The Early U.S. Market for PHEVs: Anticipating Consumer Awareness, Recharge Potential, Design Priorities and Energy Impacts

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Abstract

Vehicles that can run on both electricity and gasoline—so-called plug-in hybrid electric vehicles (PHEVs)—are proposed as both a near-term technology to achieve energy and environmental goals and a transitional step toward viable all-electric vehicles addressing many of the same goals. Whether PHEVs meet any of their goals depends not only on their design and performance on standardized drive cycles, but also on drivers' travel and refueling/recharging behaviors. To replace assumptions with observations of potential PHEV drivers' behavior in market and impact analyses, we conducted an internet-based survey of 2,373 new car-buying households in the United States. The instrument was implemented in three separate pieces, requiring multiple days for households to answer questions, conduct a review of their own driving and parking patterns, and then complete a sequence of PHEV design exercises. In this paper, we draw five conclusions from the resulting data. First, most new vehicle buyers are unaware of PHEVs in particular and are confused about electric-drive terminology commonly used by experts. Second, at least half of our target population is already equipped for at-home vehicle recharging, but currently have little opportunity for recharging at their workplace or other locations. Third, we observed widely varied interests in four possible PHEV attributes—fuel economy in both charge-depleting (CD) and charge sustaining (CS) operation, blended vs. all-electric operation, the distance over which the vehicle is in CD mode, and recharging speed. Still, the appeal of increased fuel economy appears to be highest and that of faster recharging to be lowest. Further, there is little interest in all-electric operation. Fourth, given the previous two points, we estimate that about a third of the target population has both the infrastructure to recharge a PHEV and interest in a vehicle with plug-in capabilities. Fifth, our recharge scenarios demonstrate that although widespread PHEV use could halve gasoline use, impacts to the electricity grid could highly depend on the time-of-day and location recharge management strategy. While unconstrained recharging among PHEV buyers may exacerbate current peak electricity demand, pushing vehicle recharging to off-peak hours through charging controls, time of day tariffs or other means could reduce overall electricity used by vehicles. Overall, policy, technology, and energy providers may use this information to understand whether their plans, designs, and goals align with these present understandings, or whether it would be collectively beneficial to foster new understandings of PHEVs among U.S. car-buyers.

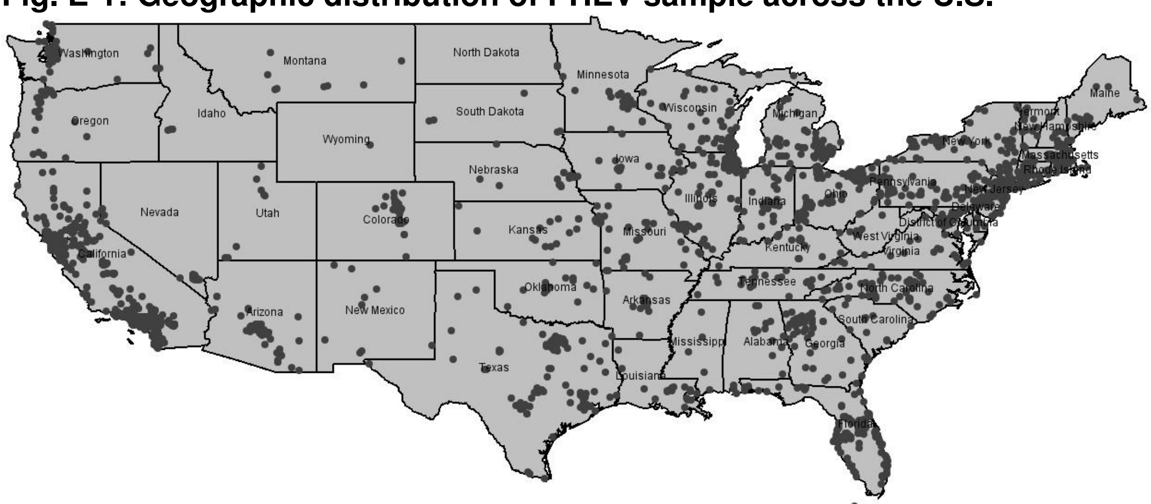
Executive Summary

The dual fuel potential of plug-in hybrid electric vehicles (PHEVs) presents inherent uncertainty to policymakers, automakers, electric utilities, researchers, and other interest groups. Predictions of gasoline and electricity use, as well as the associated emissions, depend on PHEV design, e.g., power and energy capacity, as well as driving and recharging behavior, e.g., location and timing of recharge. Due to lack of direct data, previous impact and market analyses have heavily relied on assumptions about such behavior, which are often drawn by proxy from databases of travel patterns and housing stocks. This study seeks to reduce some of these uncertainties for the potential early U.S. PHEV market. Four questions are addressed:

1. How aware are consumers regarding electric-drive vehicles?
2. How many households have regular access to vehicle recharging opportunities?
3. What PHEV design(s) currently appeal to consumers?
4. What energy impacts (gasoline and electricity) can we anticipate with significant PHEV sales?

Methods: Data were drawn from a web-based survey of 2,373 new vehicle buying households in the U.S—what we judge to be a representative sample (Fig. E-1). The survey was implemented in three separate pieces, requiring multiple days for households to answer questions, conduct a review of their own driving and parking patterns, and then complete a sequence of PHEV design exercises. First, awareness was assessed with questions eliciting respondents' familiarity and understanding regarding electric-drive vehicle technologies. Second, recharge potential data were collected with a *Plug-in Potential* diary of driving and parking for one of the household's vehicle. Third, PHEV design priority data were collected in two versions of priority-evaluator games: the D*evelopment Priority* game, and the *Purchase Design* game (Appendix C).

Fig. E-1: Geographic distribution of PHEV sample across the U.S.

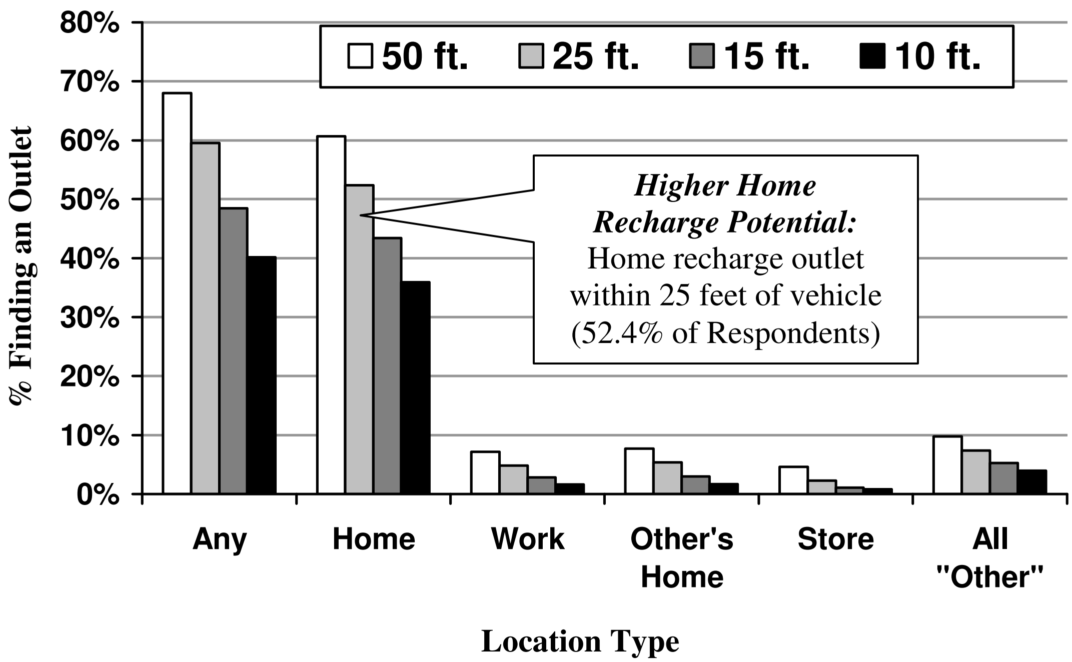


Results:

1) Consumer Awareness: Responses to this survey suggests the majority of new vehicle buyers have little or no familiarity with the idea of a PHEV, and may erroneously believe that existing hybrid-electric vehicles can perform the same basic function as a PHEV, i.e., have the ability to be refueled by gasoline and to be plugged into an electrical outlet. This lack of awareness and understanding is both a constraint and opportunity. As a constraint, unaware consumers may simply fail to recognize or identify compelling benefits of owning and operating a PHEV, serving as a soft constraint to limit the market. On the other hand, the early PHEV market in the U.S. may be viewed as a blank slate, with little preexisting understanding of what a PHEV is or expectations of what it should be. Thus, the early actions of automakers, governments, electric utilities and other stakeholders could play an important role in establishing perceptions in the market. Similarly, the first commercially available PHEV incarnations could set an early bar for consumer understanding and set expectations of performance levels.

2) Recharge Access: We conclude that just more than half the population of U.S. households that buy new cars has the potential to recharge a vehicle at home with at least 110-volt service (Fig. E-2). This proportion is one-and-a-half to three times larger than previous estimates. Few respondents located non-home recharge opportunities, such as at their workplace, friend's and family's homes, restaurants, etc. Recharge potential, that is, the spatial-temporal correspondence between a parked vehicle and a 110-volt electrical outlet, peaks between 12am and 6am when most vehicles are parked at home and reaches a broad minimum from 10am to 4pm when most vehicles are parked at work or other locations or are being driven.

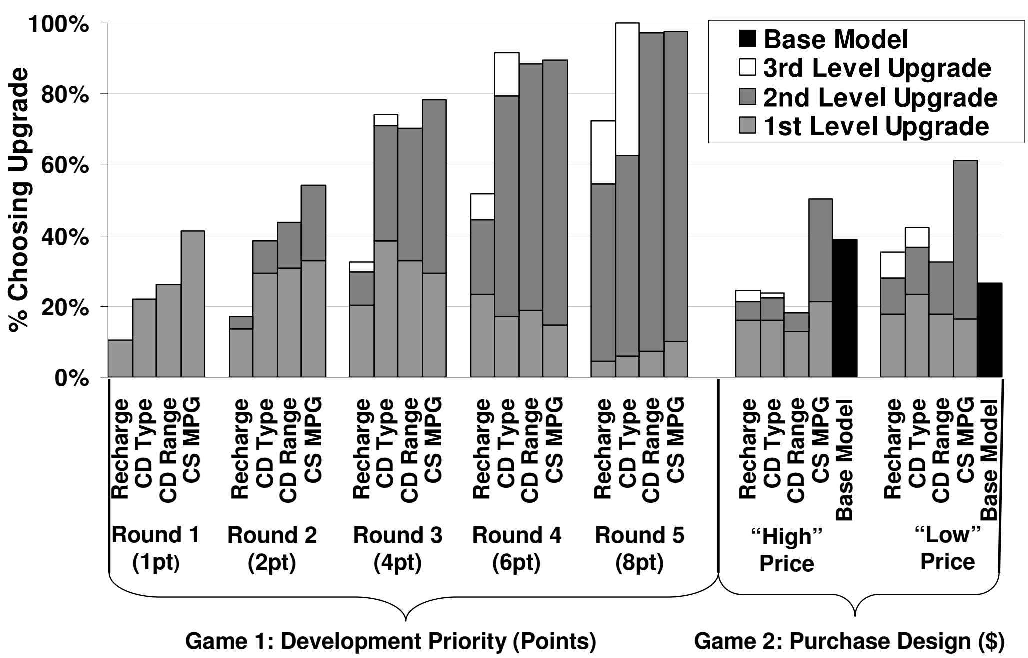
Fig. E-2: Access to recharge spot by location and outlet distance (all respondents, n = 2,373)



3) PHEV Designs and Values: Given access to recharging and the distribution of PHEV designs from the games, we estimate that about one third of U.S. new vehicle buying households have both the required infrastructure and interest to purchase a vehicle with plug-in capabilities. Within this *early market potential* sub-sample, we observed a wide diversity of consumer interests in PHEV design options (Fig. E-3). Starting with a base PHEV design offering long recharge times, short CD range, no all-electric operation, but non-trivial reductions in both CD and CS gasoline consumption, the most popular upgrade category was improved fuel economy in CS mode. Respondents also exhibited interest in increasing vehicle range in CD mode, and improving CD fuel economy. Fewer respondents were willing to devote resources to reduce recharge time. We found little evidence of inherent demand for all-electric operation in CD mode, even following the one-day diary, the tutorial on electric-drive vehicles (Appendix B), and PHEV design games. This difference suggests that while all-electric CD operation may be particularly attractive to a small subset of consumers, including those who are already knowledgeable and experienced with electric vehicles, at this point in time most households who buy new vehicles are more interested in high fuel economy.

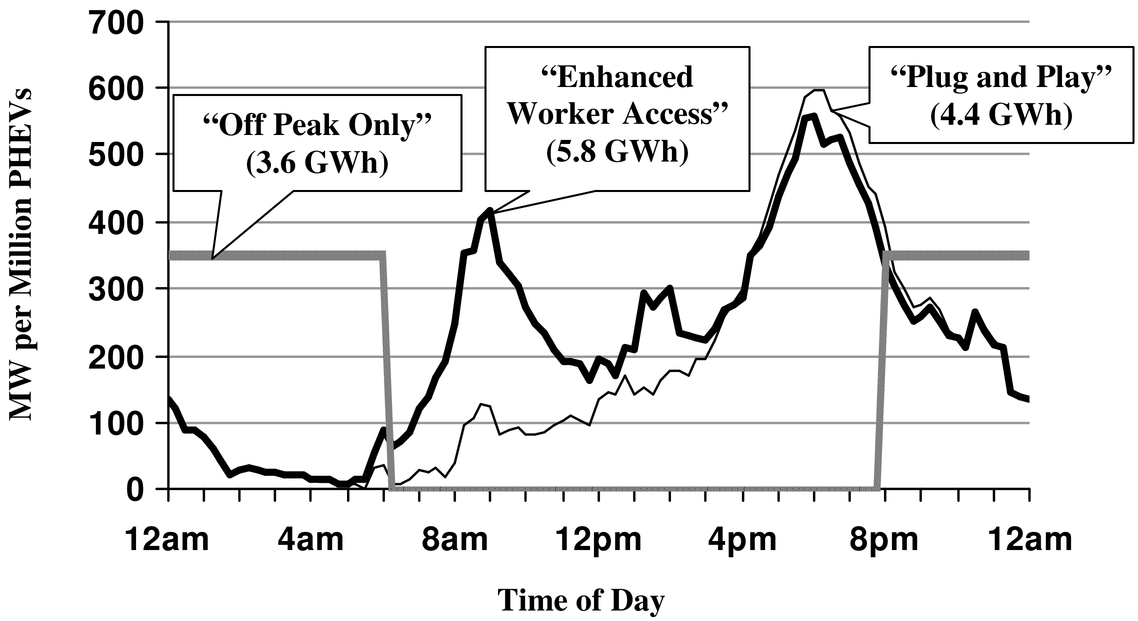
Also, about one-third of the *potential early market* respondents who constructed a PHEV variant of their likely next new car (that they selected rather than a conventional version of that car) chose no upgrades above the proffered base PHEV design. Overall, there may be substantial potential for market success with less ambitious PHEV designs, i.e. blended operation with shorter CD range but high CS fuel economy. This wide variety of PHEV design selections supports the notion of a "blank slate" early PHEV market, where early buyers may have little in the way of performance expectations.

