uni-dimensional rule: Selena drives the biggest truck they can find. This will be reinforced by the later observation that Selena's Suburban will likely be replaced by a Hummer.

big…she felt safer in it."[14] Brett notes Selena's ultimate goal is to go even bigger: "the Suburban will eventually be replaced with a Hummer, probably."

The Forts bought the Silverado new in 2004 to replace a smaller Toyota Tacoma pickup truck, as well as to tow a camper (described as an upgrade from tent camping). Brett considered several models, including Ford, Dodge, and Chevy, and "went to dealerships…went to Edmunds and did all the research…found out how much they cost and reliability and all that stuff…and then we drove them." Their decision came down to the family test drive, where everyone agreed that the Silverado was "most comfortable…most legroom…at the end of the day it was just comfort."[15] While the Forts are generally happy with this purchase, Brett discovered the low fuel economy of his Silverado made his commute very expensive. In 2007, when "gas was $4 a gallon," he bought the used Honda Accord when someone posted an ad for it on his workplace's electronic bulletin board. Since then, Brett has enjoyed the vehicle's fuel economy and reliability: "it's a Honda…I haven't had any problems with it." But to Brett, the Accord "is just a commuter car…nothing special about it…if I'm not driving back and forth to work it's parked out front."[16] At the time of their PHEV trial, Brett estimates he's spending an average of $80 per week on gasoline for the Accord and that this varies from $56 to $100 per week. He says the car's instrument display does not show fuel economy. He does not track fuel use.

The Forts bought the Dodge Ram for Julie in 2006 when she was about to graduate high school. Leaving town for a family camping trip to Lake Tahoe, they noticed the Dodge dealership was having a "super sale"; they stopped in on their way home.[17] Selena wanted to put Julie in

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[14] Under state (in California, the Song-Beverly Consumer Warranty Act) and federal (the Magnusson-Moss Act) law, if a manufacturer cannot repair an automobile (or generally, consumer goods) after a reasonable number of attempts, it must either replace the vehicle or pay a refund to the consumer.

[15] Vehicle purchase process number two is a more text book example of creating a choice set, searching for information, comparing the options on a variety of desired attributes, and making a choice.

[16] The third vehicle purchase process is more opportunistic. The Honda is purchased too minimize Brett's gasoline costs of his commute, not as the outcome of a deliberative, multi-attribute decision process. It is also the only vehicle purchase for which the Forts mention fuel costs or fuel economy.

[17] As the fourth and final illustration of the different processes the Forts have taken to the purchase of their vehicles, the purchase of Julie's Ram pickup truck is the most impetuous. It is shaped by the Forts general desire to drive large trucks, but in contrast to the prior purchase of the Silverado pick-up truck, this was clearly a more impulsive purchase impelled by the coincidence of an impending "need" for Julie to have her own vehicle, a happen-stance sighting of a truck sale, and the price cuts by the automobile dealer.

"something big…it was either a truck or a Suburban, Tahoe kind of thing." They decided on the Ram, which they thought was a great deal, Brett explained, "it was like $10,000 or $15,000 off…I think we paid $17,000 for it." They describe their purchase as "spur of the moment." Julie is happy: "a lot of people think girls are supposed to drive cars…I like my truck though…I've never been a prissy girl." She likes the power of the Hemi engine, though she admits, "[paying for] gas is a drag…[I] wish it could be a hybrid."

Prior to their PHEV trial, Brett was fairly familiar with electric-drive technology. He cites the following as sources of information: friends, seeing alternatively fueled vehicles on the road, news programs, television shows, and automotive, technology, or science magazines or websites.[18] At his workplace there is at least one EV owner and there are "tons of people that drive [HEVs]…everyone that has one loves it." Although he did not consider an HEV when buying his Accord—"they were still new …I didn't think the technology was close enough then"—he has considered HEVs as a future replacement for his Accord. *His main concern is uncertainty about cost savings: "if you're looking at it from a financial point…everything I've read…the calculations aren't there yet." Brett adds that "from an environmental standpoint, it makes a little more sense," but he personally feels that "you have to be pragmatic and look at it from a real life standpoint too."*[19] Julie feels more drawn to the environmental benefits, describing how the Dodge Ram often gets negative attention: "I get dirty looks from people that drive Priuses…that are more gas friendly…it's kind of like you get dirty looks from vegans when you're wearing leather…I was actually filling up with gas in Davis…and of course it takes forever because it was almost empty…this guy pulled up in a Prius behind me and he was like…glaring at me while I was filling it up…and I was like, sorry…so he went around me…I get lots of dirty looks at school, but that's okay."

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[18] Wherever questionnaire responses are incorporated into the narrative, as we do here, the language becomes that of the questionnaires that we the researchers wrote, i.e., the respondents are choosing language we wrote in the form of questions and answers rather than speaking in their own words. This is one example of combining data from all our sources to tell of the households' experiences. In general, these changes will only be noted if we judge them to be consequential to the meanings of the narrative.

[19] Theme: payback and collective benefits.

On a lighter note, the Forts also link the Prius to one of their favorite stand-up comedians who talks about loving his politically incorrect Hummer and feeling emasculated by his "powder blue" Prius.

The Forts have prior experience plugging in several vehicle-related technologies: an engine block heater, a recreational vehicle or motor home, an electric scooter, electric bicycle or moped, and an electric golf cart. They have plugged these items in at home, a friend's home and a recreation area.

Regarding new consumer technologies in general, the Forts believe they are about average regarding how quickly they buy new technologies such as cell phones, computers, household appliances, and vehicles.

If gasoline and diesel were no longer available the Forts believe electricity would be most likely to succeed as a replacement because it does not need to be imported from foreign countries. The Forts rate themselves as somewhat familiar with their homes electricity use; they think of it in terms of dollars spent on electricity per month or bill. They are unsure of how much electricity their household uses but Brett understands the term kilowatt-hour. Off the top of their heads they knew their previous month's electricity bill was $175, and say that over the course of a year it generally ranges between $160 and $400 per billing cycle. They had to review their bill to ascertain that they pay multiple prices per kWh, ranging from 12 to 26 cents/kWh. They claim they are charged higher rates at certain times of the day. The Forts do not know the sources used to generate their home's electricity, but believe the environmental impacts are about the same as the rest of the United States. The Forts do not believe the price of electricity will double from today's price within the next 10 years. They believe it is only mildly possible that the supply of electricity will become so low that at some point in the next ten years their household will be limited in how much electricity they can use. In addition, the Forts believe it is mildly possible that the price of gasoline or diesel will double from today's price at some point in the next 10

years or that the supply of gasoline will become so low that they will be limited in how much gasoline they can use.[20]

The Forts believe more research is needed before action is taken regarding global warming (climate change); they think it is mostly caused by humans putting holes in the ozone layer. However, they do believe air pollution and US dependence on foreign oil are serious problems and immediate action is necessary to solve them. They are unsure if global warming is caused by greenhouse gas emissions and believe governments (national or otherwise), business and industry, and users of energy consuming products are all responsible for reducing GHG. The Forts believe the best way to achieve GHG reduction is through education to teach and encourage people and businesses to reduce their use of fossil fuel. Personally, the Forts are willing to purchase a more efficient vehicle to help reduce GHG from fossil fuel use.

Driving: Gas mileage at butt level

Brett more than fully replaced his Honda with the PHEV throughout their trial. He drove it to work and for a few trips for which he would normally drive the Suburban or Silverado, such as taking Selena to an appointment in Fairfield, and taking the family to a dog show in Vacaville. Julie only drove the PHEV "three or four times total" over their trial because she hasn't "really gone a lot of places this summer…I usually go…as a passenger." She substituted the PHEV for her Ram to visit her boyfriend and to go shopping. Brett and Julie state that their trips were fairly typical for a summer months.

The Forts spent some time getting used to the Prius as a family. For example, Selena helped Brett experiment with the rearview camera to get a sense of depth perception. Brett liked the vehicle's handling, though he said, "It's kind of lacking power," relative to their other vehicles. *He expected this: "I know it was a hybrid, and it's built for gas mileage…I knew the energy wasn't going to be big…[but] I don't think it was a drawback."*[21] Julie liked the dashboard: "it's really technologically up there…how it's all digital." The Forts were very surprised and

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[20] This entire paragraph and the next are based on the Forts responses to the questionnaire they completed when the PHEV-conversion was delivered to them.

[21] Theme: prior expectations.

impressed with the spaciousness of the Prius, Julie said "it's amazing what will fit back there…I have no idea how." They refer to a family picnic in Vacaville, where all four of them fit into the Prius, "It was very tight but we made it fit," including camping chairs and "a couple coolers." Julie adds "there's more legroom in the car than my truck, in the back seat." However, from a safety standpoint, Julie feels more comfortable in her truck, particularly on the freeway. She feels the car is "just really small" and she doesn't like being "at butt level." She details one story demonstrating her discomfort with driving a smaller vehicle: "I was getting ready to turn on this street…there was this car flying behind me and I had my turn signal on, and he wasn't slowing down…I was like, oh my gosh, oh my gosh…okay turn…it would have done more damage if he had hit me in that truck…hitting me in [the Prius], I would be kind of [in trouble]."

The Fort's PHEV broke down two days before their pickup interview—Brett was at work and the car wouldn't start. Staff at the PHEV center responded very quickly, providing him a replacement within the hour—he did not seem to be strongly affected by the incident, saying later, "Stuff breaks…it's a piece of equipment."

Recharging: Not a problem

For Brett, plugging in at home was "not a problem…I just run the extension cord under the garage door…and then I close the garage door on top of it." When he gets home for the day he backs the car into the driveway and plugs it in. In the morning he unplugs the PHEV when he feeds their dog. Julie did not plug it in when she drove. Brett had more difficultly recharging at work; although there are several parking spots set aside for electric vehicles, these spots are normally taken by "golf carts" used by employees to drive around the campus. He did manage to plug in at work "a couple of times." They did not consider plugging in at other locations because they did not perceive having opportunities. Brett also explains that it "might be kind of odd…hey, can I plug this in...like at a store or something…they'll be upset that you stole their electricity." Julie adds: "somebody might steal the cord." Thinking longer term, the Forts like the idea of "more advertised spaces….like at Davis…they have 'plug in your electric car here' [signs]." They could imagine using such recharge opportunities at a grocery store, as long as it

was obvious that recharging was welcome.[22] The Forts are willing to use an extension cord to plug in from farther distances, clean out their garage to allow parking next to the plug, choosing parking spots that are further from their destination, or changing their driving patterns to allow more access to electric outlets.

During the final interview Brett made it seem as though plugging in at home was not a big deal. However, the Forts questionnaire answers at the end of their PHEV trial did not reflect this nonchalance. Rather, the Forts indicated they would sometimes not plug in at home due to: the electric cord being a hazard, the electric cord being vulnerable to damage, concerns about the electrical outlet blowing a fuse, if the weather was undesirable, or if they won't be parked long enough to bother. Things that would not stop them from plugging in include: being too busy or lazy to plug in, the electric cord looking ugly, the electrical outlet is already in use by other electrical devices, or the owner of the electrical outlet not wanting them to use their electricity. They estimated they could plug in at home 8 hours of the day, 7 days a week.[23]

During the final interview Brett also discussed recharging at his workplace. In this case his questionnaire answers mirrored his responses during the interview: he both experienced problems trying to recharge at work and he could image more problems. Hypothetically, Brett would sometimes not plug in at work due to: being to busy or lazy, the electric cord being a hazard, if the electric cord were vulnerable to damage, if the electric outlet is already used by other electrical devices, if the electric outlet might blow a fuse, if the owner of the electric outlet does not want him to use their electricity, if the weather is undesirable, or if he wouldn't be parked long enough to bother. He does not care if the electric cord looks ugly. He could plug in at work one hour a day, Monday through Friday.

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[22] Theme: recharging behavior and etiquette.

[23] These questions are asked in the final questionnaire that the respondents complete immediately prior to the researchers visiting the household for the last time to pick up the car and conduct the final interview.

The difference between the Forts nonchalance regarding recharging during their interview and their questionnaire responses may be due to the differences in what the data from each describes. The interview data describes the households experience driving the PHEV-conversion; the questionnaire data asks the households to imagine driving and recharging the vehicle. In this sense, in the interviews Brett describes recharging the car at home as easy and convenient, but in the questionnaire the Forts can imagine there might be problems. Alternatively, perhaps the PHEV was easy and convenient to recharge—for a one-month trial—but the Forts imagine it might prove more problematic over the long term.

Instrumentation: Just drove it, just watched it

Both Brett and Julie would look at the Prius' energy monitor when driving. Brett looked more at instantaneous miles per gallon (mpg) saying, he was "just curious to see at what point it was getting what gas mileage." *Throughout his trial "there was a lot of times I would try to take off slow so I could see how long it would stay on just battery." Brett says he was not trying to achieve anything in particular—"just more of entertainment, mostly." He feels he watched the monitor less as his trial went on: "after the novelty wears off…not so much." Overall, he states: "I pretty much just drove it…except some times you see how long it would stay on the battery…but not for anything other than just to watch it." Julie thought "it was cool to watch it recharging…I was just kind of learning how it worked…push on the brakes…or when you're not pushing the gas…that was the only one I looked at."*[24] *She felt she just "drove it as I would normally and watched it…[though] I guess I would let go of the brake a little earlier before a stop light."*[25]

Brett visited the V2Green (now, Gridpoint) website "at least ten" times during his PHEV trial. He thought it was "cool," and he looked at "average mpg per trip," and "the fleet average… ours was a little bit higher than the fleet average, the last time I looked." *He also was trying to determine how long the PHEV took to recharge, but found this difficult because the graphs had too poor resolution ("you can't zoom in on a certain amount of time").*[26] Julie also logged in twice, but she was mostly interested in the novelty of the maps ("more just for fun"). She showed her trip to her boyfriend after driving to his house, looking at the "squiggly" lines of the vehicle's path. Another time she looked and was surprised the see the PHEV was moving—she called her parents to confirm that they were driving the car.

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[24] Julie was watching the car regenerating while driving during braking and coasting, not on the website while it was recharging from the grid.

[25] Theme: changing driving behavior

[26] Theme: confusion—lack of information.

Energy Use: Nice savings, but Return on Investment matters

At their midterm interview, Brett thought their fuel economy was "like 50[mpg] or something" the last time he checked online. At their final interview, he was more accurate: "I think it was like 45…somewhere in the mid-to low-forties."[27] *He thought this was good, as it beat their other vehicles—though he didn't have a specific expectation for what the PHEV should achieve.*[28]

Brett tried to estimate cost savings based on number of fill-ups. He states that he would normally fill up the Accord "once a week....or sometimes more, depending on how much I drive the car," typically spending $30 on each tank. He then recalled filling up the Prius three times during their trial—"three times in a month is good." After thinking more, he revised his estimate: "that's probably not fair…I drove [the PHEV] more than I would have driven the Honda…so it may have been two tanks of gas…two or three." He tried to quantify savings in terms of return on investment—he calls it "ROI"—which he often applies to projects at work by comparing the gasoline cost savings to the price he discovered for the Hymotion PHEV upgrade: "From what I saw on the [Hymotion] website, it costs like $10,500 for the plug-in upgrade…so if you're saving $100 a month, that's $1200 a year…so it would have to be 10 years…or 8 years."[29]

Julie feels that this payback period "could be possible," but Brett replied that it's "a long ROI…at work…it has to pay itself back in less than 3 years…it's probably a rule of thumb…but it could be longer." Julie adds: "especially if it's helping the environment." Brett explains that he probably would conduct such a calculation if he considered the purchase of a PHEV—he did set up a spreadsheet when he bought his Honda to compare its fuel costs to that of his truck. He doubts that fuel savings could justify such a high price for the conversion: "I mean…if it costs

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[27] According to the vehicle data, their actual mpg was 42.3 over 1,113 miles in their first 2 weeks, 38.9 over 621 miles in their later 10 days, thus averaging 41 mpg overall.

[28] Theme: prior expectation. Brett Fort's prior expectations of the PHEV are not specific, as might be assumed since he has no prior experience with PHEVs (nor perhaps as might seem more likely, HEVs).

[29] Theme: payback.

Note Brett moves from a discussion estimating gasoline cost savings—which by itself would be an example of the theme of saving money—directly into comparing those savings with the cost of a conversion. While he uses the acronym ROI, Brett's elaboration is made in terms of simple payback analysis, at one point comparing their consideration of a car purchase to projects at his workplace that "must payback in three years." Results of an ROI analysis are typically expressed as the percent profit earned on an investment.

$10,000 more…you can buy a lot of gas for $10,000 over the life of the car." It was clear that Julie felt a long payback period was acceptable because of potential environmental benefits whereas Brett did not; he focused largely on the cost of the car and the amount of gasoline savings per year. Based on his rough calculations the PHEV was not worth purchasing because of the long payback period.

Brett did not include electricity costs in these estimates of savings: "I thought about it but…I don't think that we've gotten the electric bill yet…and then there's no real way to quantify how much…because it's not on a separate outlet or anything like that…so it's hard to tell."[30]

Julie notes that "half our family was gone last month" making it even more difficult to tease out differences on the electric bill that recharging the car may have made.

Social Interactions: Welcome to the Prius family

The Forts had at least 29 social interactions pertaining to their PHEV over their trial.[31] In terms of their overall assessment of PHEVs, the most influential of these social interactions involved talking with close family members, particularly Brett and Julie talking with Selena. She frequently rode as a passenger in the car. She would ask Brett and Julie for details of their experiences with and opinions of the PHEV. In this way, she took part in their PHEV trial, assessing the vehicle's features, instrumentation, and energy use through Brett and Julie. Overall, Selena was very impressed with the vehicle, and was "trying to talk [Brett] into getting one."

The Forts' next most influential interactions occurred with Prius-driving strangers. All four Forts were in the PHEV—as they drove along the freeway two passengers in another passing Prius waved at them. The Forts were at first baffled by the experience, and tried to understand the significance of the event:

Brett: "The wave on the freeway…that was actually pretty cool"

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[30] Themes: payback linked to confusion—lack of information.

[31] A fuller description of our analysis of social interactions is provided in Volume II, Chapter 2E. For now, respondents in a subset of all 67 households were asked to record information about all their social interactions regarding the vehicle including face-to-face (verbal or non-verbal), phone, e-mail, instant messaging or online social networking during their PHEV trial use period.