Fig. E-3: Attribute selection in design exercises (early market potential respondents only, n = 827)



4) PHEV Energy Use Scenarios: The final analysis in this report combined all the available information from each respondent—driving, recharge potential, and PHEV design priorities—to estimate the energy impacts of the respondents existing travel and understandings of PHEVs under a variety of recharging scenarios. Results suggest that the use of PHEV vehicles could halve gasoline use relative to conventional vehicles—the majority of this reduction being due to increases in CS fuel economy. Using three scenarios to represent potential boundary conditions on PHEV driver recharge patterns (unconstrained, universal workplace recharging, and off-peak only charging), we estimate tradeoffs between the magnitude and timing of PHEV electricity use (Fig. E-4). In the unconstrained "Plug and Play" recharge scenario, recharging peaks at 6:00pm, following a far more dispersed pattern throughout the earlier part of the day than anticipated by previous research. PHEV electricity use could be increased through policies increasing non-home recharge opportunities (e.g., the "Enhanced Worker Recharge Access" scenario), but most of this increase occurs during daytime hours and could contribute to peak demand (depending on a given region's definition of "peak"). We also demonstrate how deferring all recharging to off-peak hours (8pm to 6am) could eliminate all additions to daytime electricity demand from PHEVs. However, in such a scenario less electricity is used due to the elimination of daytime recharge opportunities and less gasoline is displaced.

Fig. E-4: Comparing PHEV recharge scenarios, scaled for one million PHEVs (weekdays only, early market potential respondents only, n=590)



Conclusions: In this paper, we draw five conclusions from the resulting data:

1. Most new vehicle buyers are unaware of PHEVs in particular and are confused about electric-drive terminology commonly used by experts.

2. At least half of our target population is already equipped for at-home vehicle recharging, but currently have little opportunity for recharging at their workplace or other locations.
3. We observed widely varied interests in four possible PHEV attributes—fuel economy in both charge-depleting (CD) and charge sustaining (CS) operation, blended vs. all-electric operation, the distance over which the vehicle is in CD mode, and recharging speed. Still, the appeal of increased fuel economy appears to be highest and that of faster recharging to be lowest. Further, there is little interest in all-electric operation.
4. Given the previous two points, we estimate that about a third of the target population has both the infrastructure to recharge a PHEV and interest in a vehicle with plug-in capabilities.
5. Our recharge scenarios demonstrate that although widespread PHEV use could halve gasoline use, impacts to the electricity grid highly depend on recharge management strategy. While unconstrained recharging among PHEV buyers may exacerbate current peak electricity demand, pushing recharging to off-peak hours through smart charging, time of day tariffs or other means could reduce overall electricity used by PHEVs.

Overall, this analysis provides a baseline measure of market potential—one that could be highly subject to influence. Recharge infrastructure could expand to a higher percentage of households with changes in building codes, as well as increased employer and publicly installed vehicle recharge outlets. Recharge behavior may also shift with PHEV purchase; owners might adjust driving patterns to maximize electricity use or adjust recharge locations if additional infrastructure is provided away from homes. Desired PHEV designs and capabilities may be even more subject to change. Survey respondents had little pre-existing understanding of PHEVs and the elicited responses could be sensitive to the PHEV information we provided. As information about PHEV technology diffuses throughout the economy, along with corresponding developments in PHEV values and meaning, interest in particular attributes could shift. For example, all-electric charge-depleting operation could become more meaningful to car buyers as they gain experience and as they participate in the process of identifying just what all-electric operation means to people. In the meantime, this analysis illustrates how the messages and actions of policymakers, automakers, electric utilities and other interest groups could have significant influence over future development of awareness, recharge potential, design interests, and energy impacts of the PHEV market.

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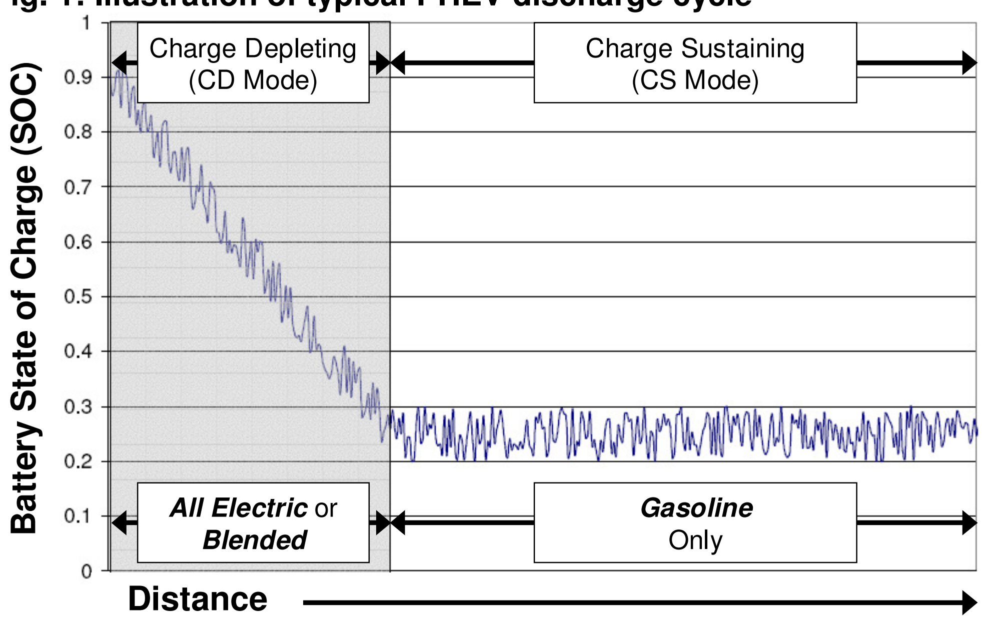
1. Introduction

Alternative fuel vehicle technologies will play a significant role in helping the U.S. meet goals to reduce petroleum use, air pollution and greenhouse gas emissions in the transportation sector. Electric drive technologies are receiving renewed attention as potential near-term solutions relative to alternatives such as hydrogen. As hybrid-electric vehicles (HEVs), typified by the Toyota Prius, continue to achieve significant commercial success in the U.S. market, plug-in hybrid vehicles (PHEVs) are touted as the next step in electric drive development (Lemoine *et al*, 2008).

PHEVs are one step closer to the pure electric vehicle (EV) initially envisioned by California's zero emissions vehicle mandate; users can charge the battery from the electrical grid and drive limited distances (less than 40 miles) in charge-depleting (CD) mode. Figure 1 illustrates CD mode as a reduction in the battery's state of charge, where the vehicle is powered either by electricity only (all-electric operation) or by electricity and gasoline (blended operation). Once the battery is depleted to a minimum state of charge (typically set at a value greater than 0 percent to preserve battery life), the PHEV uses only gasoline in charge sustaining (CS) mode, achieving the fuel efficiency of today's typical HEV. Battery size, degree of hybridization, and drivetrain design can all substantially influence the overall operation of a given PHEV.[1]

Fig. 1: Illustration of typical PHEV discharge cycle



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

Primary PHEV benefits are straightforward: by supplementing or replacing gasoline combustion with grid electricity, consumers could reduce the costs, petroleum use, air pollution and greenhouse gas emissions associated with driving—without the range

[1] For a more detailed discussion of PHEVdesign concepts, see Axsen *et al* (2008).

limitations of pure EVs. Other potential benefits are less obvious: PHEVs could provide "mobile energy" services, such as backup electricity for home use or storing excess electricity produced by utilities for load balancing (Williams and Kurani, 2006).

However, the dual fuel potential of PHEVs presents inherent uncertainty to policymakers, automakers, electric utilities, researchers, and other interest groups. Predictions of gasoline and electricity use, as well as the associated emissions, depend on PHEV design, e.g., power and energy capacity, as well as driving and recharging behavior, e.g., location and timing of recharge. Due to lack of direct data, previous impact and market analyses have heavily relied on assumptions about such behavior (Winkel *et al*, 2006; Vyas *et al*, 2007; Duvall *et al*, 2007), which are often drawn by proxy from databases of travel patterns and housing stocks. The choice of assumptions can seriously affect results; Lemoine *et al* (2008) illustrate how varying time of day recharge assumptions can substantially influence predictions of electricity grid impacts.

Also, as of the writing of this report, the California Air Resources Board (2008) is deliberating how to define a PHEV and assign air emissions credits to automakers for producing them. Similarly, automakers like Toyota and General Motors are publicly disputing the viabilities of vastly different PHEV designs: one with a smaller battery and relatively low CD range (the Prius Plug-in) and one designed to operate as a pure electric vehicle for much longer distances (the Volt concept). In summary, there is a demonstrated lack of consensus regarding consumer behavior and demand as well as subsequent environmental impacts.

This study seeks to reduce some of these uncertainties. Four questions are addressed:

1. How aware are consumers regarding electric-drive vehicles?
2. How many households have regular access to vehicle recharging opportunities?
3. What PHEV design(s) currently appeal to consumers?
4. What energy impacts (gasoline and electricity) can we anticipate with significant PHEV adoption?

To empirically answer these questions, data were drawn from a web-based survey of new vehicle buying households in the U.S. Integrating data for all four of these questions, possible PHEV market niches within the household light-duty vehicle market are described. Previous electric vehicle constraints analyses estimated that the proportion of households with home recharge access to be 28 percent in the U.S. (Nesbitt *et al*, 1992) and 15 to 30 percent in California (Williams and Kurani, 2006). Data for the present study was collected with a 24-hour *Plug-in Potential* diary, improving upon previous research in several ways: (1) instead of creating estimates from census data by proxy we elicited recharge potential directly from respondents, (2) we recorded time of day access to allow estimates of daily recharge patterns, and (3) we limit our focus to U.S. new vehicle buyers, rather than the entire population of U.S. households.

We also investigated the design priorities of the potential PHEV market using two innovative games. Previous research has used stated-preference methods to directly ask survey respondents about purchase intention for a certain PHEV design (e.g. Graham *et* *al*, 2001). Such results are typically unreliable due to the hypothetical and shallow nature of the information provided to respondents. We attempted to overcome this limitation by providing more in-depth information to respondents, described in previous research as a reflexive design (Kurani *et al*, 1996), such as visually depicting the recharge potential elicited from the *Plug-in Potential* diary back to the respondent and providing an informative PHEV buyers' guide. Respondents then completed a PHEV *Development Priority* game, choosing among several PHEV upgrade possibilities over several iterations, as well as a *Purchase Design* game, demonstrating interest in a PHEV as purchase intention under different price conditions. In addition to investigating general priority patterns among the sample, we also explored two hypotheses gleaned from Kurani *et al*'s (2007) interviews of 23 drivers of PHEV conversions: that early PHEV buyers might be particularly interested in (1) all-electric CD operation and (2) attracted to certain levels of high instantaneous fuel economy, such as 100 miles per gallon. Along these lines, we also explore the potential market for more aggressive PHEV design proposals, e.g. GM's Volt concept with 40 miles of all electric range, relative to less aggressive designs, e.g. Toyota's Plug-in Prius with less than 10 miles of CD range designed primarily for blended operation.

Taken together, the collected information regarding driving patterns, recharge potential and design priorities allow the creation of realistic recharge scenarios. The potential impacts of pure electric and PHEV use on electricity generation could be important with widespread adoption (e.g. Kurani *et al*, 1997; Lemoine *et al*, 2008; Hadley and Tsvetkova, 2008). We simulate grid impacts under three scenarios to investigate potential tradeoffs between overall gasoline and electricity use and the timing of electricity use.

2. Methods

To answer these questions, we conducted a web-based survey of 2,373 new vehicle-buying households in the U.S.

2.1 Survey Design

The survey instrument collected three types of data from new car buyers which are analyzed here: 1) their familiarity with electric-drive vehicle technologies, 2) their access to vehicle recharge opportunities, i.e., electric outlets located at or near their vehicle parking locations, and 3) their plug-in hybrid electric vehicle (PHEV) design priorities. First, awareness was assessed with questions eliciting the stated familiarity of respondents with conventional gasoline, hybrid-electric, electric, and plug-in hybrid electric vehicles. Respondents were then asked to demonstrate their understanding by choosing how each vehicle type could be fueled: with gasoline, electricity through an electrical outlet, or either. The implication of this exercise is not that consumers need to have a deep technological understanding of alternative-drive vehicles in order to make a purchase. However, we feel that a very basic familiarity is required to ensure an understanding of the fundamental benefits of a technology, i.e. whether or not the vehicle can be plugged in.

Second, recharge potential data were collected with a *Plug-in Potential* diary of driving and parking for a new vehicle (model year 2002 or later) driven several times per week by the respondent's household. Respondents were assigned a day of the week and instructed to record information for a 24 hour period starting with their first trip of the day. Information included the timing and distance of each trip, parking locations, and the proximity of those locations to an electrical outlet. Respondents recorded data in a diary printed from a PDF document and then input the data online using the instrument depicted in Figure 2 (example of physical diary in Appendix A). The respondent's diary day was immediately depicted to them as a graph as seen in Figure 2, using a technique similar to that used by Kurani *et al* (1994, 1996) to help respondents better understand their own driving behavior and how an electric-drive vehicle could fit into their lifestyle.

Third, PHEV design priority data were collected in two versions of priority-evaluator games. Commonly, researchers will infer preferences for attributes of alternative fuelled vehicles by presenting respondents with a description of one or several new technologies, followed with a set of hypothetical choice scenarios in which respondents make several choices from sets of vehicles of different attributes (see for example Bunch *et al*, 1993; Ewing and Sarigollu, 2000; Potogolou and Kanaroglou, 2007). However, Heffner *et al* (2007) demonstrate that more in-depth research, such as household interviews, can reveal important information that choice experiments cannot. To improve the quality of data gathered through a nationwide survey, prior to the PHEV design exercises, respondents were provided two types of preparatory information: (1) the 24-hour diary exercise described above served the additional role of reflecting to respondents aspects of their travel patterns and potential access to recharge spots, and (2) a PHEV buyers' guide describing basic design options for PHEVs (replicated in full in Appendix B). Respondents then completed two games (both replicated in Appendix C). The first was a PHEV *Development Priority* game in which respondents chose among PHEV design possibilities over several iterations. Second was a *Purchase Design* game, similar to the first, but with the design possibilities priced in dollars and respondents could reject buying a PHEV, retaining a conventional vehicle.

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

Fig. 2: Screenshots of Plug-in Potential Diary (for hypothetical respondent)

Plug-In Diary: Wednesday

Trip #:	Location:	Status:	Hours Parked:		2. Electrical Outlet?	3. Distance of Outlet?		
Starting Point	home	Parked	12		Yes			
Trip #:	Destination /Location:	Status:	Start Time:	End Time:	2. Electrical Outlet?	3. Distance of Outlet?	1. Total Distance	2. Highway Distance
Trip #1	work	Driving	08:00 AM	09:00 AM			45	35
		Parked	09:00 AM	05:30 PM	No			
Trip #2	Cindys	Driving	05:30 PM	06:00 PM			10	0
		Parked	06:00 PM	07:30 PM	No			

Details of Trip #3:
(Please fill in all boxes with BLUE outline.)

Trip #:	Destination/ Location:	Vehicle Status:	Start Time:	End Time:	Details	
Trip #3	home	Driving	07:30 PM	08 : 15 PM	2. Total Distance: 30 Miles	3. Highway Distance: 20 Miles
		Parked	08:15 PM	08 : 00 AM	1. Electrical outlet? Yes	2. Distance of outlet? 15 Feet

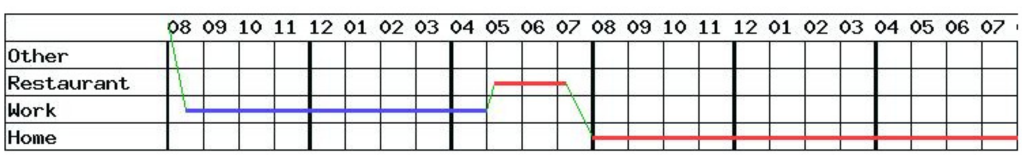
Redo Previous Entry

Is Trip #3 the last trip entry of your Diary Day?

- ☐ Yes, this is the last trip entry.
- ☐ No, I have at least one more trip to enter.

Submit This Entry as Trip #3

8) To make it easier to understand the diary you just submitted, we've made a visual graph of the parking spots you visited:



Green Line = Driving
Blue Solid Line = Parked with no plug in opportunity
Red Solid Line = Parked with plug in opportunity

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

We chose these four attributes due to their importance in determining driving patterns as well as reflecting technological capabilities. First, the time to replenish a large depleted battery would take 6-8 hours, but technology exists to allow "fast" charging in less than one hour—allowing for significantly different recharge patterns. Second, currently available PHEV conversions are designed for blended CD operation. We specified upgrades to account for several levels of gasoline only fuel economy in blended operation: 75-125 mpg. This range includes the 100 mpg "magic" number identified as important among some early PHEV conversion owners (Kurani *et al*, 2007). Because automakers such as General Motors have announced plans to release PHEVs designed for all-electric operation, we also include an all-electric upgrade option. Third, CD range depends on battery energy capacity, and proposed designs typically range from 10 to 40 miles (Pesaren *et al*, 2007; Kromer and Heywood, 2007). The fourth category, fuel consumption in charge sustaining (CS) mode, is comparable to the operation of today's hybrid electric vehicles; the battery and electric motor are used to improve the efficiency of the gasoline engine, not to use grid electricity. Most hybridized drivetrains can increase fuel economy by 10 to 30 miles per gallon (mpg) relative to a similar size, weight, and performance vehicle.

The first exercise was the *Development Priority* game presenting respondents with a hypothetical scenario: the household vehicle for which they kept their Plug-in Potential diary would be upgraded to a PHEV at no cost. The performance and appearance of their vehicle would remain the same, except for the additional capabilities of a plug-in hybrid: a battery that can be plugged in to any electrical outlet in order to power the vehicle for short distances, as well as a drivetrain that reduces gasoline consumption even after the CD range is exceeded. Respondents were presented with a base PHEV model and given points they must allocate among various potential upgrades. Over five rounds of the *Development Priority* game, respondents were provided progressively more points (Table 1). For the first three rounds of the game higher levels of upgrades of the four attributes and more combinations of upgrades were also offered, expanding the PHEV design

[2] Note that these PHEV design games are meant to represent designs that are technologically feasible, but not necessarily with exact specifications. For instance, the battery required for our base PHEV design would likely require only 2 to 3 hours to fully recharge with a 110 to 120 volt circuit. However, with careful pre-testing, we consciously chose to simplify attribute levels and ignore potential interactions among attributes to create exercises that are more likely to be understood by our respondents than to adhere to experts' knowledge.

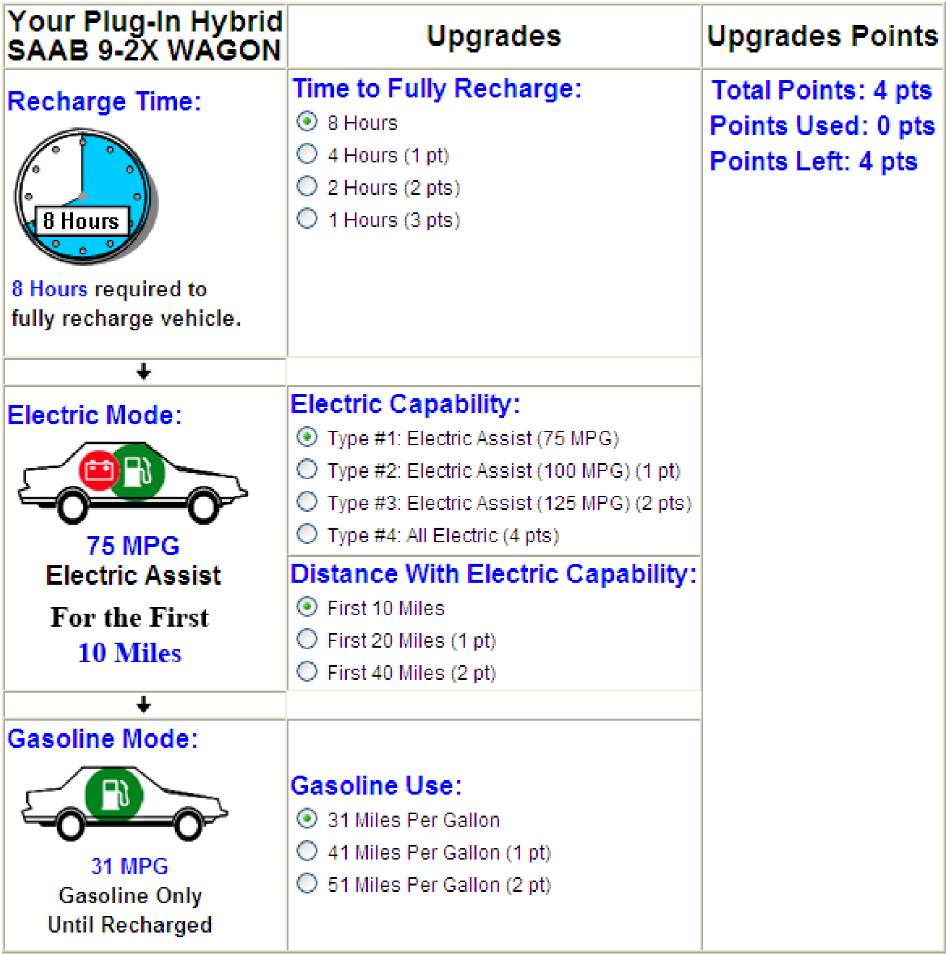
envelope to observe respondents' allocation of resources. A screenshot of the game, along with the language used for respondents, is portrayed in Figure 3.

Table 1: Upgrades for PHEV Development Priority game

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

The second exercise was the *Purchase Design* game which framed the PHEV design exercise in the context of a future vehicle purchase. The questionnaire first elicited information about the anticipated price, make and model of the next new vehicle the respondent's household would likely buy. The respondent then completed two PHEV purchase exercises, each comparing their anticipated conventional vehicle with a PHEV version of the same. Respondents were presented with a "high" price and "low" price PHEV purchase conditions, where prices in both conditions also depended on whether the vehicle was a car or truck (Table 2). As in the *Development Priority* game, each exercise started with the same base PHEV model, with additional upgrades available for added price. In each exercise, the respondent could choose either their anticipated conventional vehicle, the offered (base) PHEV, or to upgrade the PHEV. Figure 4 portrays a screenshot of this exercise.

Fig. 3: Screenshot of Development Priority game (Round Four)



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

Fig. 4: Screenshot of Purchase Design game ("high" price, vehicle model customized for respondent)

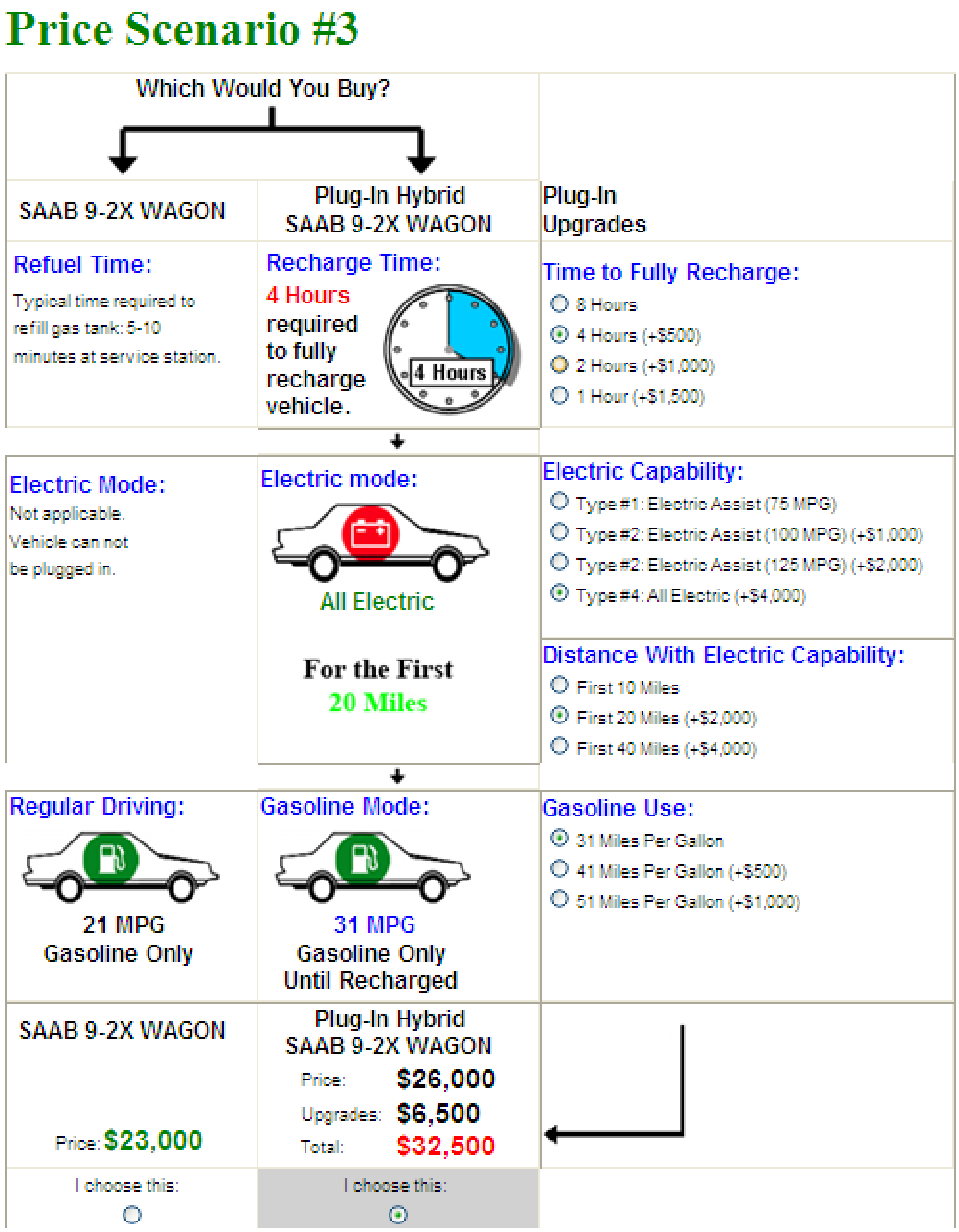


Table 2: Price of upgrades for Purchase Design game

Attributes (base level)	Attribute level	"High" price Car	"High" price Truck	"Low" price Car	"Low" price Truck
Base premium		$3,000	$4,000	$2,000	$3,000
Recharge time (8 hours)	4 hours	+$500	+$1,000	+$250	+$500
	2 hours	+$1,000	+$2,000	+$500	+$1,000
	1 hour	+$1,500	+$3,000	+$750	+$1,500
CD mpg and type (75 mpg)	100 mpg	+$1,000	+$2,000	+$500	+$1,000
	125 mpg	+$2,000	+$4,000	+$1,000	+$2,000
	All-electric	+$4,000	+$8,000	+$2,000	+$4,000
CD range (10 miles)	20 miles	+$2,000	+$4,000	+$1,000	+$2,000
	40 miles	+$4,000	+$8,000	+$2,000	+$4,000
CS mpg (Current mpg +10)	Current mpg +20	+$500	+$1,000	+$250	+$500
	Current mpg +30	+$1,000	+$2,000	+$500	+$1,000

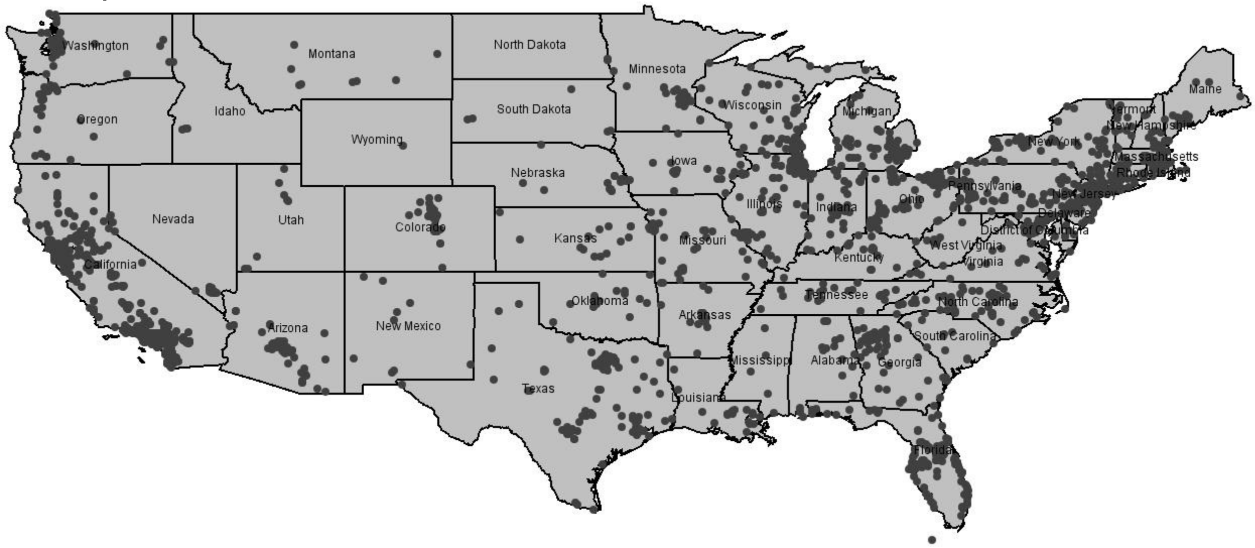
2.2 Data Collection

Our target population is new vehicle buying households in the U.S. To qualify, respondents had to own a new gasoline vehicle that they purchased in 2002 or later, which they personally drove at least 3 times per week. The respondent also must have played a significant role in the household's decision to purchase this vehicle. In limiting our study to this population, we imply that the early market for PHEVs is limited to households that tend to buy new vehicles in general. In total, 2,664 respondents completed the entire survey in December of 2007. We removed 291 respondents with incomplete diary data, leaving 2,373 used in this study.