Julie: "We don't get waved at…frequently by strangers"

Brett: "You know, you're driving a truck…someone in a Prius doesn't normally wave at you…they may flip something at you…but it won't be a wave…

Julie: "Yeah, we felt kind of like posers…driving around…this really isn't ours…you'd hate us if you really knew what we drove…you'd be giving us another symbol"…"[like] we would be part of the family if we had [a Prius]."

Brett: "I think [this type of experience] makes you feel good about doing something good…one of those feel good moments."

Julie: "And we're not all trying to kill the environment."

Related to this experience, the Forts also felt a change in how they were seen by other people while at the gas pump. Prior to the PHEV trial, Julie described getting "dirty looks" from Prius drivers when fueling her Ram. In driving the PHEV, Brett described his shift: "It's funny because I think my opinions of the Prius…have changed since driving it…the whole gas station, truck, looking at the Prius…I have found myself looking at trucks, saying, 'Wow, he's taking a lot of gas'…or something like that…it's weird how it does change the way you think…I'm filling the Prius…I see a truck or Suburban…I'm done, and I'm driving…a week at a time…and I'm guessing they're filling up two or three times a week."

Other interactions involved coworkers, a neighbor, and other friends and relatives—but most conversations typically did not go beyond the Forts offering a brief summary of the study. Overall, Brett feels that his experiences with the technology were far more influential to his evaluation of the PHEV than social interactions about or prompted by the car: "most of these conversations were just explaining what it was." Julie generally agreed with her father, but put a little more weight on social experiences: "it was kind of nice to hear other people's view on it and it kind of helps to form your own opinion."

Overall Assessment: "ROI" versus environment

The Forts mention three main motives regarding their interest in a PHEV: fuel cost savings, environment, and dependence on foreign oil. As noted above, Brett highlights cost savings, "In my head I always think of ROI." He was surprised to find the Hymotion conversion would cost "like $10,500," and he is not sure if he can "justify a new car when my car runs fine."

At the same time, Brett has begun to consider the environmental aspects of the vehicle, and the wastefulness of vehicles with lower gas mileage. On the one hand, *he is skeptical about the purported environmental benefits of electric-drive vehicles. He explains how "the footprint is a little bit bigger than people think…because batteries are really nasty to make…and then you still have to make electricity."*[32] *At the same time, from his experience working at power plants, he notes they "control the exhaust a lot better than a car does."*[33]

Julie is more convinced of the environmental benefits than Brett: "…me and him are different…if it was in a bigger car, I would definitely think about it…if it was a hybrid…and then when it gets to be a plug-in hybrid…I'm sure they'll get there eventually…making it big scale…I think that's neat…and it's not just for gas…it's for the environment too...it's a lot better for the environment… I still think even if you weighed [electricity impacts], it would be better…[for] more people to be driving something like this than a big truck…[in terms of] how much smog we have in our air…our ozone depleting."[34]

Brett and Julie link their growing environmental concerns to their household practices—describing how Selena has recently led their household to become more environmentally aware in general: "we use environmentally friendly dish washing soap and laundry soap…turn the shower off halfway…we recycle everything…[Selena's] become very green over they years."

A third motivation is dependence on foreign oil. Brett only mentioned it once in an interview; his response amplified a similar answer to a question in the first questionnaire. He states, "We have to move away from dependency [on foreign countries]…because the people that are running

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[32] Theme: Payback or Collective Benefits. Here Brett is starting to pull the effects of electricity into his assessment. Previously, we noted he did not count the cost of electricity in his cost comparison or the environmental repercussions of generating electricity. He doesn't specifically state these effects in terms of the Payback theme, so this statement might belong to the Collective Benefits theme. But elsewhere he will more specifically state this in terms of paying money to achieve collective benefits.

[33] This may explain why Brett chose to save $21/month on gasoline (instead of electricity or either) for environmental reasons in a question in the first questionnaire.

[34] Theme: Collective benefits. Julie is not only stating that she is more certain than her father that PHEVs offer collective benefits (in this case, environmental benefits), she puts them into a different evaluation frame. She does not talk about paying more for these benefits, but of waiting for PHEV technology to be offered in the types of vehicle she wants to buy—a full-size truck. In this sense, environmental benefits are a future aspiration rather than a current cost.

those countries aren't great…and eventually they're going to either run out of oil, or they're going to say, no, you can't have any more…then it's going to be…$10 a gallon."[35]

Overall Assessment: Can we have a big PHEV?

Though the Forts' used their Suburban as their vehicle to redesign as a PHEV in the first design game, Brett and Julie "thought of it, as our car in general...I think all of them get about the same gas mileage."[36] Their first priority was to increase CD range from 10 to 20 miles; Brett reasoned

[35] Theme: Collective benefits. In this case, the benefit is solving dependence on foreign oil suppliers.

[36] As with all the households, one of the ways the Forts are asked to offer an overall assessment of PHEVs at the end of their trial period is through two vehicle design games. In the first they are asked to pick a vehicle in their household, offered a PHEV version of that vehicle, and then asked to redesign it within an expanding design envelope. In the second, they are asked whether they would design a future vehicle purchase to be a PHEV and if so, to specify four performance characteristics of that PHEV. These designs and the households' motivation and reasoning for their designs are discussed in the final interview.

The Forts' Design Priority Game PHEV redesign of their Chevy Suburban (15 MPG)

Base PHEV Performance	Round 1	Round 2	Round 3	Round 4	Round 5
Recharge hours: 8	8 Hours	8 Hours	8 Hours	8 Hours	8 Hours
CD MPG: 75	75 MPG	75 MPG	100 MPG	125 MPG	AE
CD miles: 10	20 miles	20 miles	20 miles	40 miles	40 miles
CS MPG: 25[a]	25 MPG	35 MPG	45 MPG	45 MPG	45 MPG

Note: Each subsequent round of the game allows higher electric performance. As the PHEV design space is opened up across the five rounds, the Forts design changes from each prior round are highlighted; the complete design is read as the entire column in each round. See Volume II, Chapter 2a and Volume I, Appendix B and C for complete details of the design game.

a. Base CS MPG is determined by respondents' selection of a base vehicle, i.e., which of their own vehicles they nominate to be redesigned as a PHEV. The base CS MPG is this base vehicle's MPG plus 10 MPG, i.e., the Forts say their Suburban achieves 15 MPG.

that 75 mpg for 20 miles was a better deal than 100 mpg for 10 miles. Next, they upgraded CS fuel economy to 35 mpg "because when [the battery is] gone, it's better to have 35 mpg than 25." They next increased CD fuel economy, eventually up to AE by the fifth round. Although they agreed that "time to charge isn't a big deal…you just charge it over night," Brett explained that "at some point, if the infrastructure was there…then you can spend your points bringing the time of recharging down." For Brett, the PHEV design is about "using as much electric as you can, but still having the engine so you're not dead at the side of the road with no battery." Julie adds: "I think it's cool that it can get 45 mpg…and you can use this much battery…or even here…it's all-electric for the first 40 miles…that's neat…and then to still have the gas to rely on, so you're not going to be stalled at the side of the freeway…I think that's really cool.

For the price game (Table 3), they selected a Toyota Corolla as their next most likely vehicle purchase—"only because one of the guys I work with just bought one…he did the research on gas mileage…and it's a Toyota." Brett sees this as a "viable" commuter car option. Brett opted to keep the Corolla as a conventional vehicle in the high price scenario, as the "10 miles for $4,000" wasn't going to pay back. He did select the base PHEV upgrade in the moderate price scenario: "$3,000 on a $17,000 car…I think it's getting worth it…becoming more realistic."

The Forts' Purchase Game Corolla PHEV design results

	Lower Price		Mid- Price		Higher Price	
	Toyota Corolla	PHEV Toyota Corolla	Toyota Corolla	PHEV Toyota Corolla	Toyota Corolla	PHEV Toyota Corolla
Recharge hours		8		8		8
CD MPG		75		75		75
CD miles		10		10		10
CS MPG		62		42		42
Base MPG	32		32		32	
Base Price	$14,000	$16,000	$14,000	$17,000	$14,000	$18,000
PHEV Upgrades		$500		$0		$0
Total Price	$14,000	$16,500	$14,000	$17,000	$14,000	$18,000
"Bought"		X		X	X	

Note: Enhancements to the base PHEV possibility are highlighted in yellow in each round.

They both note that is difficult to provide realistic responses to a hypothetical survey—"doing this on paper is lot different than actually [buying a car]."

Overall, the Forts did not believe the PHEV could save them a lot of money. They were unsure if plug-in technology would fix any environmental problems, even if everyone in the US drove one. They were also unsure if they would pay extra for a vehicle with plug-in capabilities. They do not think it would be very difficult to find electric outlets to plug in to and in general think that plug-in technology is a good idea.

Meet the Kermodes

Ben and Ursula Kermode live in an upscale neighborhood in one Sacramento. Ben is retired; Ursula commutes to work about 6 miles roundtrip, traveling only on surface streets. They travel to the San Francisco Bay to sail their boat every few weeks and drive to Los Angeles several times a year. Ben drives a 2001 Lexus RX300. In addition to his daily trips, they drive the Lexus for long trips and to travel to choir practice near downtown Sacramento. Ursula drives a 2004 Hyundai Sonata for her commuting and local errands. When they completed their first questionnaire, they indicated that neither Ursula nor Ben had any previous experience with alternatively fueled or electric-drive vehicles. It will come up in the last interview that when Ben was running his own company, he did have electric forklifts. The recharging of these will provide an important reference to recharging the PHEV-conversion. Both Ursula and Ben have pro-environmental values and believe global warming and air pollution must be dealt with now and that PHEVs will help reduce these issues. These beliefs will be discussed again in the final interview, especially in regards to one of their favorite pastimes—sailing on the San Francisco Bay—and will prove pivotal to their evaluation of PHEVs.

Driving the PHEV

Ben and Ursula enjoyed driving the PHEV—they affectionately named it Fifi. Ursula drove it to work daily and they took turns driving to San Francisco, to and around Los Angeles, and on weekly trips to choir practice and other errands. Which is to say, they drove the PHEV far more than simply replacing either of their vehicles. Ursula liked to drive using mostly electricity,

"Because most of my commute is surface streets…generally speaking I don't really travel any faster than 35 miles an hour anyway. And certainly in and around here [her neighborhood] you're only allowed to do 25. So it's just a nice gentle commute using only electricity." She continued on to explain her daily driving, "Mostly it's using the electricity on the short little commutes in and around the city. *I've sort of taken it upon myself to try and get to work without using the gas…rather than use the braking system I tend to cruise up to the stop signs rather than brake right at the end so I don't step on the gas." Ursula played games with the car to try to keep it in electric mode because she liked the feel of the car when the engine was off, "It sort of reminds me of going to play golf, because it sounds like a little golf cart. That's actually good because it's stress free. I don't feel as stressed driving this car…because I'm consciously going a little bit slower I guess. And it's quiet."*

Like Ursula, Ben found that he drove the PHEV differently than his regular car. While on the freeway in his Lexus he normally drives in the fast lane; in the PHEV he drove in the slow lane. He explained that he was concerned about not having enough power if he needed to suddenly pass someone. He was more comfortable driving slower in the slow lane in the PHEV.[37]

If there was a flip side to Ursula's enjoyment of relaxing and driving on electricity-only on her way through their neighborhood, it came on their long trip to Los Angeles. They encountered a few instances in which they felt the power of the PHEV-conversion was lacking. For example, though it was just the two of them in the car on the way to Los Angeles, there were instances when they had five adults and luggage in the car while driving around Los Angeles. Ursula and Frank both remarked that the car was not as powerful especially when accelerating uphill.

This trip also became an extended period during which the car was not recharged. *They attempted to recharge the car at Ursula's son's home on California's central coast, but they felt uncomfortable with the cord running across the front yard with children and dogs running about; they unplugged Fifi after about five minutes. This was their only attempt to recharge over these four days and 795 miles.*[38]

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[37] Theme: changing driving behavior

[38] Theme: recharging habits and etiquette.

As reported in their questionnaire results, the Kermodes were able to determine a difference in fuel economy (MPG) when the car operated as a regular Prius versus as a PHEV because they calculated the average MPG using the odometer and amount of gasoline they used. In fact, Ben had been so eager to check the fuel economy of the car (while they were still driving it as an HEV) that he refueled the car even though it was not empty yet—"it still had two bars left" [of the ten bars that make up the gasoline fuel level display].

Plugging In

Overall, they found plugging in the PHEV at home to be easy. Away from home recharging presented them with several problems. Ben and Ursula plugged in at home nightly.

Ben said, *"Well we basically got into the habit of when I drive home I back it up and then we just plug it right in. Sometimes we remember to unplug it at 10:00 o'clock before we go to sleep but then sometimes we don't and it's been plugged in all night... So if we remember we unplug it, if not, it's no big deal. We don't really get stress over it."* [39]

They likened it to charging a cell phone and Ursula said, "It's very user friendly and it's easy to plug it in." They only recharged away from their home once, very briefly, at Ursula's son's house in Central California, despite discussing the possibility of public recharging at the local mall and other downtown locations. They were concerned with how they would pay for the electricity and the ins and outs of how that would work.

Saving Money

Ursula believes the PHEV could save her money based on the decreased frequency of refueling with gasoline. This is part of the reason she tries to keep the vehicle in electric mode, "In my head I think it's cheaper to go on electricity than it is on gas…the less gas I use the longer that tank will stay full and the more miles per gallon I'll get. So that's the perception." [40]

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[39] Theme: recharging habits and etiquette.

[40] Theme: saving money

Ben and Ursula discussed how long they could go without going to the gas station with the PHEV, "Going back and forth to work three miles commute is just perfect. I think if we only used it for that we would never have to fill up with gas because we would just continue to plug it in at night." This idea intrigued them and they spent quite a bit of time discussing this possibility. Overall, they agreed, "It's a little easier on your wallet," compared to their regular cars.

Collective Benefits

The Kermodes discussed environmental and social benefits to driving a PHEV.

Ben: *"I wouldn't mind paying a little bit more money, several thousand dollars more if we would help the environment too. But after saying that, we have to look at electricity versus gasoline, which produces more carbon, I mean, if SMUD is using [coal in] producing electricity and [it] creates more pollution, that might not be a good thing."*[41]

Ursula: "I perceive electricity as being cleaner energy…and I believe it's cheaper energy and it's convenient and I don't want to be dependent on other countries for energy."

Ben: "I don't want to go to the gas station that often…[and] if [there is] anything we can do [to] change our behavior and change our laws to protect the environment by using whatever available technology, or improve technology to do so, I'm for it."

PHEV Design Games

For the first game involving the redesign of an existing car, the Kermodes chose to redesign Ursula's Sonata. For the second game though when they were asked to think ahead to consider a car they would buy next, they chose a Prius. In fact, they were not really looking for another vehicle, and anticipated it would be two to five years before they would do so, likely prompted by Ursula's retirement. They discussed this choice, wondering about the few times they had found the Prius-conversion too small and less powerful than Ben's Lexus. [42]

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[41] Theme: payback and/or the environment shaped by confusion—lack of information about emissions from their electricity provider.

"SMUD" is the Kermodes' electric utility, the Sacramento Municipal Utility District.

[42] The Kermodes design games are summarized in these two tables.

In redesigning Ursula's car as a PHEV, the Kermodes showed no interest in increasing its CD range until the design space allowed an increase from 10 to 40 miles. They reasoned that so long as she was working and only commuted a few miles to work, the minimum ten mile CD range was all she really needed for most her day-to-day driving. They also reasoned that increasing the CS fuel economy was more valuable for longer trips, such as their semi-monthly trips to sail. Given the use they made of the PHEV-conversion, they also reasoned that faster recharging was a better option for them than longer CD-range. Both Ursula and Ben noted that even on those

The Kermodes' Design Priority Game PHEV redesign of their Hyundai Sonata (28 MPG)

Base PHEV Performance	Round 1	Round 2	Round 3	Round 4	Round 5
Recharge hours: 8	8 Hours	4 Hours	4 Hours	4 Hours	1 Hours
CD MPG: 75	75 MPG	75 MPG	100 MPG	100 MPG	100 MPG
CD miles: 10	10 miles	10 miles	10 miles	40 miles	40 miles
CS MPG: 38[a]	48 MPG	48 MPG	58 MPG	58 MPG	58 MPG

Note: As the PHEV design space is opened up across the five rounds, the Kermodes design changes from each prior round are highlighted; the complete design is read as the entire column in each round. See Chapter 2A and Volume 1, Appendix B and C for complete details of the design game.

a. Base CS MPG is determined by respondents' selection of a base vehicle, i.e., which of their own vehicles they nominate to be redesigned as a PHEV.

The Kermodes Purchase Game Prius PHEV design results

	Lower Price		Mid- Price		Higher Price	
	Toyota Prius	PHEV Toyota Prius	Toyota Prius	PHEV Toyota Prius	Toyota Prius	PHEV Toyota Prius
Recharge hours		4		4		8
CD MPG		75		75		75
CD miles		10		10		10
CS MPG		68		58		58
Base MPG	48		48		48	
Base Price	$19,000	$21,000	$19,000	$22,000	$19,000	$23,000
PHEV Upgrades		$750		$1,000		$1,000
Total Price	$19,000	$21,750	$19,000	$23,000	$19,000	$24,000
"Bought"		X		X	X	

Note: Enhancements to the base PHEV possibility are highlighted in yellow in each round.

days they went out again in the evening, faster charging would allow Ursula to arrive home in the evening and plug-in the car for a couple hours before they went out again. [43]

For the second (purchase) design game the Kermodes chose a Toyota Prius as their next vehicle. They redesigned it as a PHEV and "bought" it in the low and medium price scenarios, but not in the high price scenario. In the low price scenario the Kermodes chose to invest in a recharge time of 4 hours for an additional $250 and increased their CS mpg by 20 miles for an additional $500. In the medium price scenario they chose to increase recharge time to 4 hours for an additional $500 and increased their CS mpg by 10 miles for $500. In the high cost scenario where they chose not to purchase the PHEV they kept the recharge time at 8 hours, maintained the distance of electric assist of 75 mpg, maintained the distance of electric capability of 10 miles, and increased their mpg by 10 miles for an additional $1000.