Figure 5 portrays the geographic distribution of the sample, which corresponds to population density. Two regions, California and a particular area in Northern California, were intentionally oversampled to permit separate analyses. Because the present study focuses on the overall U.S. vehicle market, all data has been weighted to be representative of the whole U.S. including California.

Data were collected with a web-based survey. Relative to mail and telephone methods, the major strength of internet surveys is the high degree of design flexibility. Administrators can interactively adapt questions to previous responses as well as more effectively screen respondents, sequence questions, and avoid item non-response (Rhodes *et al*, 2003). Internet survey techniques can also enhance response accuracy, particularly for travel diaries (Adler *et al*, 2002). Lastly, a well-programmed survey will automate data entry to minimize data administration time and cost (Couper, 2000).

Fig. 5: Geographic distribution of PHEV sample across the U.S. (Alaska not shown)



However, web-based surveys are susceptible to non-coverage error, where a significant portion of the target population, in this case new car buyers, may be excluded if they don't have internet access. This concern is declining in the U.S. as internet usage rates have grown from 44% in 2000 to over 70% in 2007 (Internet World Stats, 2007). Also, we suspect there is a positive correlation between internet access and likeliness to buy new vehicles, implying an even higher usage rate among our target population. However, non-response bias is still an important concern because those without internet access tend to be disproportionally old, with low income and low education (Rhodes *et al*, 2003; Couper *et al*, 2007).

Respondents for this survey were recruited by Harris Interactive from their internet panel. To counteract concerns of non-coverage and non-response error, Harris estimates weights to better match the realized sample to the target population. Weights are based on geographic, demographic and attitudinal data, and matched to existing databases collected through multiple survey modes (including mail and telephone). All results presented in this study use these weights to match our sample to the U.S. population of new vehicle buyers.

To assess the external validity of our sample, as well as the impact of Harris' weights, we compare sample distributions according to five socio-demographic variables in Table 3: respondent gender, education and age, and household income and housing type. General population estimates are available from the 2000 Census, as well as the Current Population Survey (CPS) and the American Household Survey (AHS). However, because our target population (new vehicle buyers) is likely to be of higher socioeconomic status than the general population, we also drew a sub-sample of over 10,000 households owning new vehicles from the 2001 National Household Travel Survey (NHTS). Comparing our weighted sample to the NHTS, we find that the income levels of both samples are about 42 percent higher than general population estimates from similar years (2007 and 2000 respectively). Also, gender, age, and housing type follow similar distributions between the two samples of new vehicle buying households. Education levels are slightly higher in the present study, with 56 percent having a college degree of higher compared to 48 percent in the NHTS sample, but this difference is not substantial. Table 3 also shows that applying the Harris weights has little effect on gender, income and housing type, but does influence education and age distributions in the same directions as the NHTS sample. We conclude that our sample matches well with other samples of new car owners on these socio-demographic measures, strengthening claims that our results can be extended to the population of new-car owning (and therefore, new car-buying) households.

Table 3: Comparing demographic distributions of present and previous samples

Target		New vehicle buyers			General population	
Year		2007	2007	2001	2007	2000
Survey Type		PHEV unweighted[a]	PHEV weighted[b]	NHTS[c]		
Sample size		2,373	2,373	10,188		
					Pop. Est.[g]	Census[h]
Gender[d]	Male	49.3%	52.2%	43.5%	49.3%	49.1%
	Female	50.7%	47.8%	56.5%	50.7%	50.9%
					CPS[i]	Census[h]
Education[d]	Highschool or lower	9.3%	19.4%	31.2%	46.6%	48.2%
	Some college	25.3%	24.7%	20.7%	19.0%	21.0%
	College degree	38.0%	36.7%	32.8%	25.7%	21.9%
	Graduate degree	27.4%	19.2%	15.2%	8.7%	8.9%
					Pop. Est.[g]	Census[h]
Age[d]	15 to 24	2.5%	3.3%	4.5%	17.7%	17.8%
	25 to 34	12.6%	17.8%	16.2%	16.9%	18.0%
	35 to 44	18.2%	21.7%	22.8%	17.9%	20.4%
	45 to 54	25.9%	24.3%	25.5%	18.2%	17.1%
	55 to 64	26.2%	21.6%	15.7%	13.6%	11.0%
	>64	14.6%	11.3%	15.4%	15.7%	15.8%
					CPS[i]	Census[h]
Income[e]	< 30 k	5.5%	6.3%	12.2%	31.0%	35.1%
	30 k to 60 k	28.2%	26.0%	32.7%	28.6%	31.9%
	> 60k to 100k	33.7%	32.5%	32.4%	21.3%	20.7%
	> 100k	32.7%	35.3%	22.7%	19.1%	12.3%
	Mean income[f]	$86,243	$87,911	$ 72,478	$61,870	$50,864
	Ratio of new vehicle buyer mean income to general population mean income	1.39	1.42	1.42		
					AHS[j]	AHS[j]
Housing type[e]	Detached house	78.4%	78.0%	80.7%	64.3%	62.8%
	Attached house	8.9%	8.3%	7.6%	5.7%	6.8%
	Apartment	9.5%	10.2%	8.9%	23.7%	23.9%
	Mobile home	3.1%	3.5%	2.8%	6.4%	6.6%

[a] Without using weights provided by Harris Interactive; data only weighted to correct for California oversample.
[b] Data used for this study: using U.S. weights provided by Harris Interactive.
[c] NHTS sample limited to responding households that had purchased a vehicle of model year 2001 or 2002.
[d] Data reported for respondent only.
[e] Data reported for respondent's household.
[f] Mean approximated from the product of middle values assigned to each income category and the proportion of the sample in that category.
[g] 2007 Annual estimates of the population by the Population Division of the U.S. Census Bureau.
[h] 2000 Census by the U.S. Census Bureau.
[i] 2007 Current Population Survey by the U.S. Census Bureau.
[j] 2005 and 1999 American Household Surveys by the U.S. Department of Housing and Urban Development.

3. Results

3.1 Consumer Awareness

Among respondents, stated familiarity with vehicle technologies corresponded to real-world experience with automobiles; high levels of familiarity were most common for conventional gasoline vehicles, followed in order by HEVs, EVs and PHEVs (Figure 6). Familiarity with PHEVs was lowest: 69 percent of respondents reported low or no familiarity. A question eliciting demonstrated understanding of motor vehicles indicates that the vast majority of respondents understood that conventional gasoline vehicles could only use gasoline, while electric vehicles can only use electricity (Figure 7). But things are a good deal less clear for HEVs and PHEVs: 25 percent of respondents thought that a PHEV could only use electricity and 68 percent of respondents thought that an HEV could be refueled either with gasoline or by plugging in to an electric outlet. The latter is clearly false for the most common expert definitions of an HEV. This last point demonstrates enormous potential for misunderstanding PHEVs among new vehicle buyers, the majority of which seem to think that currently available hybrids can be plugged in to the electricity grid. An alternative explanation is that our choice of wording ("hybrid-electric") may have been too formal relative to commonly used "hybrid." In either case, there is at least widespread confusion regarding electric-drive terminology, and perhaps widespread misunderstanding of the functions, requirements, and benefits of different electric-drive technologies.

Fig. 6: Stated familiarity with electric-drive vehicles (all respondents)

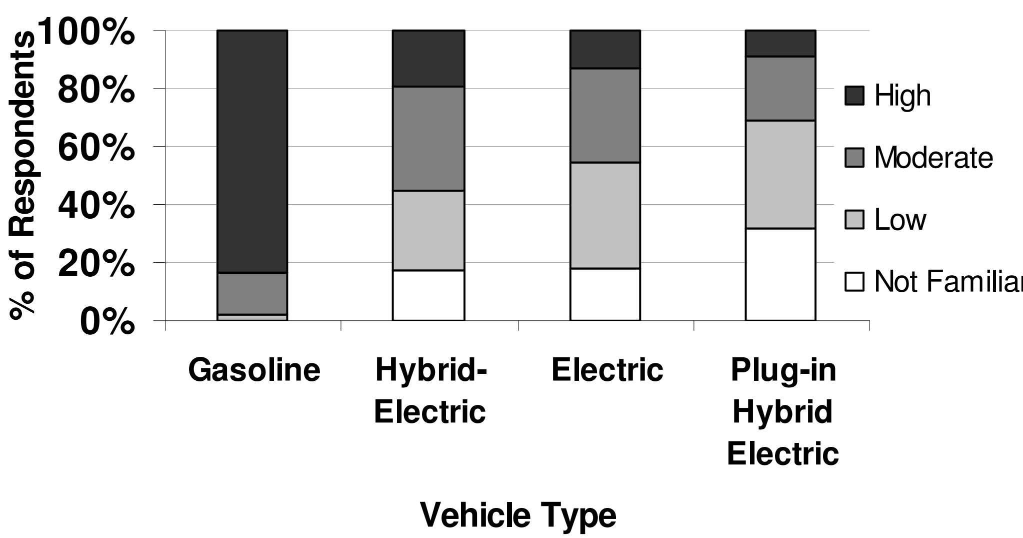
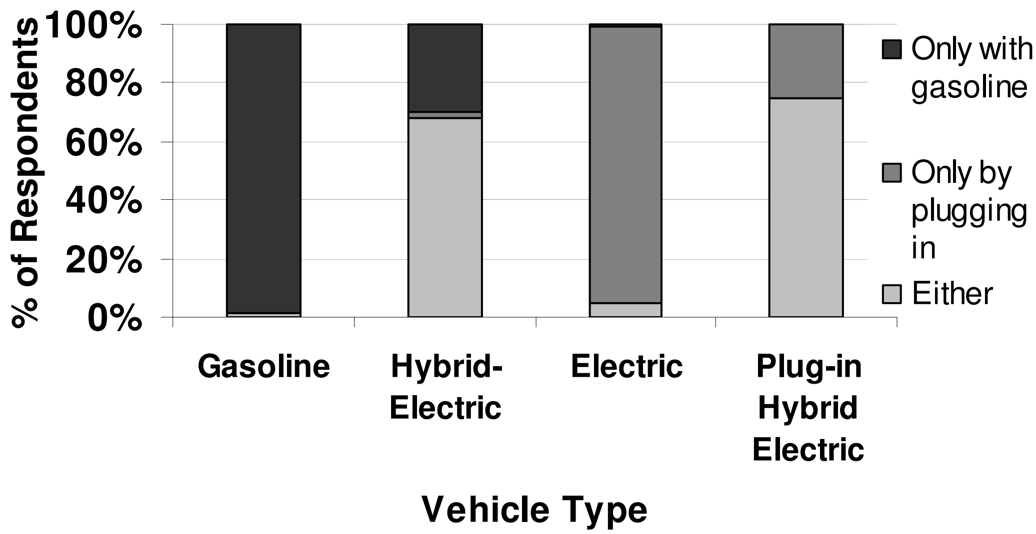


Fig. 7: Demonstrated understanding of how to fuel an electric-drive vehicle (all respondents)



3.2 Recharge Access

Results from the *Plug-in Potential* vehicle diary indicate that more new vehicle buyers may be pre-adapted for vehicle recharging than previously estimated (Figure 8). Following Graham *et al* (2001), we consider a parking spot to be viable for recharging if located within 25 feet of an electrical outlet. Of the 2,373 respondents, 59.5 percent found at least one viable recharge location during their 24-hour diary day, and 52.4 percent identified one at their home. For the remainder of this study, we consider these 52.4 percent of our sample to represent the *higher home recharge potential* segment among new vehicle buying households, that is, respondents that identified an electrical outlet within 25 feet of their vehicle parking spot at their home location at some time during their 24-hour diary.

Fewer respondents found non-home recharge locations: 4.8 percent found outlets at work (6.3 percent of employed respondents), 5.4 percent at the home of a friend or family member, 2.3 percent at a store or restaurant, and 9.7 percent at all other locations. Figure 8 also depicts the sensitivity of estimated recharge access to the assumption of the maximum distance of the electrical outlet from the vehicle. Home recharge access ranges from as high as 60.7 percent if we allow 50 feet between the parked vehicle and the nearest electrical outlet, to a low 35.8 percent if the outlet must be within 10 feet of the vehicle.