Their valuation of a shorter recharging time is continued in the second game, though to a lesser extent than in the first design game. Again Ben explained, "Let's say you come home at 2 o'clock and we need to go out and have a dinner date at 7 o'clock, we should be able to plug it in, in 4 hours we got another full battery again to go out for a second trip. If I have the choice then I would like shorter charging time...[it's] more beneficial. That gives us more incentive to charge it more frequently." Instead of focusing on daily driving they thought more about weekend trips.

Overall

The Kermodes had a positive experience with the PHEV. This was bolstered by conversations they had with friends: "The conversations on the whole have been positive and have generated I guess real interest in this because of the economy at the moment. *People are looking toward how they can save money and maybe this is something they want to do in the future."*[44] Ursula had expectations of what the PHEV would be like prior to her initial test drive, *"My expectation was*

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[43] In some ways the last round of the first design game is a referendum on all-electric CD operation since to spend all eight points without choosing all-electric operation requires the household to maximize almost every other parameter. This is what the Kermodes did, designing a PHEV with maximum charging speed, CS fuel economy, and CD range, but not all-electric CD operation.

[44] Theme: the future—of all cars.

that the car would be more economical, which has proven to be true. And I think I did also expect it to be quieter and maybe have less power, and I think that's true too, in a sense. But that's only because of the way I'm driving it." Ben chimed in, "Well my expectation was [that it] was going to get better gas mileage, and it did."[45] The Kermodes were pleased with the PHEV and are interested in when they will be available for the mass market. *As Ursula nears retirement the Kermodes are considering downsizing to one household vehicle instead of two and would prefer their one car to be alternatively fueled to help reduce the environmental impact of their driving. A PHEV would be an ideal fit for their household.*[46]

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[45] Theme: prior expectations.

[46] Theme: the future—the Kermodes' specifically.

What can we say about the Forts and Kermodes?

Returning to our "researcher-analyst" voice, even though the Forts and Kermodes drove the PHEV-conversion a similar percentage of miles in CD operation over the course of a month, were similar in their recharging habits, and designed PHEVs they thought they might buy under similar price conditions, they differed markedly in their use of the PHEV, and ultimately, in their interest in a PHEV. The difference in their interest in buying a PHEV is ultimately revealed by the differences in their narratives, not, for example, by the results of their PHEV design games.

The Forts are a four-member household with three drivers: Brett commutes alone to work; Julie commutes alone to college; and, Selena chauffeurs their son to school as part of her role as homemaker. The Kermodes are a two-member household; both drive. Ursula has a short commute to work (on surface streets); Ben is retired. Both households recharged the PHEV daily when at home; both used the PHEV for weekend trips away from their homes. But though their over all percent of CD miles for their months are similar, Brett Fort commuted 60 miles round trip in the PHEV; Ursula Kermode commuted less than 6 miles round trip, plus a few more miles for errands. Thus most weekdays, the Forts drove between one-fourth and one-third of the PHEV's miles in CD operation; the Kermodes weekday travel was almost entirely in CD operation. The Forts, primarily Brett, were concerned with the payback period for the PHEV. They had environmental concerns the PHEV helped to address but for Brett these were outweighed by the cost of the PHEV; Julie and Selena valued environmental benefits more than Bret. The Kermodes were environmentally minded and were willing to pay extra for a vehicle that is less harmful to the environment. The Forts had previous experience with alternatively fueled vehicles; the Kermodes had none. The Forts do not think the PHEV would save them money due to an incomplete payback analysis; the Kermodes noted that the PHEV saved them money because they refueled it with gasoline less often than their regular cars. Neither household had prior discernment with the PHEV-conversion from conventional cars. By the end of their trials they both discerned the differences between the PHEV and standard cars. This resulted in the Kermodes being interested in a PHEV so long as the added price was within a few thousand dollars of a likely next new vehicle for them. Notably, for the Kermodes they speculated this likely next new vehicle would be a Prius, or at least a hybrid. On the other hand, Julie Fort was

interested in a PHEV only if it is available as a large truck-like vehicle such as those they owned; Brett Fort imagined a new PHEV competing with a small to mid-size sedan to be his next commuter car.

In their own ways, both the Kermodes and Forts represent difficult cases for PHEVs. The Kermodes tend to travel both too little on weekdays and too much on weekends for a PHEV with a 25 to 30 miles CD range to be the best design. Assuming the existence of a suitable battery EV for their local travel, the Kermodes might be better off if they "hybridized" across their vehicle holdings, owing one EV and one HEV. PHEV versions of large trucks may satisfy the Forts efforts to meld personal safety and environmental motivations: whether they do may depend on what kind of "wave" the Forts get from passing drivers of smaller HEVs, PHEVs, and EVs. So long as the Forts, and Brett in particular, focuses on private costs of his commute trip and is willing to maintain ownership of a specialty-commuting car, his purchase of a PHEV may have to wait for a used PHEV market. However, Selena is a force that organizes and directs the Fort household. In a way, hers is the unheard voice in the Forts' narrative even though she organized their participation in the PHEV trial. Further the entire household is cracking the door open on a more pro-environmental lifestyle at her instigation. She may not as yet confronted the implications of their mobility for her growing environmental awareness, but it is likely that whatever the outcome of that encounter is, it will guide the entire Fort household.

2D. Project Results: Real-time Energy Feedback Systems

In 2007, the most recent year for which complete data is available, the U.S. Energy Information Administration estimated domestic passenger vehicles generated over 16 percent of U.S. Greenhouse Gas emissions (GHGs) by burning 113 billion gallons of fuel (EIA, 2001). By some estimates, improved driving behavior could have saved up to 34 billion of those gallons (Barkenbus, 2010).

Real-time Energy Feedback (REF) may be an effective and inexpensive way to encourage driving behaviors with the potential to save billions of gallons of fuel each year. However, little is known about when, why, and how individuals respond to REF, how to design maximally effective REF systems, or other ways that REF systems can compliment other developments in vehicle technology, such as PHEV technology with its multiple entwined energy systems. To investigate these questions, an experiment within the PHEV Demonstration Project retrofitted some of the PHEV-conversions with custom designed REF systems. This chapter presents a brief description of these systems and a preliminary analysis of drivers' perceptions based on interviews with two households before and after they were presented with the REF system installed in the PHEVs. The purpose of this analysis is both to explore the potential of behavioral theories to inform REF design, as well as to simply learn from drivers who have experienced the REF systems in the Project vehicles.

Although simple real-time mile-per-gallon (MPG) displays have been available in some cars and trucks for many years, more complex REF systems have been incorporated as a central component of the dashboard in some hybrid electric vehicles (HEVs)—a design decision that indicates a renewed focus on high-MPG vehicles and implements an innovative marketing device. Although this correlation between high-MPG vehicles and REF systems appears reasonable from a marketing perspective to help drivers maximize the value of their HEV purchase, it raises the question why such displays aren't more common in more vehicles. Is there something inherent to HEVs or their buyers that makes more elaborate energy feedback more appropriate? Are the devices designed to help the driver achieve the greatest fuel economy in-use, reinforce the vehicle purchase decision, or for other reasons? How do those design

decisions, i.e., which vehicles have REF displays, impact driver perceptions of their own role in fuel economy?

Behavioral Theory for REF and Research Design

To explore a broader variety of possible driver responses to a REF system, this study deploys a mixed quantitative and qualitative longitudinal experiment. Because a sufficient amount of data to warrant presentation of quantitative results was still being collected at the time this report was written, a preliminary analysis of the qualitative data is presented here; subsequent reports will be made when the analysis is complete.

A custom REF interface was designed to show information that is predicted by behavior change theories (in particular, the Theory of Planned Behavior (TPB) (Ajzen, 1991) to effectively promote behavior change. Participating drivers were observed via an in-vehicle data-logger for two weeks to create a baseline record of driving behavior and energy use. After two weeks, the drivers were interviewed, and then the REF interface was turned on, and driving and energy were observed for a further two weeks before the final interview. Psychological factors predicted to be important by the TPB were recorded in three associated surveys completed by participants prior to any driving in the PHEV, after two weeks driving (without REF), and at the end of the experiment after they have driven the PHEV with REF. Finally, and most important for this analysis, household interviews provide insight into the thought processes, attitudes, and responses to the REF system.

The driving and energy data will be used to determine if there was an overall effect from the REF and the sources of that effect, e.g., lower speeds, lower accelerations, or other behaviors, and the social and psychological precursors of these behaviors. The driving and energy data in combination with the questionnaires will be used to determine which factors, if any, are correlated with behavior change. The interviews will be used to support or reject hypotheses based on the data, help interpret the causality of the models, and generate new insights into driving behavior.

The Theory of Planned Behavior (TPB) provides the basic theoretical model of behavior change used in this study of drivers' responses to REF, and also in the design of the REF device itself.

The theory postulates that attitudes about a particular behavior, perceptions of relevant social norms, and perceptions of self-efficacy in the behavior combine to determine the individual's intention to behave in a certain way. One important revision to the TPB is the Extended Model of Goal Directed Behavior (EMGDB) (Perugini and Conner, 2000) which suggests that people make behavioral decisions based on the desire to achieve goals rather than a desire to perform the necessary behaviors. This study represents the first application of the TPB or the EMGDB in both the design of a vehicle energy feedback interface and in a model of fuel economy.

This model as applied to driver behavior change is shown in Figure 27: Figure 27a shows an open loop in the no-REF case and 27b shows a closed loop with-REF case. The closed loop model implies that drivers perceive they can change their fuel economy by changing their driving style (perceived control). Their sense of what driving styles are typical or acceptable on the road (social norms) and their general attitudes about fuel economy, driving style, and related issues (attitudes) combine with energy feedback and external factors to create driving behavior and a particular fuel economy outcome. The data sources are described in Table 4.

Figure 27: Behavioral Model Without and With Real-time Energy Feedback

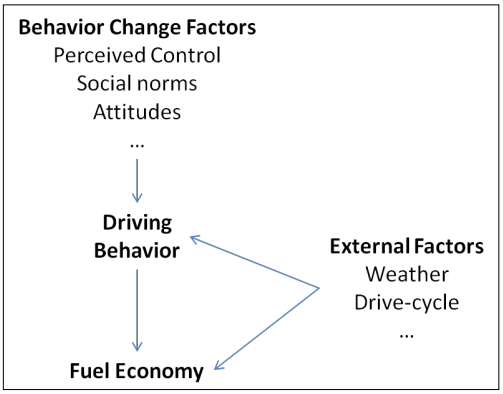


Figure 27a An open loop model of driving behavior where static behavior change factors and external factors combine to determine fuel economy.

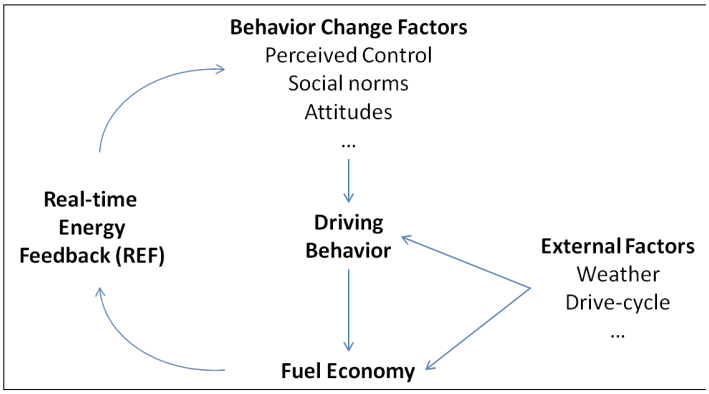


Figure 27b A closed loop version of the same system where REF creates a feedback device that can lead to changes in behavior change factors and new outcomes.

REF design

In order to test the model in Figure 27b, the REF interface and associated longitudinal survey included measures of the factors in the model. The REF is illustrated in Figure 28. The circles with lower case alphabetical characters are not displayed on the actual REF, but are shown to aid explanation. In the left panel are: a) a broad horizontal arrow showing the roundtrip average MPG+, b) driver's MPG+ history at the current drive distance and, c) the peer group MPG+ history. The center panel shows: d) real-time MPG+, e) one-tenth mile MPG+ averages, f) driver selected energy economy goal. The right panel shows the supplemental battery's SOC. Some households were given more complex or flexible interface displays although the details of those displays will not be presented here. However, one panel that is of note later in this chapter is a fourth panel depicting the real-time power used by the gasoline engine and electric motor, with three separate columns for gasoline, electricity, and regenerated electricity.

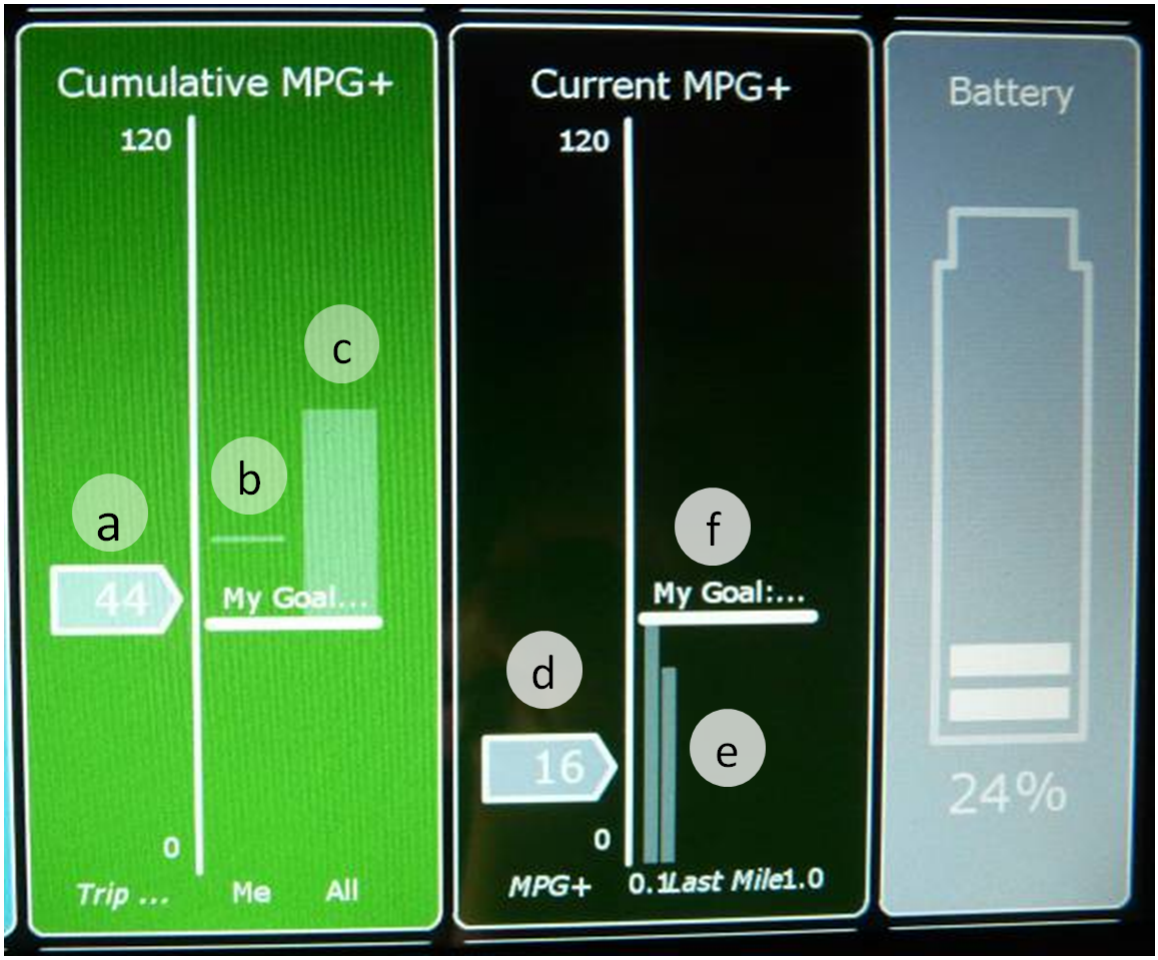
Table 4: Model Data Sources

Model Factor	Data Source
Behavior Change Factors	Questionnaire and Interview. The questionnaire is used for hypothesis testing and model building. The interview responses are used to indicate causality and expand on the model.
External Factors	Detailed driving data is collected on the vehicle along with ambient temperature. Local weather stations provide daily rainfall data.
Driving Behavior	Detailed on-board driving data. Behavioral indicators such as average acceleration rates and top speeds measured from similar trips, e.g., matched start and end-points, between the baseline period and the REF period.
Fuel/Energy Economy	On Board Diagnostic (OBD) data. Fuel use is estimated from the rate of airflow into the engine (MAF sensor) and the exhaust fuel/air ratio (Lambda sensor).

The experimental REF interface includes an "energy economy" measure, MPG+ that includes kinetic and potential energy as well as "fuel" energy from both gasoline and electricity. Including all these energy sources is designed to strengthen the driver's perception of behavioral

control over energy use. One outcome of this new energy economy metric is that the MPG+ value is usually lower than the fuel economy (MPG) values displayed by the stock Prius display (which includes only gasoline). MPG+ is calculated over the same distances as MPG, but includes all energy inputs to the motion of the vehicle.

Figure 28: Photo of the REF Screen.



In addition to real-time MPG+, the REF interface includes comparisons to social norms, personal history, and goal setting. The social norm is the peer group range of MPG+; the peer group is other drivers of the PHEV conversions similarly equipped with the REF. Personal history includes four timelines: 1) a very short term history, i.e., a one-tenth mile average, 2) average

MPG+ over cumulative trip distance, 3) round trip MPG+, and 4) the range of MPG+ on past trips of similar length. Drivers are prompted to set a MPG+ goal when the REF is turned on after two weeks of driving the car. When they exceed their goal in either the cumulative or current MPG+ panels, the affected panel changes color from darker to lighter, providing the driver with a clear visual indicator of their fuel economy performance.

Finally, certain households were able to observe a fourth panel that indicated the instantaneous power of the gasoline engine and electric motor. The panel includes three columns that present the information in the following order: gasoline thermodynamic power, electric motor power, and regenerated electric power. The rates are shown on an identical scale with an upper limit of approximately 20kw. For reference, the electric motor will expend energy at a rate of approximately 10kw maximum, and the gasoline engine can expend thermodynamic energy at over 200kw.

Preliminary Results

The following section presents qualitative studies of two households, interview excerpts, selected questionnaire responses, and discussion. These two households were chosen for discussion here because of the variety of responses that the household members expressed.[47] Following the household level data, common issues or themes are discussed and compared to the theoretical framework. In keeping with the style established in the previous chapter, the households are presented in narratives distinguished from the main text.

The McSnoopy Household

Kim and Chad McSnoopy live with their teenage boys and two small dogs in a gated community outside Sacramento. They live close to both their workplaces; both commute, separately, by car. Kim works in healthcare and commutes in a large SUV, a vehicle choice they made in response to a series of dangerous accidents. Chad works at a large computer company, and incidentally

[47] A full report of the effect of REF on the full sub-sample involved in this experiment will be released in a subsequent report.

has a co-worker who had been previously been enrolled in the PHEV Demonstration, though not in the REF test. They mainly identify themselves as a part of a church group who, they mentioned in an aside, most of who drive SUVs. They told us that their friends made a few friendly but snide comments to the McSnoopys about becoming “Prius People,” e.g., “Liberals,” after driving the Prius PHEV. The McSnoopys feel that they are on the fringe of the group in terms of their feelings about the environment and around-the-house actions but were happy to be seen as more environmental than their church peers, as shown in the following exchange when the interviewer asked for clarification about what their peer group is like and where the “Prius People” term came from:

Kim: “Our friends…your typical Republican… we're the only liberals in our group. By a long shot… so we always get made fun of…we recycle.”

…

Chad: "We're not that liberal."

Kim: "We're not that liberal, but in our group we are.”

Chad: "The stereotype of the hybrid owner is…"

Kim: "Hippies."

Chad: "Yeah."

Kim: [Re-living a comical question by a friend after seeing the new Prius] "Are you going to stop shaving your legs?" and her sarcastic reply, “Yeah, that's my plan."

…

Kim: “Where I work it is very supportive of this stuff, where I socialize and where my friends are, not at all. But it doesn't matter, so they make fun of us. It's like yeah, whatever. I'm 43, not 18.

Interviewer: “Would that stop you from purchasing a car like this?”

Kim: “No. Not at all, in fact I might…”

Chad: “It might drive her to it.”

Kim: “I care about our world, you don't. Sorry. [She laughs.]”

Chad's questionnaire answers paint a picture of somebody who is unlikely to be motivated by REF: he ranks himself fairly low on all of the personality measures that indicate competitive behavior.[48] In their interviews he also revealed that he was not very interested in better fuel economy if it were to come at the expense of time. Chad's initial importance ranking includes speed and safety ahead of fuel or monetary savings. The overall impression from his questionnaire is that he values gas savings and he feels he is aware of techniques to save gas, but he values time more when driving. In addition, Chad guessed that he could only make a 5 percent improvement in his PHEV fuel economy by changing his driving style either indicating an awareness of his own unwillingness to sacrifice time, or an indicator that he lacks perceived control over fuel economy.

Despite those indicators, Chad reported in the final interview that he was motivated by the REF screen in certain situations that he felt were more appropriate for energy conservation. In particular, Chad seemed to be convinced that low-MPG+ was inevitable when making frequent stops, and that the best behavior may be to get up to speed quickly, and then to hold a steady, high speed:

Chad: "I did try to keep it [in the low-Power range]… but I knew that unless you drive like grandma Moses that thing [the Power Meter] is going to go up to the top as you are taking off, then when you get up to speed you can balance everything out."

Chad: "Where I changed a lot was on the freeway. It really makes you aware of the grade, because you can see that your mileage is going down as you are starting to go up hill, so then you know when you get to the top you kind of let off a little bit and it [the MPG+ gauge] goes

[48] Selections from Chad's Questionnaire

	Response
Statement	Strongly Disagree (0) to Strongly Agree (5)
I'm a perfectionist	3
I like to be the person in a group who has the right answer	5
I don't care if I win in competitions	4
I'll try something a second or third time to get it right	3
I usually leave things at "good enough"	2

way up, and then… So you can get your average up higher if you manage that [hill driving] instead of just "rrrr" [makes sound and motion of driving quickly up the hill].”

In her questionnaire responses, Kim described herself as somebody who won’t stop until she has won each competition or gotten every answer right.[49] In addition, she first estimated that changing her driving style could make a 20% improvement in PHEV fuel economy. Yet, by the end of the study she indicated that her driving style would not have an impact on fuel economy.

Kim’s interview statements support the hypothesis that Kim would be strongly motivated by the REF screen, and her statements go further to describe such a strong desire to perform well on the REF metrics that it creates actual discomfort when she is not able to do so. Kim appears to have (at least, in her own perception) radically altered her in-vehicle behavior due to the additional REF information, although some of her efforts were so uncomfortable, in particular the feeling of moving too slowly and being passed by other drivers, that the durability of the behavioral modification is questionable.

Kim: “I do not like the new screen [REF]. I hate the new screen... I wish I could have turned it off. Because when you are seeing how your fuel efficiency is… I decided to go down [a nearby arterial street] with no one behind me, how I had to drive to keep it in the fuel efficient [range] - oh no, no. It doesn't work for me at all. You would miss all of the lights. You know how the lights are timed? I could never get to work on time.”

…

Kim: “It drove me nuts to not be fuel efficient. It’s the competitive part of me. I don't want to know.”

Chad “Plus it shows everybody else's mileage.”

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[49] Selections from Kim’s Questionnaire

Statement	Response Strongly Disagree (0) to Strongly Agree (5)
I’m a perfectionist	5
I like to be the person in a group who has the right answer	5
I don’t care if I win in competitions	1
I’ll try something a second or third time to get it right	4
I usually leave things at “good enough”	2

Kim: “I get horrible gas mileage, apparently. I get horrible gas mileage, and, that's fine. I'll just have to own that.”

Chad: “Don't put her in a competition she can't win.”

Kim: “So I asked Chad, "That's not driving you nuts?" And he goes, "I don't care." Okay, because when it's dark like that [high-power situations] - it's driving me nuts, but not enough to change it right now.”

Interviewer: “Before driving this car, how do you “win” at driving?”

Kim: “I don’t.”

Chad: “This has information.”

Kim: “How can I drive efficiently? Well apparently I can get out and pedal faster. I'll bring my bike [sarcastic] and be faster than what I was doing. Because it was a mild grade up, I'm just like seriously, I can ride my bike faster, and that's very fuel efficient. Because all I have to do is feed myself and I'm going to do that anyway.”

Kim: “I wouldn't want to know in the Expedition either. I wouldn't want that screen. I do not want it because I am going to get where I need to go and how I need to get there and I'm going to go the safest and best way… In the Expedition you would have to go like this [mimes a very slow driver]”

…

Kim: “If it was a longer stretch, rather than start-stop-start-stop… I stay in the black [high power] until I get to that first … light which is a couple blocks… and then I can keep it in the bright blue [low power] for a long time if I don't have to stop. And then I get irritated if I have to stop, I'm like, "god bless America, now I'm going to be in the black!””

…

Kim: “I'm like, I need to stop looking at this thing.”

Chad: “There might be somebody in front of you.”

Kim: “No, cause you can see it out of the corner of your eye, the lights, you can totally see it. Because then there were times I'm like I just don't want to see it right now, I'm just going to block it—agh, I can still see it. You know, this is how I like my life.”

…

Kim: “When I walk in the door I’m home, I’m not like, did I make the grade?”

Chad: “I kind of keep an eye on it while I’m driving. Wanted to make sure I was above my goal… I changed [my goal from 40mpg+] to 45.”

Interviewer: “Did you learn anything from what the screen told you?”

Kim: “That you have to drive so slow… Unreasonably slow.”

Overall, the McSnoopys were impressed with the PHEV and adapted easily to both the PHEV concept and to a plug-in routine. It helped that one of Kim’s friends had a Prius, and that Kim was familiar with the Prius from the start. They felt that it was easy to plug in, and Kim took the opportunity to approach employees in her workplace garage about charging at work, and with their help eventually found an outlet to use there. Chad didn’t look for a place to charge at work. By the end of the study they were enthusiastic about the monetary savings and to a lesser extent the reduced environmental impact of the vehicle. Kim was more interested than Chad, and felt that she would purchase a slightly larger version of the PHEV, although her space requirements weren’t clearly stated in the interview. Chad took a payback approach to valuation of the vehicle, based on a mental calculation he felt that the purchase would be worthwhile if the extra cost of the PHEV conversion were around $5,000 leading to a 5-year payback in his estimate, but that a $10,000 conversion, with the resulting 10-year payback, would be too costly.

The Garcia Household

Larry and Mary Garcia live outside Davis, CA. They run separate small businesses; Larry's mostly from home and Mary's mostly serving clients throughout Yolo County. They both have strong pro-environmental feelings and had already taken several energy saving lifestyle choices and product purchases. For instance, they have an energy saving evaporative air cooler installed in their home, and have also purchased, although not yet used, a device to measure the energy use of their refrigerator in order to determine if it needed replacement. Larry drives an economical Toyota Echo, and Mary (who drives much more than Larry) drives a Toyota Prius. Again and again in the interviews it became apparent that Larry and Mary considered their environmental impact when making decisions about energy use in home, how much they drive, and their vehicle purchases. They routinely weighed energy efficiency with lifecycle energy, for instance, considering not only on-road fuel economy but also the number of years (or how many miles) they would own a car before replacing it. During the course of their PHEV placement Mary was the primary driver, both because she was the driver of the household Prius, and

because she drove the most miles each day. They were already aware of a number of different vehicle types that use electricity including electric vehicles and plug-in hybrids. Mary expected the PHEV to be able to drive in all-electric CD operation, and was somewhat disappointed to discover that the PHEV-conversion she would be driving did not.

Mary rated herself as a more competitive person than did Larry, although they both displayed a mix of responses indicating both socially competitive and internally motivated behavior.[50]

The experimental REF screen stopped working shortly after it was installed in their car, leaving them with no driving feedback. Larry was generally content to drive without the information (as he does in his normal car), but Mary decided to go against the researcher's request and move the REF screen in order to read the stock Prius screen. Eventually, although the research interface only worked sporadically, they did get a chance to use it. Larry mentioned the expense of the screens, equating them to GPS devices. He had looked up information about aftermarket fuel-economy screens in Consumer Reports, although he remained unsure of the advantage of the instantaneous feedback for his own use, whereas Mary was strongly supportive of it. Larry also

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[50] Selections from Mary's Questionnaire

Statement	Strongly Disagree (0) to Strongly Agree (5)
I'm a perfectionist	3
I like to be the person in a group who has the right answer	4
I don't care if I win in competitions	3
I'll try something a second or third time to get it right	4
I usually leave things at "good enough"	4

Selections from Larry's Questionnaire

Statement	Strongly Disagree (0) to Strongly Agree (5)
I'm a perfectionist	2
I like to be the person in a group who has the right answer	3
I don't care if I win in competitions	3
I'll try something a second or third time to get it right	4
I usually leave things at "good enough"	2

noted that the watt-meter that he bought Mary does the same thing in the home, although Mary had not used it yet, as a counterpoint to her enthusiasm about energy information in the car.

Mary: "I still think if every vehicle in America had one of those screens on it that told you what you are getting...everybody who rides in my car and looks at that goes 'that is such great information' because it really helps you decide how to drive."

Mary [to Larry]: "Would you buy one for your Echo?"

Larry: "…I don't know, I know about what it's getting, as long as you keep it tuned, which I do... or you do it the old fashioned way, people can write it down..."

Mary: "Yeah but that doesn't tell you what it is while you are driving it and how it changes, which is the interesting thing to me."

Larry: "It gives you an average."

Overall, the Garcias felt that the PHEV-conversion wasn't their ideal vehicle, although they both felt strongly that an electric vehicle could help them achieve household goals such as lower environmental impact and saving money on gas. One of the reasons they gave for why the PHEV was not ideal was that Mary has a very long and unpredictable work travel, and 30 miles of blended CD operation didn't seem like enough to make a large improvement compared to her Prius' fuel economy. In addition, the cost of the conversion seemed too high to them. In Mary's thinking, it would make more economic sense to purchase a used Prius and convert it into a PHEV than to purchase a new PHEV conversion or similarly priced OEM PHEV. Also, Mary felt that more high-MPG CS miles were more important than a limited number of CD miles. From the beginning of the placement Mary expected to plug-in the vehicle in many different work related locations, e.g., her client's homes, and that is exactly what she did. Mary generally did not hesitate to ask people if she could plug in at their home or workplace, and she would generally try to plug in as often as possible. However, Mary still noticed that the fuel economy of the PHEV-conversion was often somewhat lower than her Prius, possibly due to the extra battery weight, and long driving distances that would typically exhaust the supplemental battery. Still, by the end of the placement Larry and Mary were very positive about the PHEV conversion and seemed to feel that it was a good fit with their household even though it wasn't perfect in every respect.

The Garcias were mixed in their response to the REF screen. Larry was concerned about the additional cost of such a screen, implicitly weighing the gas savings with the upfront cost. He also did not seem to feel that the instantaneous information was particularly valuable, and that long-term information about the vehicle performance was more useful since it could be used as a diagnostic measure of the vehicle health. Mary, who owns a Prius, felt that the REF was an important part of her driving and that other people would benefit from them as well. She was strongly attached to seeing REF in the vehicle, and even defeated the experimental condition to see the stock REF screen when the experimental screen was not working.

Themes from the Narratives of the McSnoopys and Garcias

To begin to extend the analysis of the effect of the REF beyond these two households, the four drivers' responses are compared and recurring concepts, or themes, were identified for further discussion. These provisional themes serve a hypotheses for the remaining households yet to be analyzed and as illustrations to the reader of the type of summary information that can be generated from the interviews. The McSnoopys and Garcias shared responses about distracted driving, particularly motivating situations, some confusion about, and misinterpretation of the feedback, a desire to see detailed fuel economy information, and competitive behavior. Each of these themes is described in detail below.

Safety and Distraction

The screen could be distracting to the point of creating a safety hazard. Both Chad and Kim mentioned that they felt the REF was too distracting in certain situations, and looked away from the screen. Kim mentioned that she used the color-changes to give her information without having to look directly at the screen, although in another statement she mentioned that sometimes she couldn't ignore the screen even when she wanted to.

> Chad: "I can't look at that, I gotta look over [to the stock Prius REF screen]."

Motivational Situations

Chad and Kim also discussed the difference between short trips with a lot of stops and traffic, and longer drives, roughly equating to "City" and "Highway" drive-cycle concepts. Whereas Kim seems to have been especially motivated by the low-MPG driving during city drive-cycles,

Chad had the opposite reaction and reported ignoring the screen in city situations and only paying attention to it in highway situations.

Chad: "…I knew that unless you drive like grandma Moses that thing is going to [show low fuel economy] as you are taking off, then when you get up to speed you can balance everything out."

Confusion or Misinterpretation

For those drivers that did see both the stock Prius screen and the experimental REF screen, certain differences in responses to the two designs could be heard in the driver responses, such as when Chad, after viewing the stock Prius screen told the interviewer, "It's cool, you're going down the freeway at like 70 [mph] and getting 99 MPG. I could [purchase a car with instrumentation like that]" after watching the stock interface. The experimental REF would have shown lower overall MPG+ values than the MPG values Chad found so motivating, as well as showing a roundtrip average, both of which would have disabused Chad of the notion that he was achieving 99MPG: his highway driving "energy economy" was closer to 60 MPG+.

Desire to See Information

The REF screen was placed directly in front of the stock Prius REF screen so as to obscure it. To generate a pre-REF baseline experience, the new display initially shows only battery SOC and the participants are asked not to move the experimental REF. However, experienced Prius drivers, including both Kim and Mary, tended to access the stock Prius REF screen during their baseline period by moving the research screen out of the way. Although the propensity for drivers to move the screen even when specifically asked not to by the researcher could be seen as a behavior related more to curiosity than a specific interest in information, the fact that experienced Prius drivers such as Kim and Mary tended to be the ones to defeat the experimental baseline condition (in which no fuel or energy economy information is shown) also indicates that the vehicle information has a strong pull once a driver has been exposed to it.

Relationship Between Stated Competitiveness and Driving Behavior

These four drivers showed a strong relationship between self-reported competitiveness and interest in the REF screen. These results indicate that competitive people are more motivated by this type of information. However, the two respondents with lower self-reported competitiveness

scores on the survey (Larry and Chad) indicated that they felt that high-MPG driving was important to them and both reported modifying their driving behavior, albeit to a lesser extent than Kim and Mary. In Kim's case, her competitive nature both supported and undermined high-MPG+ driving behavior in the case of city driving where other drivers were moving faster than her. She was simultaneously attempting to achieve high-MPG+, and distressed by being perceived as driving too slowly. It was not clear if her distress was mostly from social pressure to drive faster, general anxiousness about time, or a sense that driving too slowly was unsafe.

2E. PROJECT RESULTS: SOCIAL INFLUENCE

Background

> *"Transport planning and even more so transport modeling has ignored the social dimension of travel in the past. There is therefore no empirical literature to fall back on."*
>
> Axhausen (2005, p127)

As noted in Volume I, consumer perceptions of PHEVs can be complex and amorphous. Table 5 presents a conceptualization of perceived PHEV benefits according to two dimensions: functional/symbolic and private/societal. From a *functional* perspective, consumers may interpret the desirability of a PHEV according to its ability to save them money on transportation, to improve drivetrain reliability, or to simply improve the experience of driving. PHEVs may also be perceived according to *symbolic* benefits—what the technology represents to others (Heffner, et al., 2007; Hirschman, 1981). Consumers may also value *societal* benefits (Brown, 2001), such as the PHEV's ability to reduce greenhouse gas emissions, air pollution and foreign oil dependence. Further, such interpretations and reinterpretations may change over time (e.g. Gjoen and Hard, 2002). Thus, the assessment and adoption of electric-drive vehicles entails an ongoing social discourse about their functional, symbolic, and pro-societal benefits. Here we explore the role of *social influence* in the formation of car buyers' interpretations of these benefits—that is, how an individual's perceptions and behaviors regarding PHEVs can be affected and shaped by other people.