Fig. 8: Access to recharge spot by location and outlet distance (all respondents, n = 2,373)

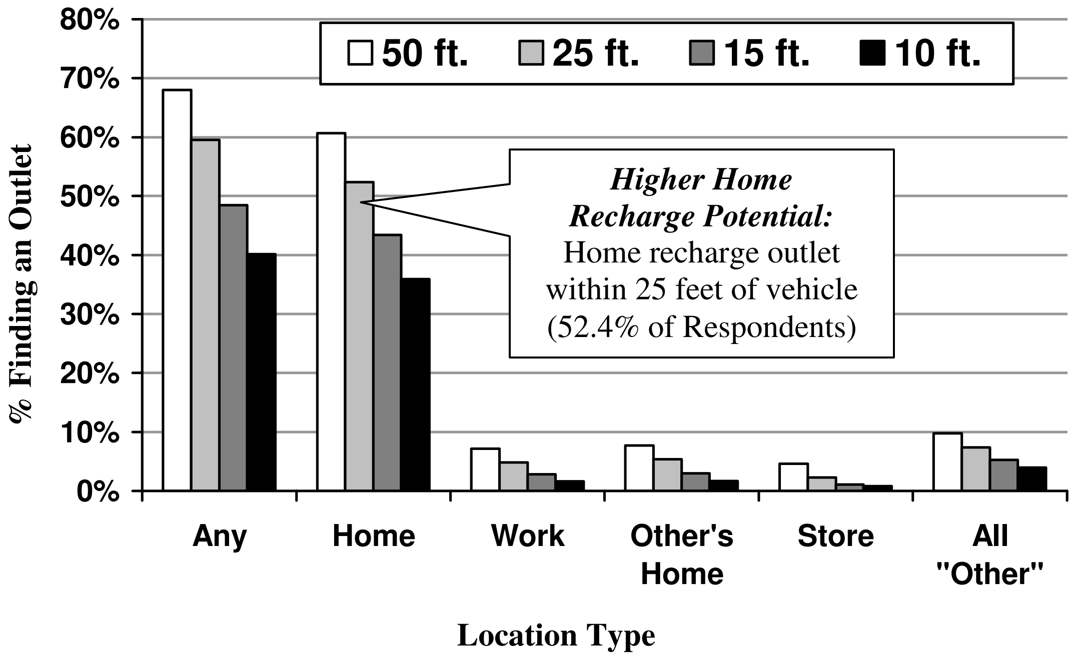


Figure 9 depicts the split of this *higher home recharge potential* segment by housing type: detached homes (single family dwellings), attached homes (including duplexes and townhouses), apartments and mobile homes. Most respondents lived in detached homes (single family dwellings), and most respondents who lived in detached homes parked their vehicle at home within 25 feet of an electrical outlet. Over the entire sample, 45.9 percent of our new car buyers live in a detached home and park near an outlet. Somewhat less than half of residents of attached homes and mobile homes park a car at home near an outlet. Only about one-in-six apartment dwellers parks a vehicle near an outlet. Overall, residence in a detached home is positively correlated with at-home recharge potential, but is neither necessary nor sufficient.

Figure 10 shows that the proportion of our sample with *higher home recharge potential* is highest for those parking in attached garages (71.9 percent) and detached garages (61.6 percent). Driveway and carport locations yield lower proportions of 42.4 and 40.3 percent, respectively. The lowest proportions were found for respondents parking on the street (17.4 percent) and in parking lots (4.7 percent). Our findings suggest that the use of home garages supports at-home recharge potential, but as with detached homes this condition is neither necessary nor sufficient.

Fig. 9: Access to home recharge by housing type (all respondents, n = 2,373)

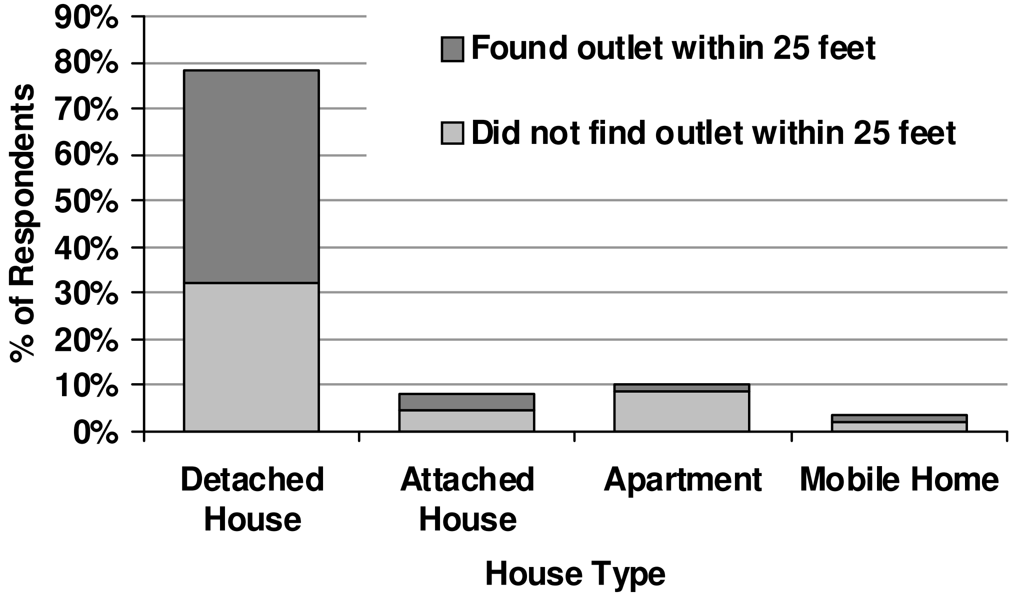
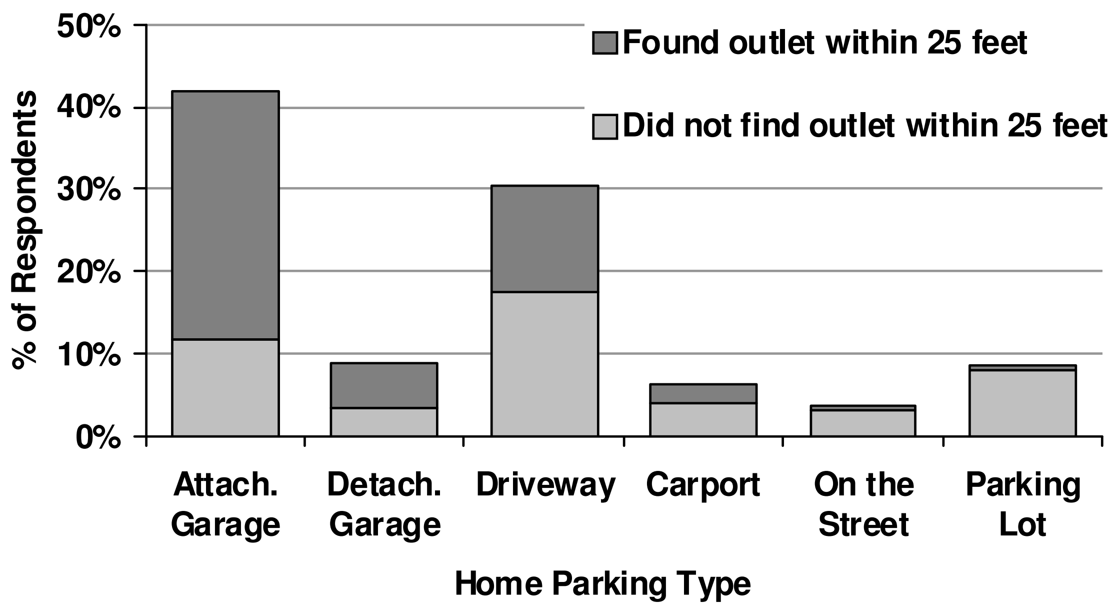
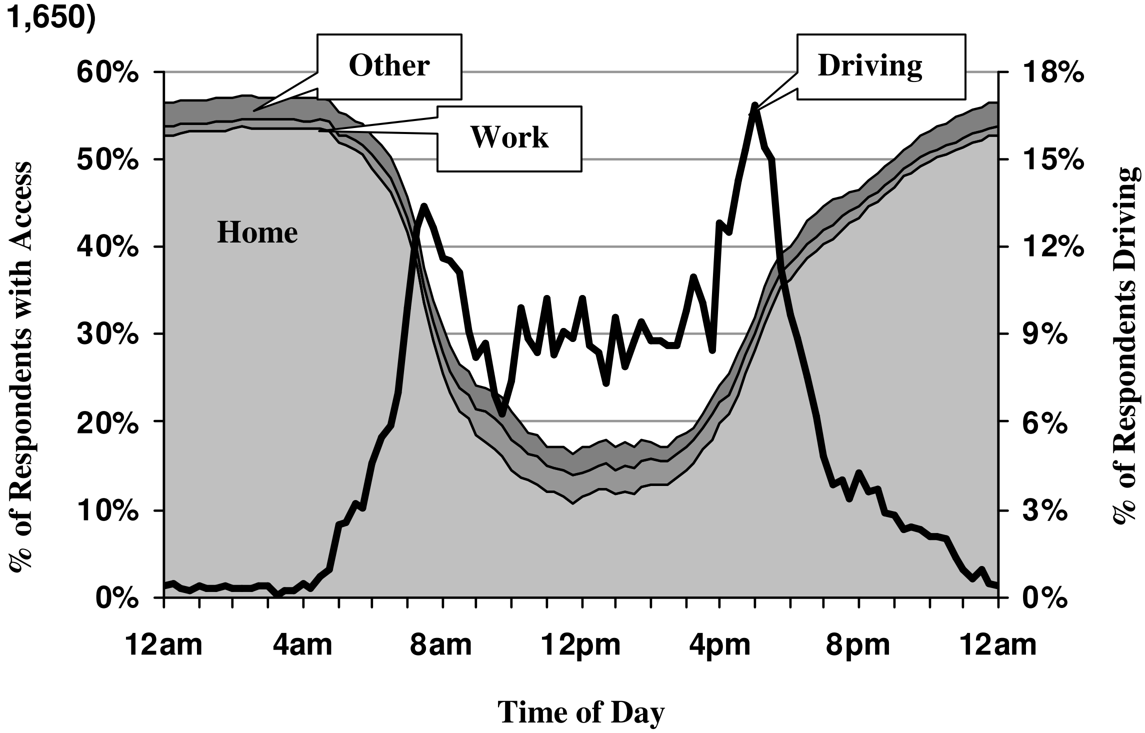


Fig. 10: Access to home recharge by type of home parking spot (all respondents, n = 2,373)



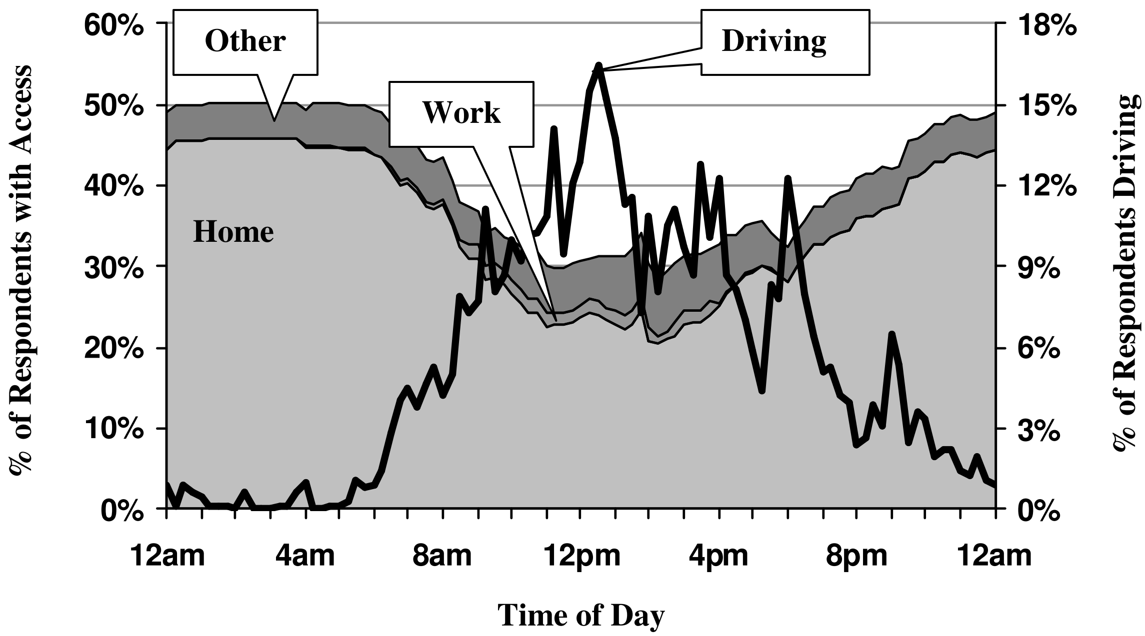
We also investigated driving and recharge potential over a 24-hour cycle (in 15 minute intervals); the sample was proportionally assigned a weekday (Figure 11) or weekend-day (Figure 12) on which to complete their diary. On weekdays, the proportion of respondents' driving follows an expected daily pattern, peaking during common commute hours at 7:30am and 5:00pm. At a given point in time, total recharge potential ranges from over 50% of respondents from 9:00pm to 7:00am, to under 20% from 10:00am to 3:00pm. Throughout the day, home is by far the most frequent location of recharge opportunities within respondents' existing travel and recharge potential. Neither work nor other non-home locations have recharge potential that surpass 4 percent of respondents for any 15 minute interval during the day. The general pattern in Figure 11 is consistent with driving patterns; recharge potential drops when many respondents are driving or parked at work or other locations, and rises when vehicles are parked at home.

Fig. 11: Time of day driving and recharge potential (weekdays only, n = 1,650)



As seen in Figurve 12, relative to weekdays, driving patterns on weekend days do not have the two morning and afternoon peaks, but rather a single broad mid-day rise to a peak at 12:30pm (with a lesser peak in the later evening). Weekend recharge potential during any given 15 minute interval ranges from a high of 50.3 percent to a low of 28.6 percent of all respondents; home also dominates the potential recharge locations.

Fig. 12: Time of day driving and recharge potential (weekend days only, n = 493)



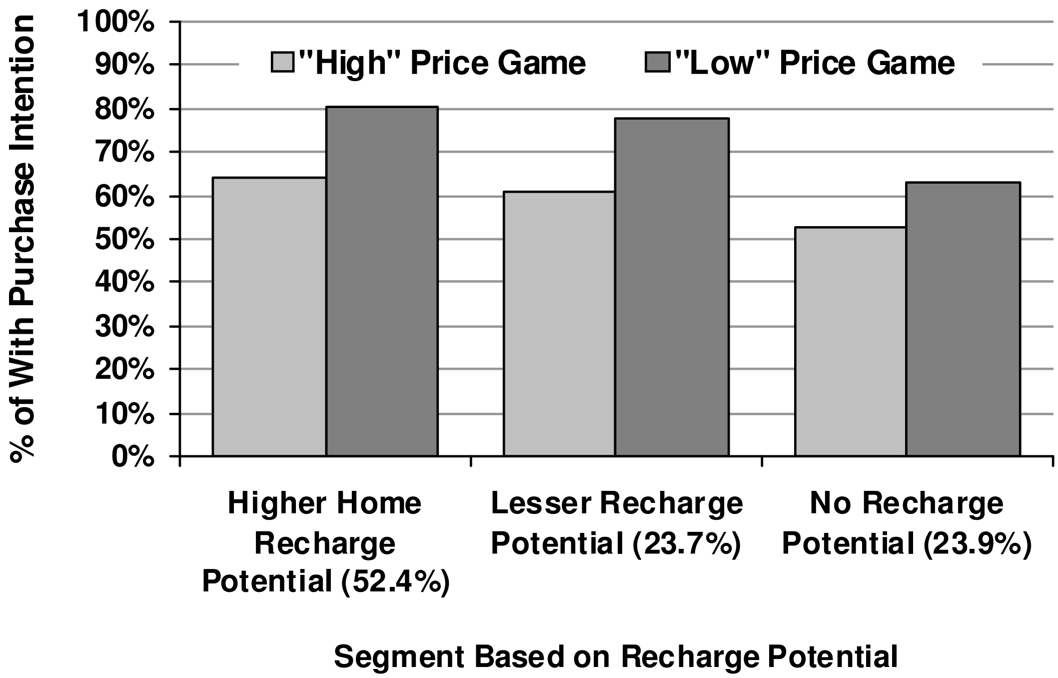
3.3 PHEV Design and Value

We use recharge potential estimates from the previous section to shape the analysis of respondents' PHEV design games. We divide the sample into three segments according to their demonstrated recharge potential:

1. *Higher home recharge potential*: this segment consists of the 52.4 percent of respondents that found an at-home electrical outlet within 25 feet of their vehicle during their diary day, as identified in Figure 8.
2. *Lesser recharge potential*: this segment includes the 23.7 percent of respondents that did not identify a home recharging location in their diary day as specified above, but elsewhere in the survey indicated they could potentially recharge at one or more locations at least 8 hours over an average week.
3. *No recharge potential*: the remaining segment (23.9 percent) includes all respondents that did not indicate they could potentially recharge their vehicle at one or more locations for at least 8 hours in an average week.