Table 5: Conceptualization of PHEV benefits (hypothetical examples)

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

Transportation researchers are only beginning to explore the role of social influence in transportation behavior. Prior approaches to the study of travel and mobility typically ignore

social influence and either focus on aggregate patterns within a transportation system or market, or represent individuals as autonomous agents of self-interest, i.e. the rational actor model. Specific to alternative fuel vehicles, recent studies have attempted to introduce social factors to rational choice models, through the empirical estimation and inclusion of parameters representing preference changes as a new technology gains market share (e.g. Axsen, et al., 2009; Mau, et al., 2008), word-of mouth effects (Struben and Sterman, 2008), and information search channels (van Rijnsoever, et al., 2009). However, these approaches still rely on aggregated representations of behavioral dynamics, in these examples loosely connected to empirical findings from diffusion research in other disciplines (e.g. Rogers, 2003), and ultimately yield little insight into the role of social interactions in vehicle purchase behavior.

One challenge of social influence research is defining an appropriate unit of analysis. In place of the individual consumer or household, social influence researchers often turn to the social network—representations of the relationships among different consumers or agents in a given social system. However, methods of defining and mapping social networks are in their infancy. As noted by Bandura (2006, p123) the "right" network may change depending on context: "there is no single social network in a community that serves all purposes…different innovations engage different networks." For instance, a social network can be defined by location, group membership, common attributes, kinship, roles, affection, interaction patterns, or flows of information, beliefs or resources (Borgatti, et al., 2009), and a given network can change over time (Feld, et al., 2007).

Another challenge is that social influence itself is difficult to define, observe and measure. When relying on quantitative research approaches, researchers struggle to tease out the effects of social interactions from other events. Manski (2000, p128) calls this the reflection problem, where "data on outcomes do not reveal whether group behavior actually affects individual behavior, or group behavior is simply the aggregation of individual behaviors." Manski (2000, p127) distinguishes between the "endogenous interactions" that are processes of social influence from those that are not, i.e., "contextual interactions" such as socioeconomic factors and "correlated effects" effects common to the entire group. For example, Christakis and Fowler (2007) reported that obesity is in part caused by social influence. However, a follow-up study that accounted for environmental factors i.e., one of Manski's correlated effects, reported that the endogenous

social interactions are statistically insignificant (Cohen-Cole and Fletcher, 2008). For these reasons, some researchers suggest that data gathered through larger-scale survey methods may not yield sufficient insights into the role of social influence (e.g. Valente, 2005)—likely because such approaches typically measure social interactions in a superficial manner, if at all.

Given the challenges of mapping social networks and observing social influence, we employ a qualitative research approach to explore these processes within the context of the PHEV Project. Rather than infer social influence effects from a large data set, we seek to "elicit them directly" from participants (Manski, 2000, p131). Echoing this point, Geertz (1973) explains the importance of eliciting "thick" description in behavior research, accounting for the context of observed behavior by recruiting the participant as expert and storyteller to explain social phenomena. Further, though quantitative researchers may resist the "subjectivity bias" inherent in such an approach, such subjectivity may be strength in the context of social influence, where it may be more useful "to measure a person's perception of their world than to measure their actual world" (Borgatti, et al., 2009, p895). Our exploratory methodology investigates three research questions:

1. What aspects of a car buyers' social network are stimulated by their multi-week trial of a PHEV?
2. Do interpersonal interactions play a significant role in a household's assessment of the PHEV?
3. If so, what types of interpersonal interactions are more influential (including discussions of functional, symbolic and societal benefits)?

In this study we seek to observe social influence as it occurs through *social interactions*. We define a social interaction as a set of one or more social episode(s) (verbal or non-verbal communication) between the primary household and one other individual.

Methods: Observing Interpersonal Influence

Social influence occurs in part via social interactions, i.e. verbal and non-verbal communication between individuals. Social interactions take place within social networks, which, as noted above, can consist of multiple individuals connected by a wide variety of relationships. To study social influence, the methodology used here consists of four main components: i) *mapping* the

social networks of participating households, ii) *stimulating* the network through a multi-week PHEV trial and assessment, iii) *observing* the social interactions and interpersonal influence that occur within the network pertaining to the PHEV, iv) *analyzing* the observed social interactions, and v) *synthesizing* the results.

Social network literature differentiates between analyses at the *total network* level versus those at the *personal* (or egocentric) level. A total network attempts to represent every link among all individuals in a given social system. Such an approach is feasible when researching a narrowly defined and bounded social network, such as mapping out relationships among employees at a small company, or farmers in a particular community. However, in most situations it is only feasible to collect data from different personal networks (Carrasco, et al., 2008; Degenne and Forse, 1994)—particularly when considering the broad, disparate nature of new vehicle buyers and the people that might influence or be influenced by them. A personal network is represented by: i) a primary individual or household (the *ego*), ii) the other individuals they are socially connected to (the *alters*), and iii) characterizations of the relationships, or ties, between all individuals (Carrasco, et al., 2008), i.e., between primary and alters and amongst alters (at a minimum as those relationships are perceived by the primary). In a sense, a personal network is a sample from a total network.

The primary goal in the present study is not to construct a total network, but rather to map enough of a given PHEV demonstration participant's personal network to permit the observation of social interactions and influence pertaining to the vehicle. That is, only a finding of no social influence would be susceptible to the argument that our method to map (admittedly partial) personal networks rather than total networks was inadequate. To implement this methodology, we selected a subsample of 10 participating households from the Project. We call each of these households a *primary household*. Each individual they identify in their personal network is an *alter*. We recruited several of these alters as *secondary participants* to take part in an online survey and phone interview.

Eliciting personal network data can be very challenging, including efforts to scope network size, overcome limitations in respondent recall, and mitigate respondent burden (Carrasco, et al., 2008; Marsden, 1990). In this project, we used 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 were 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 that represent social proximity.

Given the exploratory nature of these research questions, we followed a "multi-method" approach (McCracken, 1988, p28) including the instruments already described for the main Project sample, as well as a vehicle purchase history interview, the sociogram construction exercise, a social episode diary, and an influence ranking game. Figure 29 illustrates the study design according to one hypothetical personal network, following four stages that are described next. The components of each stage are also depicted in Figure 30 according to a timeline for one hypothetical primary household and secondary participant (though it doesn't break these components down according to the four stages).

Figure 29: Research design stages according to hypothetical personal network

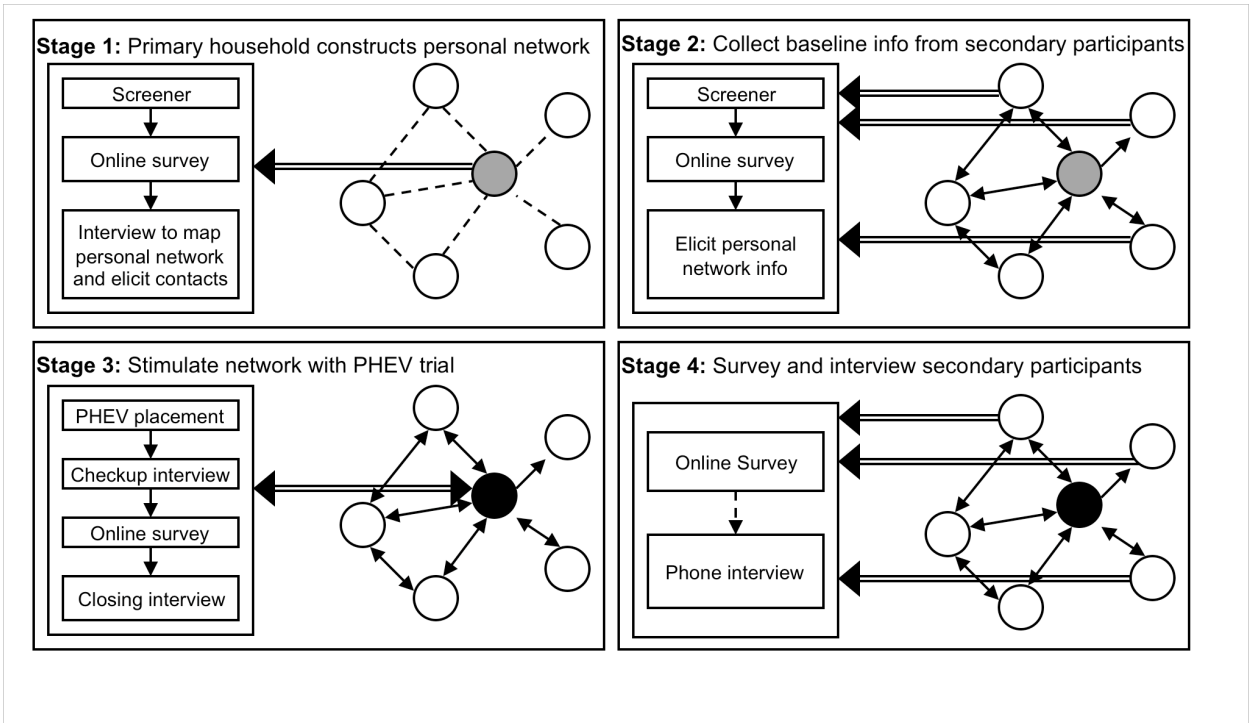
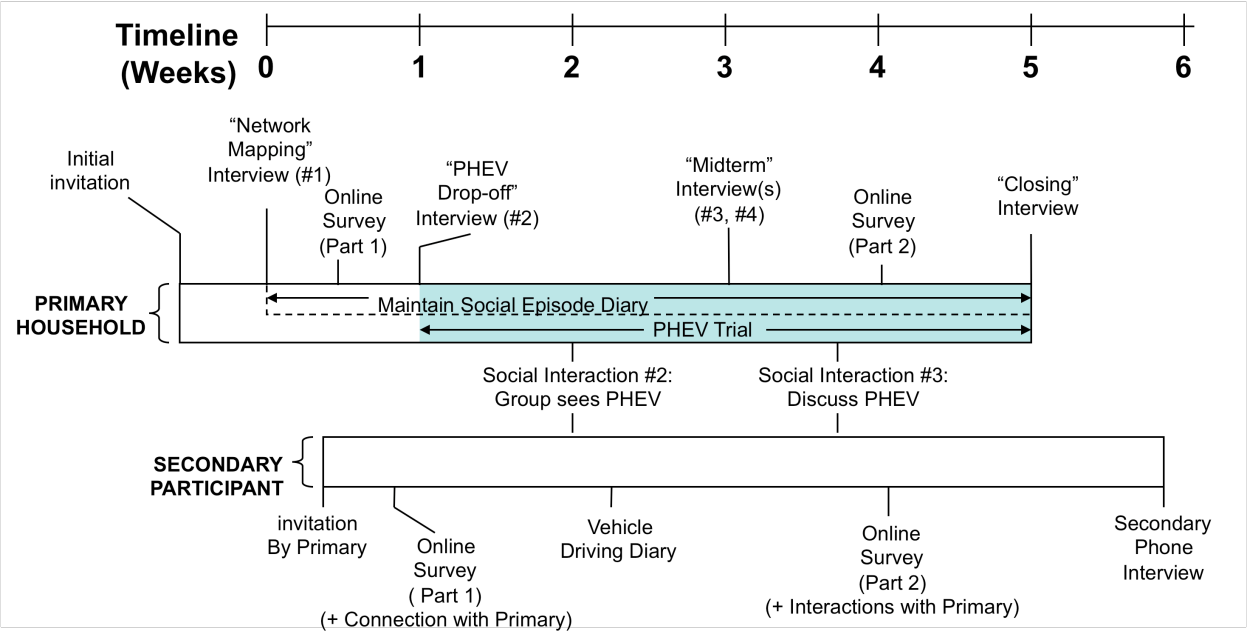


Figure 30: Approximate timeline of research design



The four stages of Figure 29 were implemented as follows.

Stage 1: Contact primary household and elicit personal network.

Along with being screened for eligibility and completing the online questionnaire, the subset of primary households engaged in an extended "network mapping" interview, including:

1. *Household vehicle purchase history and future*: eliciting the primary household's narratives of the vehicles currently and previously owned by the household, including the perceived benefits and drawbacks of each. The primary household was also asked to provide information about any potential future plans to purchase a new vehicle, including the primary objectives of purchase and any specific models that are being considered.

2. *Personal network mapping:* identifying a core network of "very close" and "somewhat close" individuals according to the primary household's criteria, but with prompts of several role categories, e.g. family and coworkers, and vehicle experts (e.g. those they would typically consult regarding the purchase of a new vehicle) and vehicle dependents (e.g. those that would consult them).

3. *Instructions to recruit secondary participants*: asking primary households to personally invite several network members to the study by phone, email, or personal contact. Secondary participants were promised monetary rewards. To encourage follow-through, primary households were asked to identify five to ten alters they would invite within the following week.

4. *Social-episode diary*: providing a booklet and instructing primary households to make brief notes of any social episodes in which they discuss PHEVs, electric-drive technology, or vehicle purchases in general over the four to six-week period of the PHEV trial in Stage 3. The purpose of the diary was not to be an exhaustive record of social interactions, but rather to better stimulate participant recall during interviews.

Stage 2: Collect baseline information from the personal network.

Primary households were given about one week to recruit secondary participants. Primary households and recruited secondary participants were all requested to complete the online questionnaire before the PHEV trial began. The online questionnaire was nearly identical for secondary participants as the version used for primary households, but an additional set of questions confirmed 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.

In interview #2, researchers returned to commence the primary household's PHEV trial. The primary household was given a brief introduction to the technology and guided test drive, and asked to provide an update of their social interactions. The household was asked to substitute the PHEV for one of their vehicles and thus integrate it into their lifestyle as if they owned the vehicle. During their trial, the household completed several tasks, including:

1. The social episode diary.
2. The online PHEV design questionnaire (survey Part 2).
3. One or two midterm interviews (every two weeks) including updates of social episodes.
4. A closing interview, consisting of questions regarding:
    a. The household's overall experience with the PHEV (narrative).
    b. Recharging, driving, and fueling behavior.

c. The participant's overall assessment of the PHEV, including functional, symbolic and pro-societal interpretations, and the dynamics of these interpretations over the course of their trial.

d. Assessment of interests in future vehicle purchases (assisted by previously elicited responses in the PHEV design questionnaire).

e. Social interactions with members of the personal network (and others) including the content and frequency and perceived importance of such discussions.

f. An experience ranking exercise, considering three categories of experience: i) *technology* experiences, such as driving and recharging the PHEV; ii) *social* experiences, including each reported social interaction; and iii) *research* experiences, including each interview, survey and other tasks the household was asked to complete. These categories were selected to allow us to compare the influence of social experiences (the topic of this study) with two other categories of potentially influential experiences: interactions with the PHEV itself, and interactions with researchers. Researchers first compiled the list of experiences as elicited from previous interviews then allowed the household to add to or alter the list. Each experience was phrased to be as personal and specific as possible, using the participant's own wording when possible. The household was then asked to rank each experience using a 10-point scale, with highly influential experiences assigned up to 10 points, and non-influential experiences assigned as little as one point.

Stage 4: Network questionnaire and selected interviews.

At the close of the trial, secondary participants were again contacted to share their observations of the primary household's PHEV trial. All secondary participants completed the online PHEV design questionnaire, which also elicited information about any social interactions that occurred with the primary household during the trial. Secondary participants also took part in a telephone interview eliciting details of any experience with the PHEV, interpretations of the vehicle during the primary household's trial, specific social interactions with the primary household or others during the trial, and interests in future vehicle purchases.

The Sample

Figure 31 depicts the geographic distribution of the sub-sample of 10 primary households (18 individuals) as well as the 22 secondary participants they recruited. All primary households and most secondary respondents reside in the Sacramento area—five secondary participants reside elsewhere (the San Francisco Bay Area, the Sierra Nevada foothills, and Pennsylvania). The

characteristics of this subsample are similar to the full Project sample on several criteria including the distribution of environmental beliefs, electric-drive knowledge, and PHEV design interests. Although the goal was not to necessarily produce a representative sample, participants in the social networks span a variety of ages, incomes, household sizes, and employment categories (see Table 6).

Figure 31: Geographic distribution of primary households and secondary participants

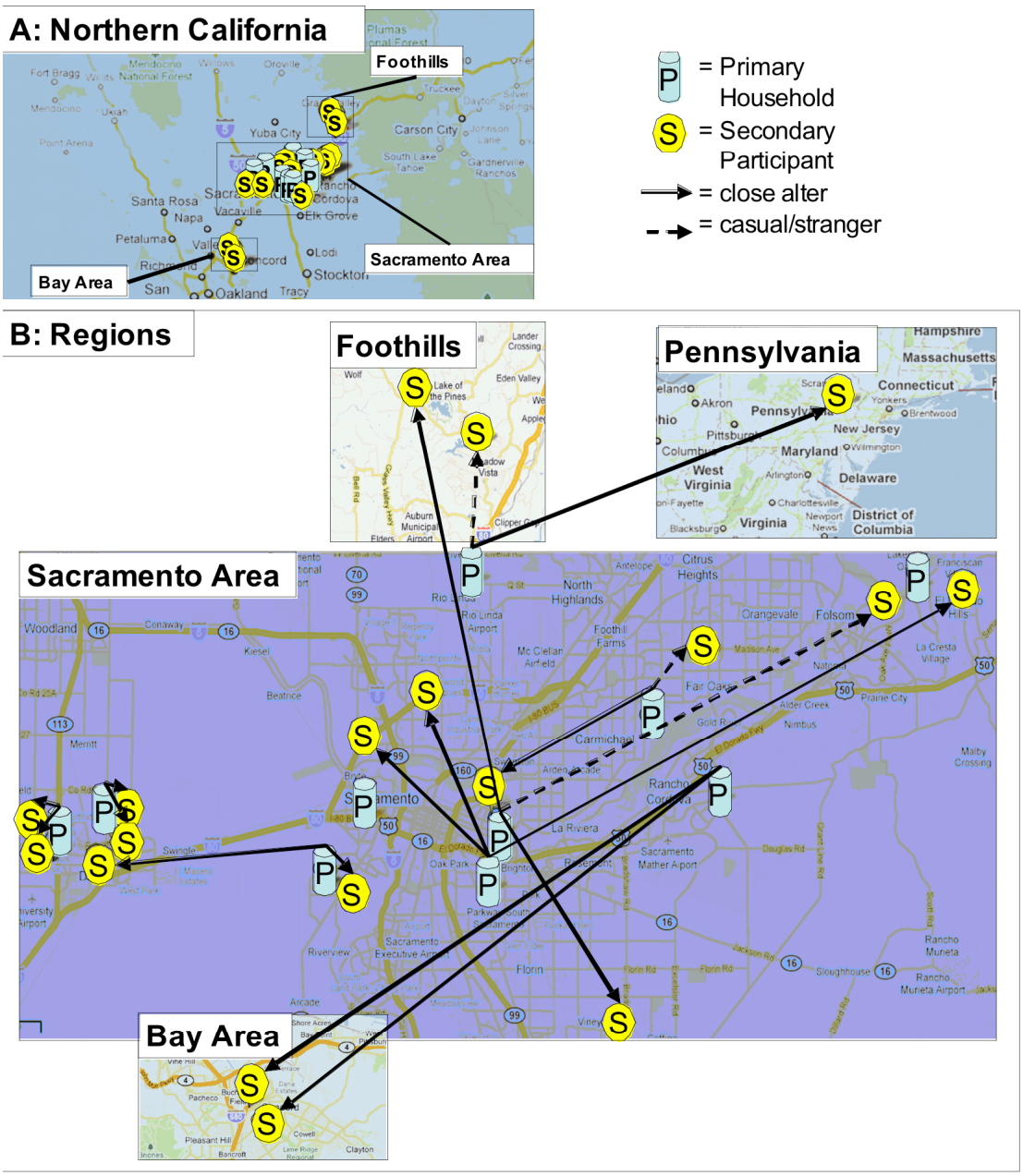


Table 6: Characteristics of primary households and secondary participants

Surname—Primary only	First name **Primary** Secondary	Age	Household income	Demonstrated lifestyle practices	Relation to primary	For primary: Social proximity[2]	For primary: Influence	For secondary: Social proximity	For secondary: Influence
Woods	**Billy**	40s	$100-124k	Recreation					
	Pat (F)	40s	$70-79k	Family	Girlfriend	V. close	Low	V. close	High
	June (J)	40s	$80-89k	Recreation	Friend	S. close	High	V. close	High
	Chris (K)	40s	$80-89k	Recreation	Friend	S. close	n/a	V. close	High
	Harry (R)	40s	$125-149k	Enviro./tech.	Coworker	Stranger	High	Stranger	Low
Noel	**Rupert**	40s	$80-89k	Family					
	Amy	40s	$80-89k	Family					
	John	60s	$125-149k	Family/tech.	Coworker	S. close	Mod	Casual	Mod
	Ray	20s	$70-79k	Family	Friend	S. close	High	V. close	Mod
	Anita	30s	$125-149k	Family	Friend	V. close	Mod	V. close	High
Petrov	**Adam**	60s	$40-49k	Tech./construction					
	Katrina	30s	$40-49k	Student					
	Pavel	20s	$30-39k	Rec./tech.	Son	V. close	High	V. close	Low
Earhart	**Betty**	30s	$50-59k	Work/family					
	Hazel	40s	$50-59k	Family	Friend	Casual	Low	S. close	Mod
	Macy	20s	$70-79k	Student	Daughter	V. close	High	V. close	Low
Stashe	**Darren**	50s	$100-124k	Work/family					
	Pat	50s	$100-124k	Work/family					
	Cliff	30s	$100-124k	Work	Coworker	Casual	Low	S. close	Low
	Melissa	20s	$100-124k	Student					
	Graham	20s	$80-89k	Recreation	Friend	S. close	High	S. close	Mod
Ranchero	**Ed**	30s	$100-124k	Family/tech.					
	Silvia	30s	$100-124k	Family					
Potter	**Ethel**	50s	>$150k	Family					
	Jane	20s	$40-49k	Rec.	Daughter	V. close	Mod	V. close	Low
	Christy	20s	n/a	Student/rec.	Daughter	V. close	Low	V. close	Mod
	Tom	30s	$70-79k	Construction	Son-in-law	S. close	Low	V. close	Mod
Fort	**Brett**	40s	$100-124k	Family/rec.					
	Julie	20s	$100-124k	Student					
	Selena	40s	$100-124k	Family/rec.	Wife	V. close	High	V. close	High
	Guy	30s	$125-149k	Tech.	Neighbor	S. close	Low	V. close	Mod
	Lindsey	40s	$60-69k	Family	Friend	S. close	Low	V. close	Low

Table 6: continued: Characteristics of primary households and secondary participants

Surname—Primary only	First name **Primary** Secondary	Age	Household income	Demonstrated lifestyle practices	Relation to primary	For primary: Social proximity[2]	For primary: Influence	For secondary: Social proximity[2]	For secondary: Influence
McAdam	**Craig**	40s	>$150k	Enviro./tech.					
	Siobhan	40s	>$150k	Enviro.					
	Hannah	30s	$20-29k	Enviro.	Friend	V. close	Mod	V. close	High
	Steve	40s	>$150k	Enviro./tech.	Friend	V. close	Mod	V. close	Mod
Rhode	**Larry**	40s	>$150k	Fam./enviro./tech.					
	Cheryl	30s	>$150k	Fam./enviro.					
	Nicole	50s	$100-124k	Fam./enviro.	Neighbor	S. close	Low	S. close	Low
	Betty	30s	$100-124k	Fam./enviro.	Friend	S. close	High	S. close	Low

Table 6 also categorizes each participant according to demonstrated lifestyle practices. These categories were established by researchers based on observations from interviews and surveys, and often relate the participant's interest in vehicles. For example, "recreation" participants devote much of their time to activities such as golfing, skiing or camping, and may describe considering such activities when selecting a vehicle for purchase. "Family" participants tend to spend most of their time with their children and perhaps extended family, and may select vehicles based on family concerns. "Environment" participants devote significant time and resources to environmental concerns, such as consistently recycling, buying organic foods, composting, and may have considered or purchased an HEV or fuel-efficient vehicle in the interest of reducing their environmental impacts. "Technology" participants are highly interested in researching and purchasing new products, such as those that have built or are planning to build their own EV. "Work" participants are career focused, "students" engage primarily in schooling activities with a limited income, and "construction" participants tend to be interested in pickup trucks that can haul tools and supplies.

Results

Mapping Social Networks

To illustrate the methodology used to elicit network data, Figure 32 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 alters 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 32 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." Recruited 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 30 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 6 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 secondary participants. 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 32: Billy Woods' Sociogram

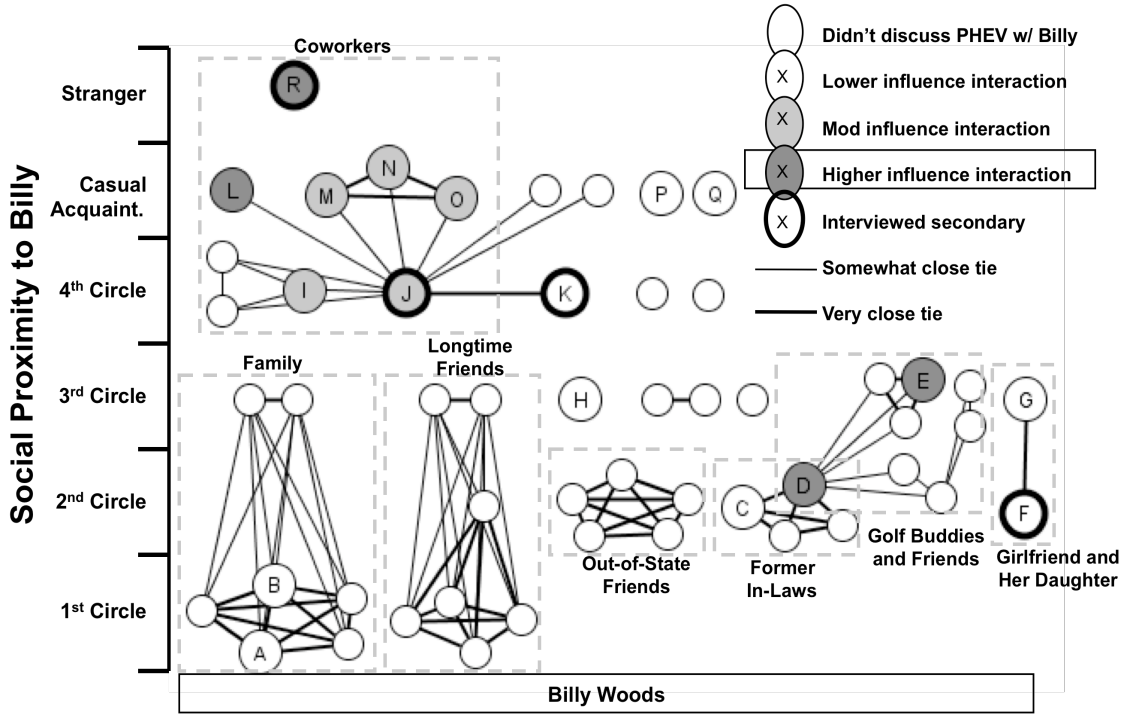
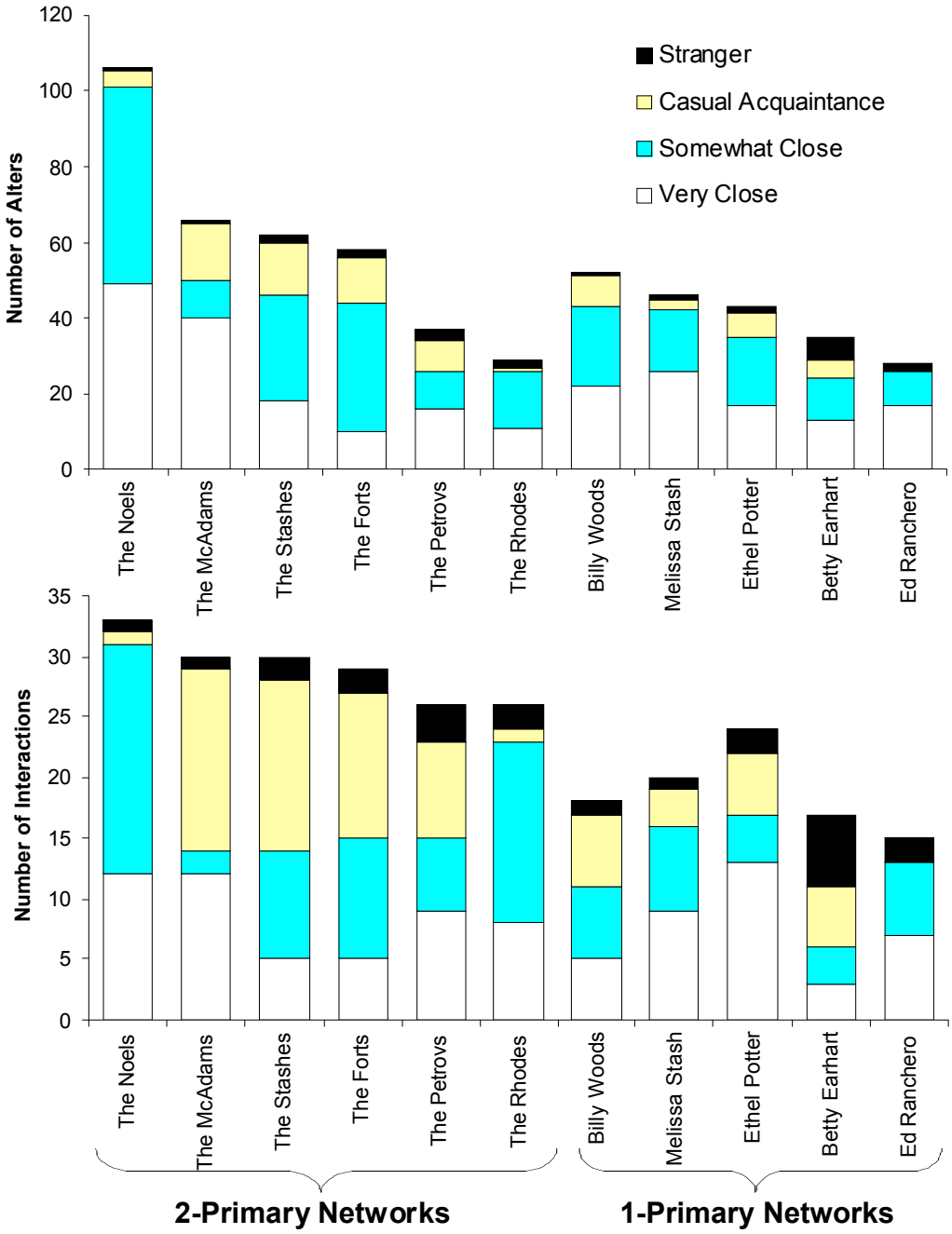


Figure 33 compares the number and distribution of alters across all 11 social networks (one household constructed two networks—one for the parents and one for the daughter). In total, 562 alters were identified, with the majority being classified as very close (43 percent) or somewhat close (40 percent), followed by the casual acquaintances (14 percent) and strangers (4 percent). The former two categories were intended to be exhaustive, but the latter two categories were identified by primary households via social interactions that occurred during the PHEV trial. The total number of close alters per household ranged from a high of 101 (the Noels), to a low of 24 (Betty Earhart). In terms of alters per person (six networks include two primary participants or egos), the number ranges from 51 (again the Noels) to a low of 13 (the Petrovs and the Rancheros). The mean and mode of close alters per participant (29 and 25, respectively) are higher than those yielded by another study (24 and 21) using a similar methodology in a different region (Hogan, et al., 2007). One explanation could be sampling differences, such as the different regional context or the smaller sample size perhaps being skewed by one or more particularly large networks. Also, the present study allowed more opportunities for primary households to "correct" their social network by presenting their sociogram at each interview—participants often added alters they had forgotten during initial construction of their sociogram (the previous study used only one interview).

Figure 33 also portrays the distribution of social interactions regarding the PHEV reported by each primary household. As noted above, we define a social interaction as a set of one or more social episode(s) (verbal or non-verbal communication) between the primary household and one other individual. For example, although Billy Woods discussed the PHEV with June on almost a daily basis during his trial, this set of episodes is recorded as one social interaction. When Billy Woods discussed the PHEV with a group of three co-workers, three separate interactions are recorded (one for each co-worker). Further, an interaction does not require face-to-face or verbal communication—it may consist of an email, a written note, or a meaningful body gesture such as a wave of the hand or nod of the head. Using this definition, the ten primary households reported a total of 275 social interactions over the course of their PHEV trials, ranging from 33 (the Noels) to 15 (Ed Ranchero) per primary's network, or 24 (Ethel Potter) to 13 (the Petrovs and the Rhodes) per individual. The majority of interactions took place with very close

(33 percent) or somewhat close (32 percent) alters, followed by casual acquaintances (26 percent) and strangers (9 percent). However, this distribution varies substantially across social networks (Figure 33).

Figure 33: Number of alters and interactions per primary's network, by social proximity



Do Social Interactions Matter?

We use these reported social interactions to investigate the role of social influence. As noted in the methods section, the primary household provided their assessment of the PHEV vehicle technology in Stage 3 of the research design. Afterwards, they were consulted to help generate a list of their various experiences during their PHEV trial, then asked to rank how influential each experience was over their assessment of the vehicle. For illustration, Table 7 summarizes Ethel Potter's ranking of experiences. For Ethel, the most influential experiences with the PHEV technology were i) regularly using it to commute to and from work, and ii) a moment where the Prius monitor showed her she had achieved 89 miles per gallon for a given trip. Her most influential social experience, which was ranked on par with the two technology experiences, was talking with one of her daughters that was enthusiastic and supportive of the PHEV. Her most influential research experience was interview #2, where researchers first dropped off the PHEV and explained the technology. At the bottom of Table 7 are experiences she ranked as having little influence over her PHEV assessment, such as refueling the PHEV, telling two uninterested coworkers about her PHEV trial, and reading the "PHEVs Buyers' Guide" for the online survey.

Figure 34 summarizes the distribution of rankings across all 10 households. Seven out of 10 primary households ranked at least one social interaction as being highly influential, and nine out of 10 rank at least one as moderately influential. This comparison does not tally up experiences from each category to determine a "winner," but is instead provided to yield one answer to our first research question. The high ranking of at least some social interactions across the majority social networks suggest that indeed, social interactions play a significant role in participants' assessment of PHEVs.

Under What Conditions do Social Interactions Matter?