Within each recharge segment, we compared interest in PHEVs as measured by whether the respondent stayed with a conventional vehicle or designed a PHEV to be their next new vehicle in the *Purchase Design* games described in Section 2.1 (Figure 13). Among respondents with *higher home recharge potential*, 64.1 percent designed a PHEV for their next new vehicle in the "high" price condition. Such "purchases" of PHEVs are more frequent across all recharge potential segments in the "low" price condition than in the "high" price condition, by 11 to 16 percentage points. PHEV purchase intentions are less frequent in segments with less demonstrated recharge potential, i.e., the *lesser* and *no* *recharge potential* segments. Surprisingly, this decrease is only slight; relative to the *higher home recharge potential* segment, purchase intention decreases by 3 percentage points for the *lesser recharge potential* segment, and by 12 to 17 percentage points for the *no recharge potential* segment. Regardless of the degree of demonstrated recharge potential, the majority of respondents in each segment assigned significant value to a vehicle with plug-in capabilities they designed.

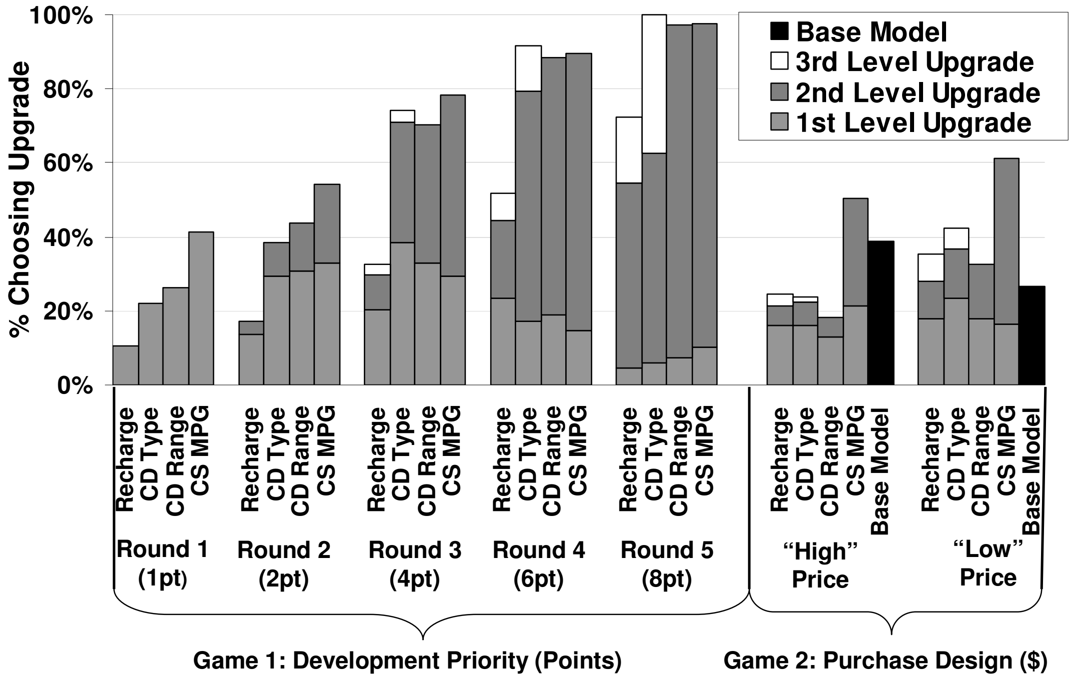
Fig. 13: PHEV interest among three recharge segments (all respondents, n = 2,373)



Because recharge opportunities are relatively sparse at work and other non-home locations, we isolate home recharging as the key criteria to characterize a potential early PHEV market in this analysis. This constraint is substantiated by the experience of drivers of PHEV-conversions reported by Kurani *et al* (2007). We feel that the *higher home recharge potential* segment identified above provides a conservative yet realistic sub-sample from which to explore the size of early PHEV markets; we limit further consideration of the early PHEV market to the *higher home recharge potential* segment. We further constrain this segment based on PHEV interest as indicated by purchase intentions in the "high" price condition. Thus, we select the 33.5 percent of respondents that demonstrate both access to sufficient recharge infrastructure and PHEV interest as a group best representing the early PHEV market. We will refer to this subset as the *potential early market* respondents.

Focusing on the interests of these *potential early market* respondents, results of the two PHEV design games are summarized in Figure 14. PHEV performance priorities varied substantially; no single PHEV design emerged as a favorite of the majority. In Round One of the *Development Priority* game, respondents were given one point to allocate towards one upgrade to the base PHEV model. As described in Section 2.1, four upgrades were available: recharge time (from 8 to 4 hours), gasoline-fuel economy during CD operation (from 75 to 100 MPG), CD distance (from 10 to 20 miles), or CS gasoline-fuel economy (from 10 to 20 MPG over the conventional version of the vehicle). Improving the CS gasoline-fuel economy was the most frequently chosen upgrade (41.1 percent).[3] The general ranking of attribute upgrades in Round One continues through later rounds: a higher percentage of *potential early market* respondents designed PHEVs with CS MPG upgrades than faster recharge times.

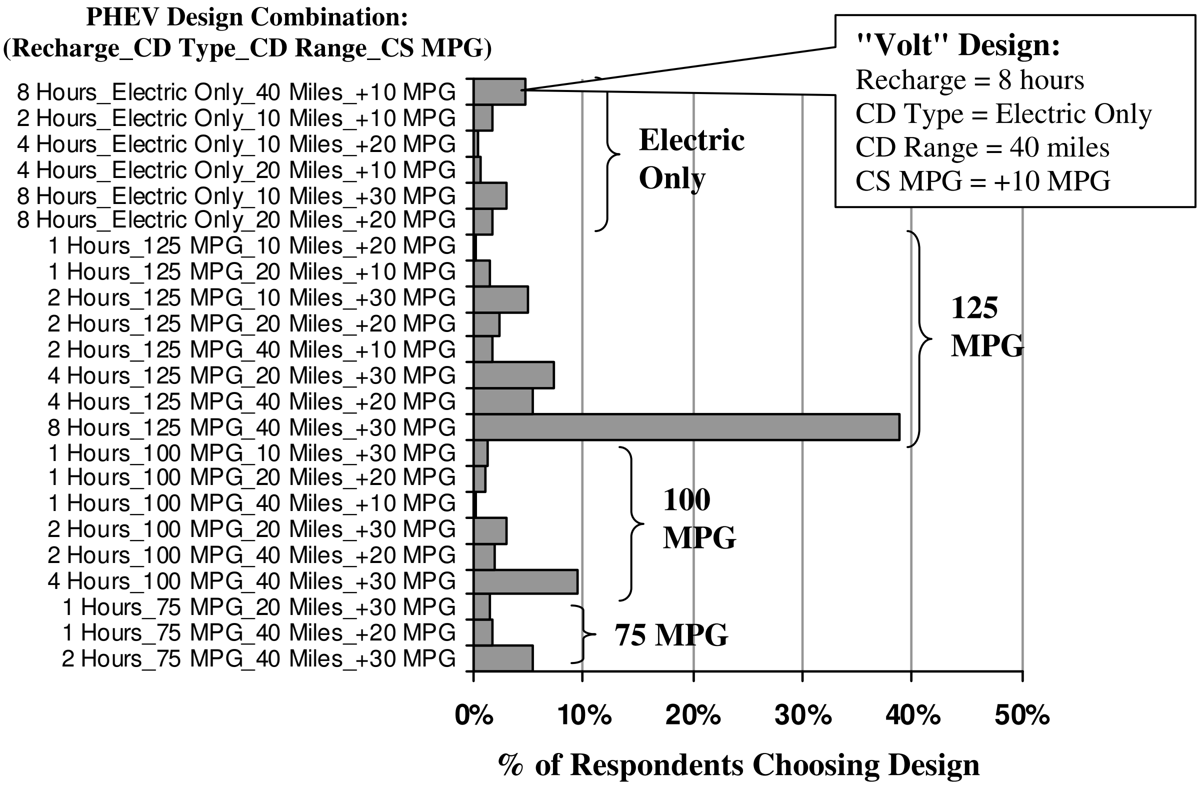
Fig. 14: Attribute selection in both design games (early market potential respondents only, n = 827)



All-electric operation (in CD mode) was first offered to respondents in Round Three; only 3.4 percent made this upgrade, which came at the expense of any other upgrades available in prior rounds. In Round Four, the proportion of *potential early market* respondents designing a PHEV with all-electric operation rose to 12.3 percent. Figure 15 portrays the 23 different possible PHEV designs possible in Round Four. This is the first round providing a design envelope allowing respondents to choose a PHEV with 40 miles of all-electric range—a vehicle similar to GM's Volt concept. Only 4.7 percent of *potential early market* respondents chose this specific design. Overall, all-electric operation, a feature stated by some automakers to be essential to assure market success, was not a chosen frequently when points were relatively scarce, i.e. in Rounds Three and Four.

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

Fig. 15: Distribution of selected PHEV designs in Round Four of Development Priority game (early market potential respondents only, n = 827)



As previously noted, results of the *Purchase Design* game suggest that the majority of *higher home recharge* respondents (64.1 to 80.2 percent) would value PHEV capabilities in their next vehicle. Figure 14 depicts the proportion of upgrades chosen in the price conditions detailed in Section 2.1. A substantial portion of *potential early market* respondents chose the base PHEV models with no upgrades—38.8 percent in the high price condition, and 26.5 percent in the low price condition. Among those that chose to pay extra for upgrades, overall patterns are similar to the *Development Priority* game; CS fuel economy upgrades were chosen more often than other upgrades, and there is no evidence of the strong interest in all-electric operation observed among some pioneer PHEV conversion drivers (Kurani *et al*, 2007). All-electric upgrades were chosen by 1.5 and 5.7 percent of respondents in the high and low cost conditions, respectively. However, unlike the tradeoff game, CD operation and range improvements were chosen relatively less often, likely due to our representation of the added price of increasing battery power and energy density.

3.4 PHEV Energy Use Scenarios

To create scenarios of gasoline and electricity use among early PHEV buyers, we integrate the information presented thus far from respondents in the *higher home recharge potential* segment: driving behavior and recharge potential as recorded by their 24-hour diary, and PHEV design choices as demonstrated in the *Purchase Design* game. In other words, we create scenarios of gasoline use and recharge patterns for each *potential early market* respondent as if they were driving their chosen PHEV design on their 24-hour vehicle diary day. These scenarios rely on the following assumptions:

- Gasoline use is modeled using the estimated miles per gallon (MPG) of the vehicle, without accounting for potential variation in driving patterns. In other words, if the vehicle is rated at 50 MPG, we assume this constant rate for each mile driven (neglecting potential for different drive patterns over a given trip or across drivers).
- For charge depleting (CD) operation, electricity use (kWh/mile) and available battery energy capacity (kWh) is estimated as in Table 4, based on car estimates from Kromer and Heywood (2007), scaled up to truck estimates based on Duvall *et al* (2002).
- Each vehicle's assumed battery state of charge at the beginning of the day is a function of the distance driven the previous day (assumed to be the same as the diary day due to lack of multi-day data) and the respondent's estimated hours of recharge potential from the previous day (elicited elsewhere on the survey).
- Following Lemoine *et al*'s (2008) assumptions, the minimum recharge rate for a PHEV battery using a regular 110-120 V outlet is 1 kWh per hour. If the respondent's chosen PHEV design has a recharge rate higher than that required for their battery size, we apply the faster of the two recharge times. For example, if the respondent chose a PHEV requiring 8 hours for complete recharge, yet their battery size is only 1.9 kWh (requiring a maximum of 1.9 hours for full recharge), we apply the 1.9 hour time. In contrast, if the same respondent selected a recharge time of one hour, we apply the one hour time.
- Following Lemoine *et al*'s (2008) assumptions, vehicle recharging is approximately 83 percent efficient—increasing the battery's state of charge by 1 kWh requires 1.2 kWh from the electrical outlet.
- Each scenario is scaled up to represent 1 million vehicles. This value is not selected in anticipation of a particular sales volume for a particular year, but instead is a relatively feasible market size that serves to normalize energy use to allow comparisons across scenarios (with different sample sizes).[4]
- Vehicles are recharged on a daily basis as detailed in the scenario descriptions below.

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[4] An alternative approach would be to estimate the effect of each recharge scenario on the size of the potential PHEV market, such as the addition of potential PHEV buyers resulting from the expansion of public vehicle recharge infrastructure, e.g. at the workplace. However, we leave such analyses to future research, and instead focus on a set market size for each scenario.

- The PHEVs are used precisely as were their non-PHEV variants; the scenarios are based on replicating the travel-days as recorded in the diaries and do not allow for households to change the assignment of vehicles within the household or otherwise change vehicle use in response to the PHEV.
- We assume for this analysis that one-day cross-sectional data are adequate to characterize travel and therefore energy impacts. One-day diaries systematically under-represent longer travel unless the sampling is conducted according to the frequency distribution of travel-day or trip distances across people and days. By sampling across all seven days of the week we attempt to reduce the effect on our analysis, but do not represent that it is immune. It seems plausible that we, and anyone using one-day travel data, will underestimate total energy use and gasoline use in particular. We leave the estimation of the size of this potential problem to future research.