We next try to understand why some social interactions are ranked as more influential than others. To look for patterns among the 275 reported interactions, we view distributions and employ simple statistical analyses. To guide this exploration, we

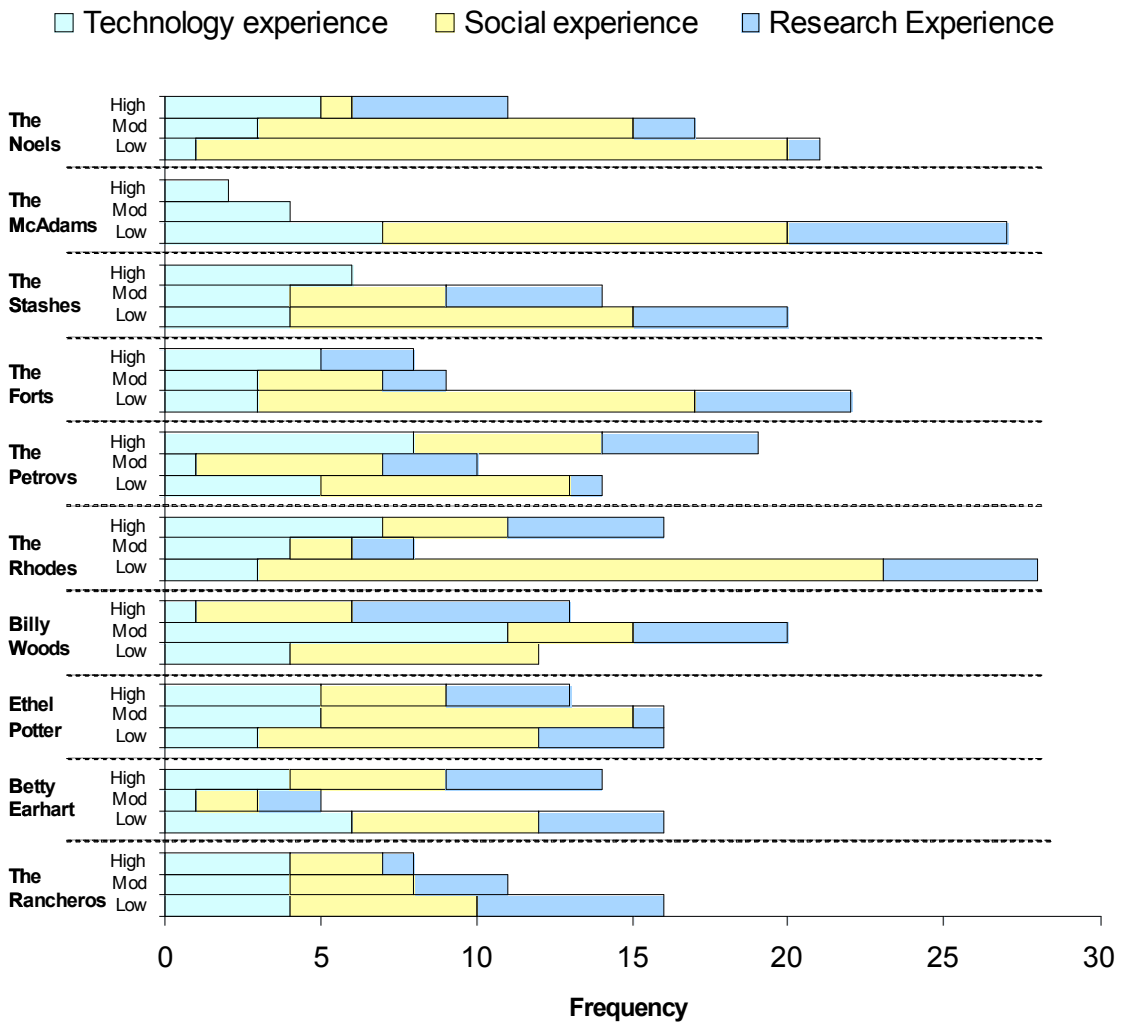
consider five categories of characteristics that may explain why some interactions are more influential, including:

1. The relationship between the primary household and alter, including role category, social proximity and tendency to discuss vehicles.
2. The mode of the interaction, including face-to-face (verbal or non-verbal), phone, or electronic, e.g., e-mail, instant messaging or online social networking.
3. The types of PHEV benefits or attributes addressed in the interaction, i.e., private vs. societal and functional vs. symbolic.
4. Prior experience with alternative-fuel technology on the part of the primary household or the alter.
5. The presence or absence of pro-environmental values for the primary participant and the alter.

Table 7: Ethel Potter's Ranking of Socio-Technical Experiences

Rank	Type of Experience		
	Technology	Social (talking with…)	Research
More influential experiences			
9-10	• Driving to/from work • Getting 89 mpg	• Daughter 1	• Interview #2
8-9	• Initial test drive	• Daughter 2	• Initial phone call • Interview #4
7-8	• Driving to/from Grass Valley • Driving to run errands	• Irrigation repairman • Husband	• Interview #3
6-7	• Comparing MPG with the fleet	• Coworker 1 • Boss • Daughter 3 • Pottery teacher • Sister	
5-6	• Watching mpg reading • Watching Prius monitor	• Daughter 4 • Pottery student	• Interview #1
4-5	• Visiting V2Green website • Using only the battery on highway	• Daughter 5 • Friend 1 • Solar panel salesman	
3-4	• Plugging in at home • Watching the battery deplete	• Daughter's boyfriend • Son	
2-3	• Refueling the PHEV	• Friend 2 • Daughter 6	• Invitation letter • Online survey part 1
1-2		• Friend 3 • Coworker 2 • Friend • Church Guy • Coworker 3	• Online survey part 2 • PHEV Buyers' Guide
0-1			
Less influential experiences			

Figure 34: Primary household's ranked influence of their PHEV trial experiences over their PHEV assessment



The distribution of these characteristics is depicted in Table 8. Two types of statistical analysis were employed to look for patterns among these characteristics. Two-way tests of independence were conducted to look for association between the ranked influence of an interaction (three levels: high, moderate, or low influence) and the characteristic in question. Logistic regressions were also estimated to consider multiple explanatory factors, with ranked influence as the dependent variable (two levels: 1 = high-moderate, 0 = low influence). The first logistic regression model in Table 9 includes all factors, while

the second model only includes statistically significant categories. Each factor is explained below:

Relation with alter: We considered three measures of relations between the primary household and alter. First is the role category, including family, friend, coworker, neighbor or other. Across the 275 reported interactions, we find no evidence of association between the alters' role category and the ranked influence of the social interaction.

A second measure of relation is whether the primary and alter typically discuss vehicle purchases. When primary household's constructed their sociogram in Interview #2, they were asked to identify alters they had talked to regarding a previous vehicle purchase, alters they might talk to regarding a future vehicle purchase, and alters that would likely talk to them in such a situation. We categorize the 63 reported social interactions with these alters as occurring with "typical vehicle discussants." A two-way test of independence between this category and ranked interaction influence suggests there is no association ($X^2 = 1.594$, $df = 2$, *p-value* = 0.45), which is supported by regression results.

The third relational measure is social proximity, which we employed in construction of the primary households' sociograms. This factor is found to be statistically significant in the logistic regression, as well as a two-way test of independence ($X^2 = 16.91$, $df = 6$, *p-value* < 0.01). Interestingly, the standardized residuals in Table 10 indicate the relationship may not be linear; interactions with very close alters and strangers may be more influential, while interactions with somewhat close alters and casual acquaintances may be less influential. Figure 35 visually depicts this relationship for all primary households, and illustrates differences among households with two examples. Billy Woods' (recreation-oriented lifestyle) most influential social interactions take place with alters from each category of social proximity, including several casual acquaintances. In contrast, the Noels (family-oriented lifestyle) only ranked interactions with very close or somewhat close alters to have high or moderate influence—particularly the very close alters. The non-linear association depicted in Table 10 may be a product of aggregating such differing patterns across households.

Table 8: Characteristics of interactions

Factor (reference)		Number	Percent
Relation with alter			
Role category	Family	49	17.8%
	Friend	84	30.5%
	Coworker	85	30.9%
	Neighbor	18	6.5%
	Other	39	14.2%
Typical vehicle discussant	Yes	63	22.9%
	No	212	77.1%
Social proximity	Very close	89	32.7%
	Somewhat close	87	31.6%
	Casual Acquaintance	75	27.3%
	Stranger	23	8.4%
Mode of interaction	Face-to-face verbal	250	90.9%
	Face-to-face non-verbal	7	2.5%
	Phone	10	3.6%
	Electronic	8	2.9%
PHEV benefits discussed			
Private vs. societal	Private	241	87.6%
	Societal	34	12.4%
Functional vs. symbolic	Functional	258	93.8%
	Symbolic	17	6.2%
Alt-fuel experience			
Primary owns HEV	Yes	57	20.7%
	No	218	79.3%
Alter has alt-fuel experience	Yes	22	8.0%
	No	253	92.0%
Pro-environmental values			
Demonstrated by primary	Yes	110	40.0%
	No	165	60.0%
Reported for alter	Yes	22	8.0%
	No	253	92.0%

Table 9: Logistic regression model predicting rated influence of social interactions

	Full Model		Reduced Model	
Factor (reference)	Estimate	SE	Estimate	SE
Intercept	0.05	1.05	0.26	0.47
Relation with alter				
Role Category (family)				
Friend	-0.23	0.24		
Coworker	-0.14	0.29		
Neighbor	0.49	0.41		
Other	-0.08	0.38		
Typical vehicle discussant	-0.12	0.21		
Proximity (very close)				
Somewhat close	-0.69	**0.24****	-0.53	**0.18****
Casual	-0.80	**0.28****	-0.71	**0.20****
Stranger	-0.71	0.40	-0.52	0.30
Mode of interaction (FTF verbal)				
FTF non-verbal	0.37	0.72		
Phone	-0.51	0.42		
Electronic	0.29	0.42		
PHEV benefits discussed				
Societal (private)	1.42	**0.34****	1.45	**0.30****
Symbolic (functional)	-0.21	0.43		
Alt-fuel experience				
Primary owns HEV	-0.79	**0.34***	-0.89	**0.27****
Alter has alt-fuel experience	0.94	**0.34****	1.02	**0.31****
Environmental values				
Primary	-0.22	0.21		
Alter	0.52	0.39		
r-square	0.247		0.219	
Log-likelihood	-134.0		-138.9	
AIC	267.9		277.8	

* $p < 0.05$ ** $p < 0.01$

Mode of Interaction: Of the 275 recorded interactions, the vast majority involved face-to-face verbal communication (91 percent). Seven interactions involved face-to-face non-verbal communication, such as a friendly wave on the highway, a jogger's look of surprise, and a neighbor's hand motion indicating the PHEV looked expensive. 10 interactions were based on phone calls, and eight involved electronic forms of communication, including e-mail, instant messaging, and in one instance a PHEV-related

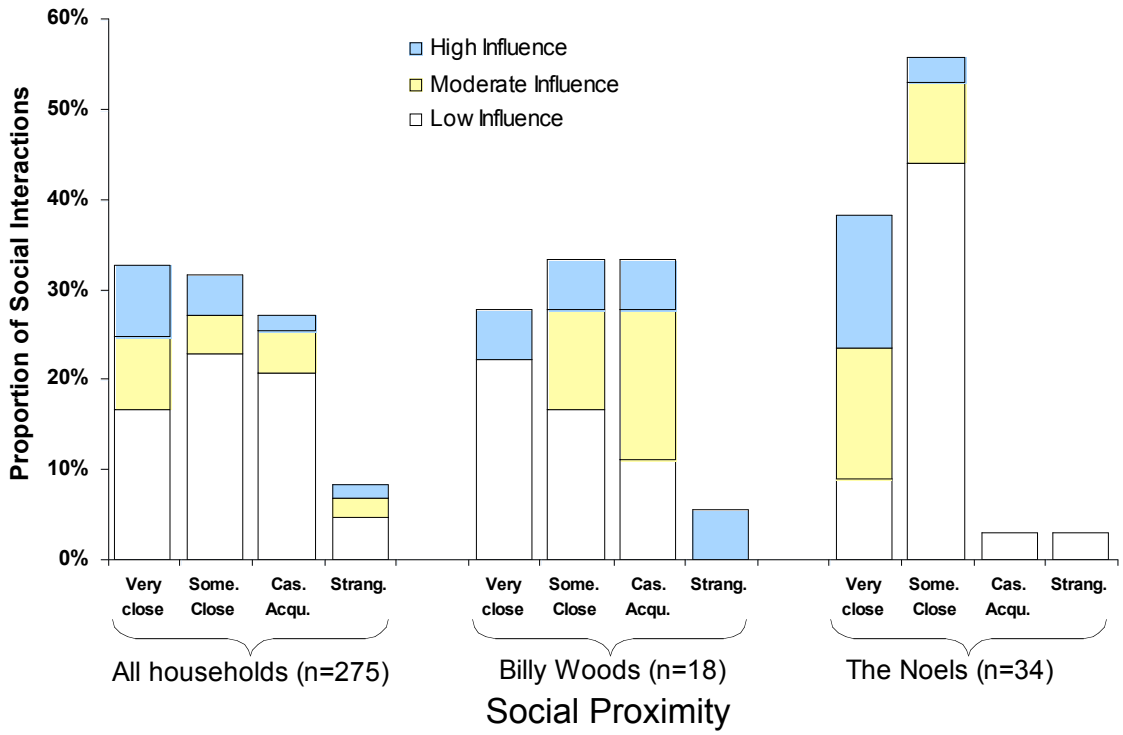
posting on Facebook (an on-line social networking tool). We find no statistical evidence of association between the mode of interaction and ranked influence.

Table 10: Contingency table of rated influence by social proximity (standardized residuals in brackets)

	Ranked Influence			
Social Proximity	High	Moderate	Low	Total
Very close	22 (**2.81**)	22 (1.52)	46 (**-3.39**)	90
Somewhat close	12 (-0.57)	12 (-1.57)	63 (1.73)	87
Casual acquaintance	5 (**-2.51**)	13 (-0.50)	57 (**2.32**)	75
Stranger	4 (0.24)	6 (0.87)	13 (-0.90)	23
Total	43	53	179	275

PHEV attributes discussed: Considering the typology of potential PHEV benefits in Table 5, researchers categorized the interactions reported by participants according to whether they discussed PHEV benefits that were private or societal, and functional or symbolic. Billy Woods provides examples of interactions for each category, where in different contexts he discussed the PHEV's: ability to reduce fuel costs (private-functional), his belief the car would be perceived as unattractive at nightclubs (private-symbolic), ability to help the environment (societal-functional), and link to a broader vision of alternative-fuel mobility (societal-symbolic). Across households, the vast majority of reported interactions focused on private (88 percent) and functional (94 percent) aspects of the PHEV technology. Two-way tests of independence suggest that interactions are more likely to be ranked as more influential if societal benefits were discussed rather than just private benefits ($X^2 = 38.51$, $df = 2$, *p-value* < 0.0001), and if symbolic benefits were discussed rather than just functional benefits ($X^2 = 25.69$, $df = 2$, *p-value* < 0.0001). However, the logistic regression indicates that the discussion of symbolic benefits becomes insignificant when controlling for other factors.

Figure 35: Social interactions: rated influence by social proximity (all interactions, Billy Woods and the Noels)



Alternative-fuel vehicle experience: We considered two measures of alternative-fuel experience that might relate to social influence. First is whether the primary household owns an HEV, which accounts for 57 social interactions (in the Rhodes' and McAdams' social networks). Second is whether the alter has previous alternative-fuel experience (accounting for 22 social interactions), including current or previous HEV ownership, building their own EV, or other demonstrated interest and knowledge in alternative-energy issues, such as membership in related social groups. Both factors are statistically significant, where social interactions are more likely to be ranked as influential if the primary household does not own an HEV, and if the alter has some alternative-fuel experience.

Pro-environmental values: We also consider whether the primary household or alter demonstrate pro-environmental values: neither is statistically associated with ranked social influence.

3. Discussion and Conclusions

Putting Discussion and Conclusions in Context

The total sample of 67 households at once conforms to the sampling plan initiated during the first year of the Project and expands the geographic region from which the sample was drawn. The description of the sample and how it differs from other samples of households is therefore much the same as described in Volume I. Conclusions regarding PHEV designs and energy effects are amplifications of those reported in Volume I, reading very similarly in their substance. In contrast, the discussions of the use of narrative, the effects of energy instrumentation feedback, and the role of social networks all contain discussion of new results, as well as substantive elaborations and extensions of the earlier conclusions.

The PHEVs used throughout the Project were conversions of Toyota Priuses using A123Systems' conversion. The conversion involved 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 charged from a standard US three-prong, grounded, 110-volt outlet. A "fully" discharged battery takes approximately five hours to recharge. The PHEV-conversions were 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 was easier, though by no means easy, to keep the ICE off during CD mode in the PHEV-conversions than in a stock Prius.

One way to measure the performance of a particular technical specification for a PHEV is to recast it in terms of the range of realized performances based on our participants' driving and recharging behaviors. In this way the vehicle used in this project is updated from a similar characterization in Volume I to be:

1. A PHEV that operates in blended mode during CD operation;

2. In exchange for about 4KWh of grid-electricity, it will achieve (47 to 120) mpg (gasoline-only) during CD operation;
3. CD operation will last for (24 to 40) miles using a definition of CD range that references only when the switch from CD to CS operation occurs;
4. Achieves (34 to 57) mpg in CS operation (where percent improvement in CD operation is positively correlated with CS fuel economy *across drivers*), and;
5. Drivers achieved changes in total tank/battery-to-wheels energy intensity ranging from a (7 percent increase to a 32 percent reduction).

The ranges of CD, CS, and total energy performance 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' last week of their PHEV trials, in CD operation for 49 percent of their total miles (a reduction from the 53 percent measured across the first 34 households); the range across household means was 0 to 100 percent. The zero value is from a household who had decided by their final week that recharging did not make a big enough difference to them. The lowest non-zero value, as an indication of the values by households who were at least still engaged with the question of recharging, was 13 percent. It is unsurprising, but important, that the range within a single household across their recharging intervals can be as large, e.g., from less than two to 100 percent in one household.

As before, the results of the PHEV Demonstration and Market Research Project are put into context partly through comparison to 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 Project 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.[51]

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 were 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 were much more likely to be between the ages of 35 and 54 than the general population. Our Project and survey respondents were more likely to live in detached homes than the general population. The gender balance of the Project participants did tip slightly toward more women than men during the second year, but remains 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 still cannot be considered to be so pro-PHEV, so pro-electric-drive technology, or so pro-environmental compared to other samples of new car buyers as to skew Project participants' 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. The differences remain slight and we judge them to be unlikely to make a substantive difference to any conclusions we may draw between the samples. For example, a rank order of the urgency of these three economic-environmental problems is the same across these three samples: air pollution first, followed in order by dependence on foreign oil, and climate change.

There was 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.

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[51] 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.

Across all samples, very high percentages of respondents knew that a plug-in hybrid can be both fueled and plugged-in; the highest percentage was among our Project participants. There were a few opportunities for "information leaks" about PHEVs to respondents in the present Project: notably, the information unavoidably provided to households when the PHEV was first delivered.[52]

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.

PHEV Design Conclusions

PHEVs (still) aren't about all-electric driving; they're about high fuel economy

As stated in the conclusions to Volume I, we found more evidence to support our prior conclusion from the large-sample survey that consumers create PHEV designs that emphasize (gasoline-only) fuel economy in CD and CS mode and found 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 that relied on blended operation in CD mode, i.e., designs 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-

[52] The questions about electric-drive knowledge were part of a longer, more substantive questionnaire that could not be administered until after the household was fully enrolled in the Project, which occurred when the vehicle was delivered.

electric operation throughout its CD range, it remains the case that experience with a PHEV did not lead 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)

The substantive conclusions drawn from the PHEV designs created by the additional households who participated in the Project since Volume 1 of this report was written support those of that initial volume: 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 and for policy makers to design appropriate packages of incentives, social marketing, and requirements. Within this variety of designs however, we continue to find little evidence of inherent demand for all-electric operation in CD mode—though we cannot presently exclude the possibility of participants anchoring on what is now familiar to them, i.e., blended rather than all-electric CD operation.