Table 4: Assumed PHEV specifications

CD mpg		Car	Truck
75 MPG	CD electricity use	0.19 kWh/mile	0.32 kWh/mile
	10 mile capacity	1.9 kWh	3.2 kWh
	20 mile capacity	3.8 kWh	6.4 kWh
	40 mile capacity	7.6 kWh	12.8 kWh
100 MPG	CD electricity use	0.20 kWh/mile	0.34 kWh/mile
	10 mile capacity	2.0 kWh	3.4 kWh
	20 mile capacity	4.0 kWh	6.8 kWh
	40 mile capacity	8.0 kWh	13.6 kWh
125 MPG	CD electricity use	0.21 kWh/mile	0.36 kWh/mile
	10 mile capacity	2.1 kWh	3.6 kWh
	20 mile capacity	4.2 kWh	7.2 kWh
	40 mile capacity	8.4 kWh	14.4 kWh
All electric	CD electricity use	0.26 kWh/mile	0.45 kWh/mile
	10 mile capacity	2.6 kWh	4.5 kWh
	20 mile capacity	5.2 kWh	9.0 kWh
	40 mile capacity	10.4 kWh	18.0 kWh

Following these assumptions, we created four scenarios using data from the 827 *potential early market* respondents:

1. No PHEVs: In this scenario, we estimate and aggregate the gasoline used by the respondents on their actual diary days.
2. Plug and Play: In this scenario, we simulate the gasoline used for driving *and* the electricity used for recharging, allowing that the conventional vehicles are displaced by a vehicle with the PHEV upgrades chosen in the "high" or "low" price conditions of the *Purchase Design* game. Drivers are assumed to recharge

whenever they are parked within 25 feet of an electrical outlet. In other words, there are no pricing mechanisms, e.g., time of use electricity tariffs, or technologies, e.g., smart charging mechanisms, to divert recharging to off-peak.

3. Enhanced Worker Recharging Access: This scenario starts with the conditions in *Plug and Play*, but further supposes that all workers can recharge a vehicle at work.
4. Off-Peak Only Recharging: Finally, using the same recharge potential and PHEV designs as *Plug and Play*, in this scenario no PHEV recharging is allowed during daytime peak hours (6am to 8pm). Smart charging technology is used to optimize the timing of electricity use over this period, represented as a flat line (the actual shape of this line would likely vary according to the needs of a particular electric utility).

Taken together, these scenarios are meant to represent potential boundary conditions, that is, where the entire market adheres to a selected condition (no regulation, enhanced workplace policy, or off-peak charging). Of course, the early PHEV market may include elements of more than one of these scenarios, as well as other potential conditions we do not consider here, all of which are likely to change over time. However, the purpose of this exercise is to present these boundary conditions to frame discussions of the potential benefits and drawbacks of different recharge strategies and policies.

Figures 16 to 19 portray each scenario for respondents who completed weekday diaries given the PHEV designs they selected in the "high" price conditions. Results from respondents with weekend day diaries, as well as "low" price conditions PHEV designs, are detailed in Table 5. Each figure depicts the time of day gasoline use (gallons per minute) and electricity use (MW) per million vehicles over a 24-hour period. The area under each curve represents the total gallons of gasoline, or MWh of electricity, used over the day, respectively. In the *Plug and Play* scenario, most recharging occurs at home locations, peaking at 6:00pm at 596 MW (705 MW in the "low" price condition)—significantly lower than the 1,200 MW peak anticipated by Lemoine *et al* (2008) for 1 million PHEVs. Their higher peak electricity demand estimate is due to their assumptions about a uniform PHEV design across the market (20 miles of all-electric CD range) and relatively uniform recharging patterns of PHEV drivers.[5] In contrast, the present study allows for substantial variation in PHEV designs and daily driving.

Time of day gasoline use corresponds with the rush hour periods observed in Figure 11. These simulations indicate that in the *Plug and Play* scenario overall gasoline use is estimated to cut gasoline by half relative to the *No PHEV* scenario (Table 5). Notice that gasoline use is reduced by a larger degree in the morning due to the higher proportion of miles driven in CD mode earlier in the day. Table 5 also shows that a large portion of this gasoline reduction (76 to 81 percent) is due to upgrades to CS fuel economy with CD capabilities eliminated.[6] For this reason, overall gasoline savings varies little across the

[5] In each recharge scenario presented by Lemoine *et al* (2008), PHEV drivers are assumed to begin recharging at approximately the same time of day for the same duration.
[6] However, simulating only CS fuel economy upgrades may be inappropriate—respondents might not have chosen the vehicle upgrades without plug-in and CD capabilities.

three charging scenarios or the price levels in the design game; in all instances, gasoline use is cut in about half compared to the *No PHEV* scenario.

However, the peak magnitude and timing of recharging varies significantly across scenarios. Figure 20 plots all three recharge scenarios. The *Enhanced Worker Recharging Access* scenario increases overall electricity use by 34 percent relative to *Plug and Play*, with much of the addition occurring in the morning as drivers arrive at work. In contrast, the *Off Peak Only* scenario reduces electricity use by 16 percent, largely due to the elimination of work and other non-home recharge opportunities that occur during peak hours. Of course, this scenario has the benefit of eliminating all electricity use during peak hours, with nightly demand balanced at 365 MW. As noted, the specific balancing strategy used in this scenario would likely vary by electric utilities to flatten out overall off-peak demand, as seen in Lemoine *et al*'s (2008) "optimal charging" scenario. Our scenario merely demonstrates the potential for shifting and minimizing peak demand.

Table 5: Summary of recharge scenarios, scaled to one million PHEVs (early market potential respondents only, n = 827)

		PHEV Design Game 2: "High" price		PHEV Design Game 2: "Low" price	
Scenario		Weekday (n = 590)	Weekend (n = 168)	Weekday (n = 590)	Weekend (n = 168)
No PHEVs	Gasoline (Gal.)	1,678,681	1,383,481	1,678,681	1,383,481
CS upgrade only	Gasoline (Gal.)	1,017,273	803,156	988,387	766,027
	% Gas reduced	39.4%	41.9%	41.1%	44.6%
Plug and Play	Gasoline (Gal.)	866,830	660,561	821,488	567,867.3
	% Gas reduced	48.4%	52.3%	51.1%	59.0%
	Electricity (MWh)	4,354	4,284	5,353	5,782
	Peak (MW)	596	384	705	520
	Peak Time	6:00pm	1:45pm	6:30pm	1:45pm
Enhanced Worker access	Gasoline (Gal.)	819,174	655,104	774,019	559,107
	% Gas reduced	51.2%	52.6%	53.9%	59.6%
	Electricity (MWh)	5,815	4,488	6,861	6,042
	Peak (MW)	559	384	625	524
	Peak Time	6:00pm	1:45pm	6:30pm	1:45pm
Off peak only	Gasoline (Gal.)	892,361	688,324	844,107	604,952
	% Gas reduced	46.8%	50.2%	49.7%	56.3%
	Electricity (MWh)	3,647	3,533	4,633	4,815
	Peak (MW)	365	353	463	482
	Peak Time	8pm-6am	8pm-6am	8pm-6am	8pm-6am

Fig. 16: Gasoline use in "No PHEV" scenario, scaled for one million vehicles (weekdays only, early market potential respondents only, n = 590)

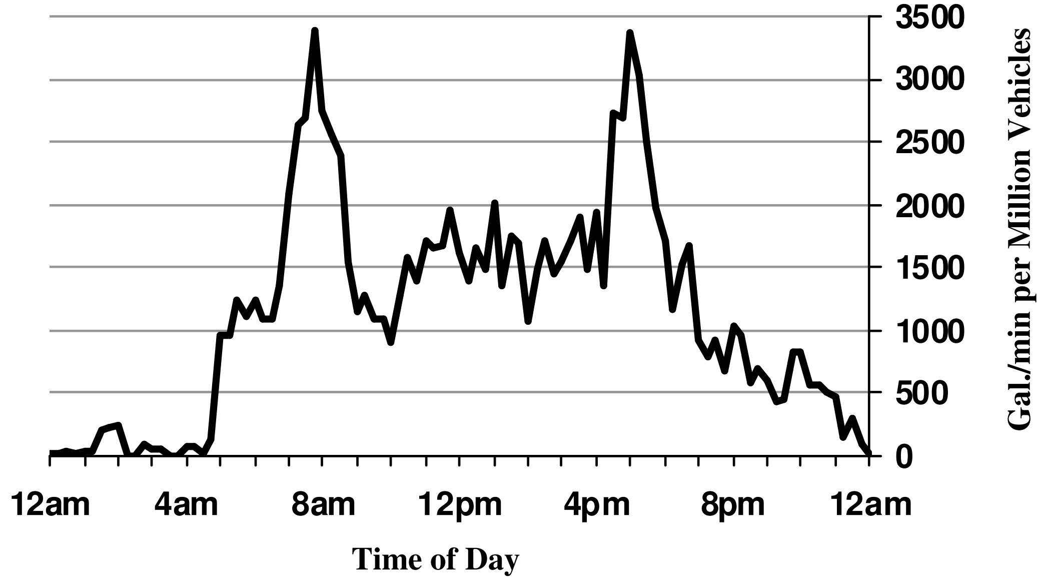


Fig. 17: Energy use in "Plug and Play" scenario, scaled for one million PHEVs (weekdays only, early market potential respondents only, n = 590)

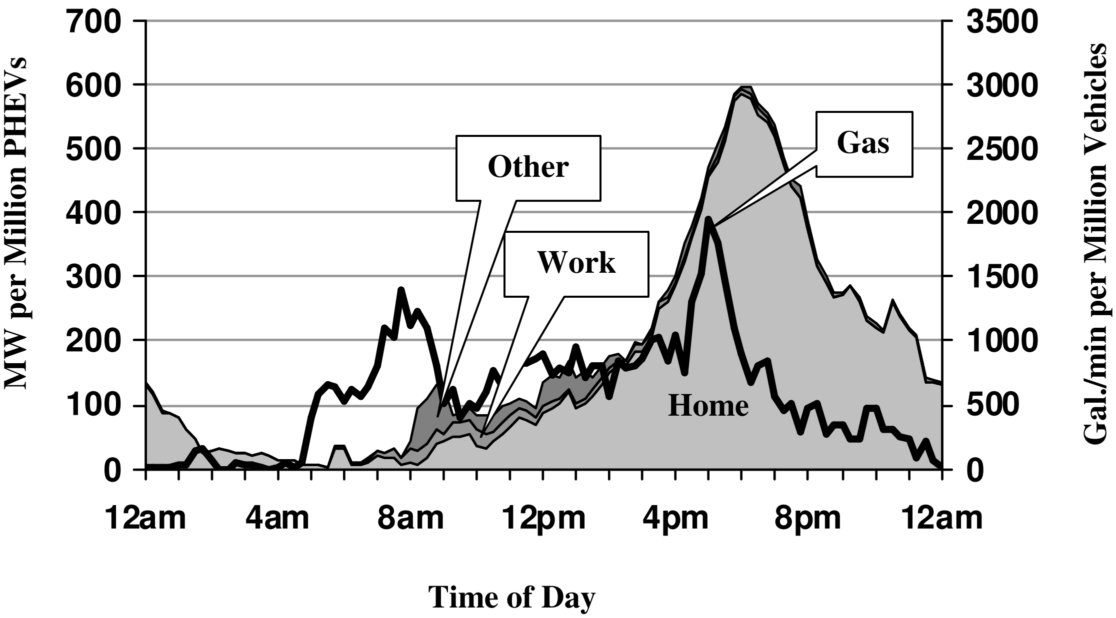


Fig. 18: Energy use in "Enhanced Worker Recharging Access" scenario, scaled for one million PHEVs (weekdays only, early market potential respondents only, n =590)

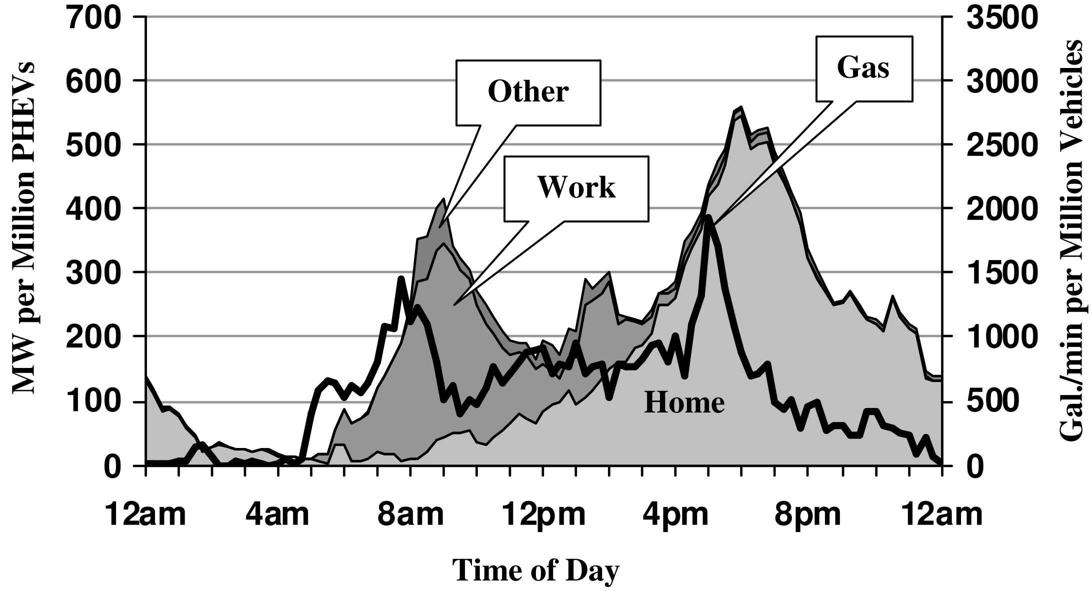


Fig. 19: Energy use in "Off Peak Only" scenario, scaled for one million PHEVs (weekdays only, early market potential respondents only, n =590)