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.

Project results do differ from survey results in some important ways

These results contrast with the findings of Heffner et al.'s (2009) 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 a PHEV that affords little practical all-electric operation CD mode, i.e., a blended CD mode PHEV.

Participation in the Project appears to have decreased the importance of improvements in recharging speed compared to prior survey respondents, but 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 a likely next new vehicle.

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. Evidence of this will be reported in the section on household narratives where we describe the additional themes that emerged from the later participants.

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.

Recharging Conclusions

Households 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 a little more than once per day, and do so more often on weekdays than weekend days. There is large variation though even in the mean number of daily plug-in events across households—from zero to 2.6 mean plug-in events per weekday and zero to 4.0 per weekend day. The higher average frequency of plugging-in on weekdays is associated with 1) some incidence of recharging at work on weekdays by a few households, and 2) recharging at home during weekdays by retired households, telecommuters, and homemakers. Overall frequency of plugging-in on weekend days is lower not only because there is no workplace recharging taking place, but because the PHEVs may be away from home and thus away from the primary or sole recharging location, or the householders may be away from home in a vehicle other than the PHEV. Compared to the first 34 households, differences in the sample mean of the household means of weekday and weekend day frequency of plug-in events and the range of such household means are slight.

Comparing electricity availability and instantaneous power demand provides a picture of aggregate recharging behavior and potential 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.

While the electricity availability and instantaneous power demand represent 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 of driving the PHEV conversion, that record of actual driving during the PHEV trial may not be representative of every week or month of a household's life—just as any week may vary in its representativeness of a households travel during any period.

The total energy savings and gasoline (tank-to-wheels) displaced by electricity (battery-to-wheels) from households driving of the particular PHEV-conversion used in this research were modest in aggregate and highly variable across households. Those households who were able to closely match the distances between plug-in events to their achieved CD range were able to achieve 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 was 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.

Total Energy, with and without recharging

In contrast to Volume I where we analyzed whole months of driving, recharging, and energy data, in Volume II we limit the period of analysis to the households' final week driving the PHEV. We compared the total energy (gasoline plus electricity) used by the households to drive the PHEV-conversions for the last week of their PHEV trial to the gasoline they would have used had they not recharged at all.[53] This is a close approximation to the question, "What difference does it make that this PHEV-conversion can be plugged into the electrical grid?" Though we generally stress the behavioral differences that affect results, here we also stress that the specific numeric results also depend on the particular PHEV-conversion used in this Project. On average, the households saved about one gallon of gasoline per week at the "cost" of 18.4 kWh, or 0.054 gallons per kWh tank/battery-to-wheels compared to if they had not recharged at all. Reductions in gasoline consumption ranged from as little as 0.1 to 5 gallons over the final week of PHEV driving and recharging. Grid-electricity use varied from 3.8 to 47 kWh. The amount of electricity substituted for gasoline was related to the ability of a household to match their vehicle's recharging interval to their achieved CD range. Households achieved percent of miles driven in CD operation ranged from 15 to 100 percent for their final week. Approximately half of Project households were able to drive 63 percent or more of the vehicles miles in CD operation during that last week.

Such analysis of total energy is entirely a construction of the analysts—no household created an integrated accounting of both their gasoline and electricity use. Not even those few households who used the website presenting measures of gasoline and electricity use and estimates of costs for both had any idea how much electricity they used or what it cost them. A few households have remarked how hard it is to see their electricity use through their monthly utility bill.

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[53] In general, we do not compare the PHEV to the households' own vehicles. The households varied widely in the extent to which they substituted the PHEV for one household vehicle. The PHEV was often driven more miles than would any household vehicle have been driven.

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

Borrowing from the conclusions 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.

Narrative Conclusions

Narrative methods allow people to express their beliefs and the motivations behind their actions to researchers, policymakers, and manufacturers. These insights from the households in the Project are distilled into the following themes: changing driving behavior, recharging habits and etiquette, confusion, payback, saving money, collective benefits, prior expectations, and the future. The last four are elaborations on our prior meaning of payback and additional themes to those heard from the first year's participants. The themes that were expressed in these narratives suggest new hypotheses, probable reactions to policies, and desired PHEV capabilities.

Some participants changed how they drove the car after seeing their instantaneous fuel economy; others drove the PHEV as any other car, and specifically like they had no control over energy use. Some likened plugging in the PHEV to recharging a cell phone—part of their daily routine—but were hesitant to recharge the PHEV away from their homes due to a lack of etiquette and concerns for safety. Such people may feel workplace and public recharging locations solve the problems of social relations as much as increasing their use of electricity. Many people were confused about the state of charge of the battery; this influenced 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. Others simply calculated their cost savings based on gasoline prices and did not complete a payback analysis. Most participants were disappointed with the distance they could drive "on the battery" and had expected it to last longer. Many households valued the PHEV as a car of the future, and some specifically of their future.

One implication of this research is who would be interested in purchasing a PHEV. It may seem reasonable to assume that only people who understood how PHEVs work and

could discern what the differences between the PHEV and a standard car meant to them would be interested in purchasing a PHEV. This research indicates otherwise: throughout the Project there were households who had no discernment before or after the trial, yet were interested in purchasing a PHEV; Nancy is an example. Despite her lack of understanding or discernment, Nancy is excited about the idea of a PHEV. Several times during her interviews she asked if she could by a PHEV such as the one she drove: "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." In contrast, the Polluck's, who like Nancy were unable to discern the difference a PHEV would make at either the start or end of their trial, had no interest in purchasing a PHEV. The Polluck's (lack of) interest in a PHEV was shaped by their lack of recharging; Mr. Polluck drove the car to a night-shift job and Mrs. Polluck drove the car during the day. Thus they further lacked discernment of the difference between a conventional Prius and a plug-in Prius. The Fort's began their trial with no discernment and ended their trial discerning the differences between PHEVs and standard vehicles. Brett's interest in comparing the PHEV to other possible commuter cars appeared shallow. Selena Fort, though, remains a moving force in their household. Despite the fact she did not drive the PHEV, her evolving sensibilities about pro-environmental behaviors—even, or especially because the conflict with her sensibilities about large trucks—may provide further impetus for considering PHEVs in the future. Both Octavia and the Kermode's however, were interested in purchasing a PHEV after moving from a lack of discernment to discernment. The experience driving the PHEV-conversion had allowed them for the first time to consider how to relate their concerns for the environment to their day-to-day mobility. Even those who began their trials with discernment had different conclusions. Sarah and Jerome Bluth understood the differences between the PHEV and standard cars from the beginning; they were not interested in purchasing a PHEV—it didn't seem to make enough difference from the Prius Sarah already drove. Conversely, the Lakes were very interested in purchasing a PHEV and began and ended their trial with discernment—even as Rick Lake experimented with replacing his payback assessment of the PHEV with a new goal, i.e., commuting-round trip in CD operation. As with understanding the technical function of PHEVs, discernment alone does not distinguish households who

were interested in purchasing a PHEV by the end of their trial from those who were not. If not understanding or discernment, the next step is to take a more inductive look at households to see if what distinguishes those with favorable PHEV purchase intentions from those without arises from their narratives.

Energy Feedback Conclusions

There are two distinguishing characteristics of this field test of the effect energy information feedback to drivers. The first is its grounding in an explicit theory of behavior change. The theoretical framework is built upon the Theory of Planned Behavior and the Extended Model of Goal Directed Behavior. The empirical test of whether real-world changes in the energy-intensity of driving changes in hypothesized direction will be completed after a sufficient sample has been collected. The second is the energy metric, which integrates gasoline and electricity consumption (as well as electricity regeneration during coasting and braking), and includes kinetic energy. Thus the metric addresses two concerns observed among Project households—that households did not create an integrated assessment of electricity and gasoline consumption and that many households misinterpreted the stock HEV feedback (which does not incorporate kinetic energy) as encouraging excessive braking (in order to regenerate electricity).

Although the limited sample size to date doesn't allow any strong conclusions about the specific effect of the experimental REF screen, it is clear that the drivers described here were interested in the information and generally decided to use the screen to increase their own fuel economy without prompting from the researcher. The level of engagement varied from mild interest to near-compulsion, and the engagement seemed to be related to self-reported competitiveness.

In the meantime, the exploration of the narratives of two households use of PHEVs equipped with custom-designed real-time energy feedback (REF) instrumentation reveal initial themes that serve as hypotheses for exploration with subsequent households. These themes are 1) safety and distraction, 2) motivational situations, 3) confusion about, or misinterpretation of, the information, 4) desire for some feedback, and 5) relationship between self-described competitiveness and driving behavior.

Tension between energy and safety goals may be resolved with a simplification of the REF display. Motivational situations suggest there may be differential outcomes of REF for different people in the same situation and the same people in different situations. The new energy metric may resolve issues of total energy use, but by accounting for all sources of motive energy, tends to display lower "miles per energy" numbers than a simple "miles per gallon (of gasoline)" metric. These lower numbers may be inherently less exciting than the occasionally very large mpg numbers drivers see. Experienced HEV drivers tended to violate one of the experimental conditions by "peeking" to see the stock HEV display during what was supposed to be their "without" feedback phase. As they freely talked about this, it may be more a sign that people can be taught to want feedback, rather than as evidence of "cheating" on the part of these participants. Self-described competitiveness may by linked to a desire to achieve high energy efficiency, but it may also cause competitive people to drop the quest for high energy efficiency if it conflicts with other goals, e.g., speed, time, or safety.

Future work based on this preliminary research will include a sample of approximately forty drivers. The larger sample size will support more extensive analysis of the driving data, questionnaires, and interview responses. Two major questions will be investigated, the first related to behavior change within subjects, and the second related to differences between subjects. In the first case: what attitudes, knowledge, and personality factors lead to behavior change when a driver is presented with REF? In the second case: how much do relatively static personality factors, such as competitiveness, impact overall driving behaviors and fuel use?

Social Network and Conclusions

By observing social interactions and measuring social influence in several social networks, we find several insights that may help to guide future policy, markets, and research. One research objective was to determine an appropriate method of defining social networks in order to observe social interactions. In the context of the PHEV Project, we observe the following:

- Social proximity (very close, somewhat close, etc.) has been demonstrated as a more useful relationship measure than role categories (friend, family, etc.) or an "expert" list of alters typically consulted regarding vehicle purchases. Using this measure, ego-centric networks vary widely in the number of alters and their distribution by social proximity.
- Further, the number of socially close alters does not necessarily correspond to the number of social interactions—casual acquaintances and strangers make up a substantial portion of interactions in some households. Because social interactions can occur at any level of social proximity, it may be difficult or impossible to establish a complete relevant network a priori.

Thus, to observe social interactions regarding new vehicle technology, researchers should employ a broad definition of social network (such as social proximity) that can scale up as interactions arise.

A second objective was to determine if social interactions are worth studying at all. Indeed, we find that in the context of the PHEV Project, social interactions do matter; in most primary households, at least one social interaction was ranked as being highly influential over their assessment of the PHEV technology. Thus, the assessment of PHEV technology does not occur in isolation—participants often consult others to form their own interpretations about functional, symbolic and societal benefits.

We also looked for patterns to help explain why some social interactions are rated as more influential. In this subsample, we find statistical evidence for three important factors: the discussion of societal benefits, the alternative-fuel expertise of the primary household and alter, and the social proximity of the alter. First, discussion of societal benefits tended to be rated as more influential. This finding supports the theoretical discussion in Volume I that the adoption of new vehicle technologies is not just driven by the "diffusion" of functional information, but also by the social negotiation of societal benefits. Although we do not find evidence of importance for discussions of symbolic benefits, we note that this category is difficult to measure—a participant's perceptions of symbolic meanings often occur upon reflection of several interactions, or from a general sense of social norms rather than particular interactions. The present methodological focus on specific social interactions may thus be insufficient to detect the role of symbolic discussions.

Another factor of importance is alternative-fuel experience. Households that already own an HEV tend to rank social interactions as less influential than those who don't—likely because they had already formed functional, symbolic and societal perceptions of electric-drive technology prior to their participation in their PHEV trial. On the other hand, interactions with alters have alternative-fuel experience or knowledge are ranked as more influential by primary households. Thus, we find evidence that patterns of social influence may depend on the relevant experience, or lack thereof, between the participants in a social interaction.

A third factor of importance is social proximity, which may have a non-linear relationship with social influence. On the one hand, as conventional wisdom might suggest, interactions with very close alters are more likely to be rated as influential. On the other hand, interactions with strangers also tend to be ranked as more influential than those with somewhat close alters and casual acquaintances. One explanation may be that our analysis compiles interactions from at least two different types of social network: those that tend to interact with and draw influence from closer alters, e.g. a tightly-knit family, and those that tend to do so with more socially distant alters, e.g. a single man engaging in multiple recreations. The small sample size of the present research makes it difficult to assess consistency of such patterns, but future research may explore how different network types are influenced by social proximity.

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APPENDIX: HOUSEHOLD PHEV ENERGY USE AND SAVINGS DURING THEIR LAST WEEK DRIVING THE PHEV, SORTED BY PERCENT DECREASE IN TOTAL ENERGY USE

Household	Last Week VMT	Percent Miles in CD	Gasoline Displaced (Gallons)	DC Electricity (KWh)	Δ Total Energy (KWh)	Percent decrease in Total
1752_01	57	98%	0.7	10.8	12.7	31.9%
1753_09	402	99%	4.7	49.2	105.0	29.4%
1746_07	193	80%	2.2	20.8	51.1	28.3%
1753_06	151	88%	1.4	18.3	29.4	24.7%
1746_05	136	100%	1.3	21.9	20.4	21.5%
1748_07	141	92%	1.1	20.9	15.0	18.3%
1751_02	120	71%	0.8	10.9	17.1	17.3%
1751_01	329	88%	2.2	35.1	37.4	16.7%
1748_06	92	95%	0.8	13.6	12.9	15.8%
Octavia	106	68%	0.7	10.8	12.7	15.3%
1762_02	25	77%	0.2	3.8	3.4	15.2%
1750_06	247	57%	1.7	22.8	33.2	15.1%
1749_01	184	64%	1.0	15.5	17.5	13.7%
1745_06/1749_07	305	66%	1.6	26.4	26.5	13.7%
1748_01	93	71%	0.7	9.5	12.2	13.3%
1764_01	157	68%	1.0	16.9	14.9	13.1%
1764_03	236	98%	1.6	31.6	21.3	13.0%
1748_04	268	80%	1.4	24.0	23.3	12.7%
1747_01	557	66%	2.6	39.5	45.4	12.2%
1762_03	148	99%	1.0	20.0	12.7	11.9%
1753_05	137	73%	0.9	17.4	13.9	11.3%
1762_04	153	65%	0.9	16.7	13.6	11.0%
1746_06	197	38%	0.9	10.4	18.0	10.9%
1745_03	157	50%	0.8	11.2	15.2	10.7%
1750_07/1747_04	293	56%	1.3	20.9	23.1	10.7%
1749_04	248	80%	1.2	23.5	17.0	9.8%
1749_06	159	75%	0.8	15.5	12.3	9.7%
1751_06	211	84%	1.0	20.2	12.0	8.4%
1753_01	391	41%	1.3	22.7	20.5	8.4%
1750_03	147	54%	0.5	7.5	8.8	7.4%
1745_05	391	34%	1.1	17.9	19.4	7.1%
1746_08	158	98%	0.8	17.3	7.9	6.8%
1764_02	465	32%	1.3	21.1	21.8	6.8%

1752_04	698	44%	1.9	28.5	32.6	6.5%
Kermodes	145	74%	0.7	15.8	6.2	6.0%
1753_04	455	50%	1.4	28.1	17.2	5.9%
1748_02	327	55%	1.1	24.2	11.5	5.3%
1750_04	158	63%	0.5	11.9	5.5	5.1%
1763_02	509	29%	1.1	16.2	21.7	4.8%
1750_05	430	63%	1.6	39.9	13.4	4.8%
1748_03	660	23%	1.2	21.2	19.3	4.5%
1746_04	689	38%	1.5	22.4	25.9	4.3%
1750_01	314	26%	0.6	11.6	9.5	4.2%
1751_03	158	76%	0.6	14.5	4.4	4.0%
1747_05	392	28%	0.7	13.2	9.7	3.5%
1752_02	184	16%	0.2	4.1	4.0	2.3%
1748_05	630	18%	0.7	13.0	10.4	2.3%
1747_02	400	14%	0.4	7.8	6.2	2.1%
1746_02	440	48%	0.9	23.6	6.0	2.0%
1746_01	423	48%	0.7	20.4	3.0	1.0%
1751_05	431	60%	0.9	25.5	2.7	0.9%
1748_08	529	23%	0.4	12.3	2.2	0.5%
Nancy	947	13%	0.6	17.9	0.9	0.1%
1753_03	353	0%	0.0	0.0	0.0	0.0%
1749_09	811	31%	0.8	27.3	-0.3	0.0%
1752_03	372	40%	0.7	22.4	-0.7	-0.3%
Lakes	284	52%	0.6	20.2	-0.9	-0.5%
1749_05	225	14%	0.1	4.6	-1.2	-0.7%
1753_08	188	95%	0.6	21.6	-1.5	-1.2%
1749_03	124	52%	0.2	8.8	-1.1	-1.3%
1751_04	122	79%	0.3	11.3	-1.9	-2.3%
1752_06	98	63%	0.3	10.1	-1.7	-2.8%
1749_02	142	100%	0.5	20.1	-2.6	-2.8%
1753_07	91	76%	0.3	11.2	-2.3	-3.6%
1764_04	227	75%	0.5	22.2	-5.1	-3.9%
1752_05	174	14%	0.1	8.6	-5.7	-4.1%
1749_08	223	84%	0.5	24.9	-9.8	-7.1%
Total	19411	49%	64.7	1230.2	905.0	