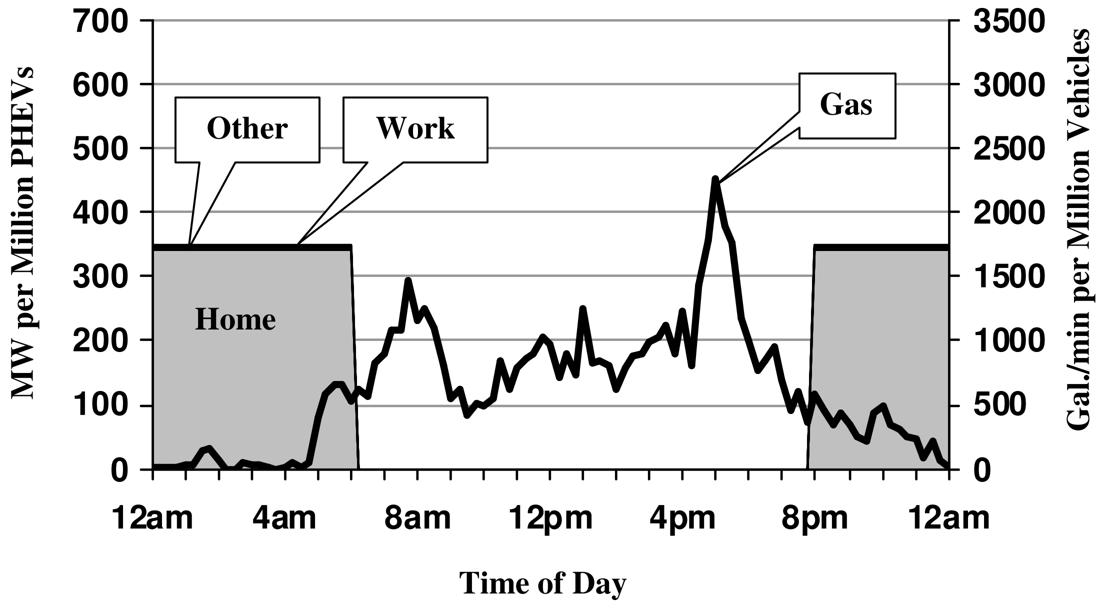
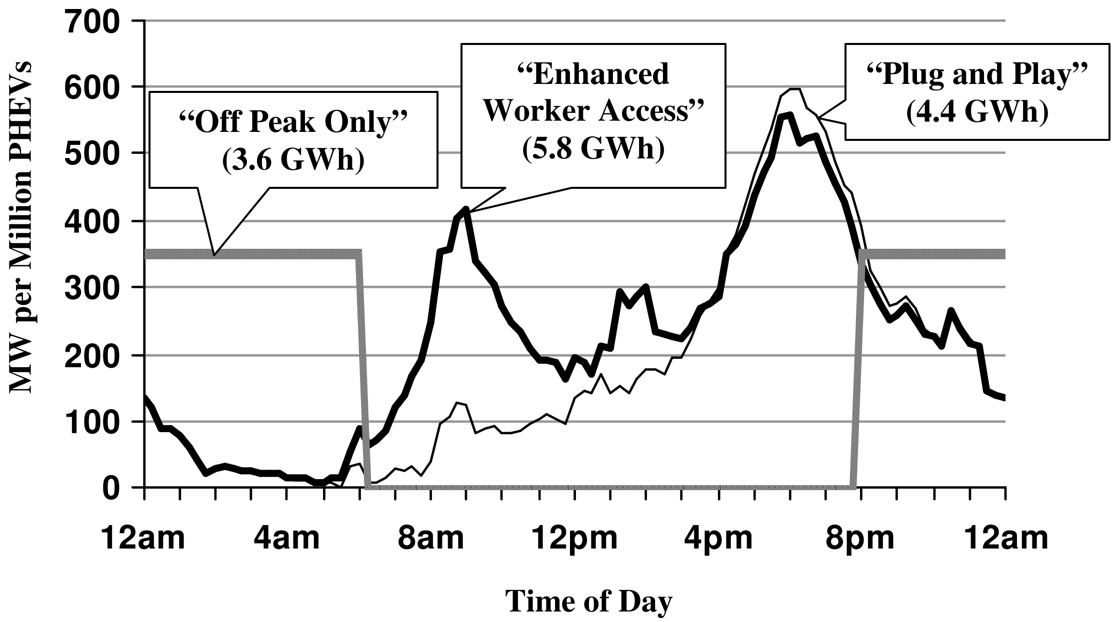


Fig. 20: Comparing PHEV recharge scenarios, scaled for one million PHEVs (weekdays only, early market potential respondents only, n =590)



4. Discussion and Conclusions

Results from this analysis offer initial answers to our four research questions: anticipating consumer awareness, recharge potential, design priorities, and energy impacts of the early PHEV market. In regards to the last three, our simulated world contains far more variety of PHEV designs than any prior study. This is an intentional difference, allowing respondents to design the PHEV they would most desire given their current understanding and valuation of four PHEV performance parameters. We believe this is a more realistic representation of a plausible near future than the imposition of one or a few PHEV designs on the entire population of vehicle drivers. Certainly as we analyze "one-million PHEV" scenarios—suggesting that we are attempting to analyze a world existing a few years after the introduction of PHEVs—a world of greater variety is more plausible than a world of one or a few PHEV designs. Our scenario analyses remain susceptible to other threats endemic to such efforts. Radically changing travel behavior—in response to fuel prices, competition from other alternatives, or in response to PHEVs themselves—could invalidate our use of data on existing real travel. Rapid technology development and cost reductions—or their delay—may render our design games under-, or over-optimistic. And as discussed in the description of our recharging scenarios, none of them likely capture precisely what will happen with workplace recharging, efforts to control time of day of recharging, or efforts to provide home recharging to the one-third to nearly one-half of new car-buying households who do not now find that where they park their cars at home has access to electricity.

4.1 Awareness of Electric Drive Vehicles

Acknowledging that vehicle buyers generally do not need intimate technological understanding of a given vehicle to ensure purchase, we do suspect that basic levels of awareness and understanding can play an important role in the introduction of a vehicle that operates in a fundamentally new way and provides symbolic meanings not previously available from motor vehicles. Responses to this survey suggest that presently the majority of new vehicle buyers have little or no familiarity with the idea of a PHEV, and may erroneously believe that existing hybrid-electric vehicles can perform the same basic function of a PHEV, i.e., have the ability to be refueled by gasoline and to be plugged into an electrical outlet. The latter finding is particularly surprising, given that HEVs have been available in the U.S. auto market for almost a decade. These perceptions of HEVs indicate there is both potential for misconceptions and confusion regarding the availability and purported benefits of PHEVs and that such misconceptions may persist for years. Potentially related to this is the further finding that respondents did not exhibit a strong attraction to all-electric operation in CD mode for PHEVs. Given that the vast majority of respondents have not experienced electric drive vehicles, they may have limited understanding of potential benefits including functional attributes such as reduced noise, vibration, emissions, and costs, as well as the personal and shared meanings that have come to be associated with HEVs (see Heffner, 2007 and Heffner *et al* 2007).

This lack of awareness and understanding is both a constraint and opportunity. As a constraint, unaware consumers may simply fail to recognize or identify compelling benefits of owning and operating a PHEV, serving as a soft constraint to limit the market. On the other hand, the early PHEV market in the U.S. may be seen as a "blank slate", with little preexisting understanding of what a PHEV is or expectations of what it should be. Thus, the early actions of automakers, governments, electric utilities and other stakeholders could play an important role in establishing perceptions in the market. For example, despite the initial lack of PHEV awareness among our sample, once respondents were provided with basic descriptions of the technology (in the *Plug-in Buyers'* G*uide* provide to them as part of their survey), the majority expressed interest during the design exercises. Similarly, the first commercially available PHEV incarnations could set an early bar for consumer understanding and set expectations of performance levels.

4.2 Recharge Potential and Timing

Based on the results reported here, we conclude that just more than half the population of households that buy new cars has the potential to recharge a vehicle at home with at least 110-volt service. This estimate is one-and-a-half to three times larger than previous estimates of home recharging potential in the entire population of American households by Nesbitt *et al* (1992) and Williams and Kurani (2006). The reasons for this difference are that the present analysis (1) targets new vehicle buying households rather than general population of American households, and (2) draws information directly from the respondent's identification of recharge opportunities instead of relying on proxies from U.S. Census or other data. Given their own observed driving and parking behavior, few drivers perceive an opportunity for non-home recharging opportunities, such as at their workplace, friend's and family's homes, restaurants, etc. Therefore, we selected access to home recharging as a key constraint for what we call the *higher home recharge potential* segment. Within this segment we find that although a higher proportion of respondents with single-family dwellings found home recharge opportunities than respondents in other housing types (attached, apartments or mobile homes), this condition is neither necessary nor sufficient for recharge potential. We find a similar pattern for respondents who typically park their vehicle in a private garage at home.

As previously assumed and reported, e.g., by Lemoine *et al* (2008), Duvall *et al* (2007), Samaras and Meisterling (2008), and Hadley and Tsvetkova (2008), vehicle access to recharge infrastructure as identified by diary respondents follows an inverse of the diurnal pattern of driving activity. Recharge potential, that is, the spatial-temporal correspondence between a parked vehicle and a 110-volt electrical outlet, peaks between 12am and 6am when most vehicles are parked at home and reaches a broad minimum from 10am to 4pm when most vehicles are parked at work or other locations or being driven.

The present analysis is useful in providing a plausible baseline for the early PHEV market; but a baseline from which consumers, infrastructure and vehicle providers, and policy makers can create change. Research suggests that with the right incentives, consumers might locate more recharge locations, modify existing recharge locations, e.g. clean up the home garage, and adjust driving patterns and adapt vehicle use among the household fleet to maximize electricity use (Kurani *et al*, 1996, 2007). Much adaptation by consumers may not occur until after they purchase a PHEV, and their perceived recharge potential that may lead to PHEV purchase may be based on existing driving patterns, i.e., current perceptions of recharge locations.

Still, it may be possible to lead PHEV purchases by changing perceptions of the availability of vehicle recharging, by actually increasing the availability of recharging for those households who do not now find it and by improving the visibility and viability of existing electrical infrastructure for vehicle recharging. Recharge infrastructure could expand to a higher percentage of households with changes in building codes, as well as increased employer and publicly installed vehicle recharge outlets.

4.3 Design Priorities

Among the respondents with at-home vehicle recharging, most constructed more expensive vehicle designs that added plug-in capability to their next vehicle purchase than did those without access to recharging. Given access to recharging and the distribution of PHEV designs from the games, we estimate that about one-third of U.S. new vehicle buying households have both the required infrastructure and interest to purchase a vehicle with plug-in capabilities. The variety of PHEV designs created by respondents suggests there is still ample opportunity for automakers to explore and develop different PHEV designs.

We observed a wide diversity of consumer interests in PHEV design options. Starting with a base PHEV design offering long recharge times, short CD range, no all-electric operation, but non-trivial increases in both CD and CS gasoline fuel economy, the most popular upgrade category was to further improve fuel economy in CS mode. Respondents also exhibited interest in increasing vehicle range in CD mode, and improving CD fuel economy. Fewer respondents were willing to devote resources to reduce recharge time; most *potential early market* respondents have access to periods of home-based charging long enough to fully recharge each day even at the slowest offered rate.

We found little evidence of inherent demand for all-electric operation in CD mode, even following the one-day diary, the tutorial on electric-drive vehicles, and PHEV design games. An even smaller subset was interested in creating a vehicle with performance attributes including 40 miles of all electric CD range. These patterns contrast with the findings of Kurani *et al*'s (2007) interviews with "pioneer" PHEV conversion drivers who exhibited strong interest in maximizing CD range in all-electric mode—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 are already knowledgeable and experienced with electric vehicles, at this point in time most households who buy new vehicles are more interested in high fuel economy.

Also, about one-third of the *potential early market* respondents who constructed a PHEV variant of their likely next new car (that they selected rather than a conventional version of that car) chose no upgrades above the proffered base PHEV design. Overall, there may be substantial potential for market success with less ambitious PHEV designs, i.e. blended operation with shorter CD range but high CS fuel economy. This wide variety of PHEV design selections further supports the notion of a "blank slate" early PHEV market, where early buyers may have little in the way of performance expectations.

Desired PHEV designs and capabilities may be subject to change. 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 particular attributes and performances could shift. For example, all-electric CD operation could become more meaningful to car buyers as they gain experience 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 awareness, recharge potential, design interests, and energy impacts of the PHEV market.

4.4 Energy Impacts

The final analysis in this report combined all the available information from each respondent—driving, recharge potential, and PHEV design priorities—to estimate the energy impacts of the respondents existing travel and understandings of PHEVs under a variety of recharging scenarios. Results suggest that the use of PHEV vehicles could halve gasoline use relative to conventional vehicles—the majority of this reduction being due to increases in CS fuel economy. Using three scenarios to represent potential boundary conditions on PHEV driver recharge patterns (unconstrained, universal workplace recharging, and off-peak only charging), we estimate tradeoffs between the magnitude and timing of PHEV electricity use. In the unconstrained "Plug and Play" recharge scenario, recharging peaks at 6:00pm, following a far more dispersed pattern throughout the earlier part of the day than anticipated by Lemoine *et al* (2008) and Hadley and Tsvetkova (2008). The more dispersed time-of-day recharging pattern in our work is due to our ability to realistically account for heterogeneity in driving and parking behavior and to allow for heterogeneity of PHEV designs. PHEV electricity use could be increased through policies increasing non-home recharge opportunities (e.g., the "Enhanced Worker Recharge Access" scenario), but most of this increase occurs during daytime hours and could contribute to peak demand (depending on a given region's definition of "peak"). We also demonstrate how deferring all recharging to off-peak hours (8pm-6am) could eliminate all additions to daytime electricity demand from PHEVs, similar to what Lemoine *et al* (2008) call "optimal charging." However, as also found by Kurani *et al* (1997) for EVs, in this scenario less electricity is used due to the elimination of daytime recharge opportunities and less gasoline is displaced.

This analysis provides one measure of the potential threat and opportunity for electric utilities. The threat is that without control, the majority of recharging may occur during peak hours (6am-8pm), with a peak at 6pm during weekdays. This spike coincides with seasonal peak electricity demand periods in some U.S. states and with a large enough PHEV market, overall electricity generation requirements may be increased (Lemoine *et al*, 2008). However, the observed 12am-6am recharge potential in late evening and early morning presents an opportunity for "smart charging" strategies in which PHEV recharging (as well as any other electrical load) can be shifted to off-peak periods subject to varying levels of control by electricity users and suppliers.

Our scenarios are limited in that we do not represent recharge scenarios specific to the various regions and electric utilities across the U.S. Instead we produce an aggregated nationwide pattern without explicitly representing current electricity demand patterns, i.e., without PHEVs. Our intention is to represent energy use according to general trends rather than to provide a specific energy analysis for a given region. Further analysis will be conducted based on our over-sample of California. Such refinement will be of relevance to the California Energy Commission and the California Integrated System Operator, though not for specific utilities even in California.

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References

Adler, T., Rimmer, L., Carpenter, D., 2002. Use of an Internet-based household travel diary survey instrument, Transportation Research Board 2002 Annual Meeting CD-ROM.

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

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

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

Couper, M., 2000. Web Surveys: A Review of Issues and Approaches, Public Opinion Quarterly 64(4), 464-494.

Couper, M., 2002. New technologies and survey data collection: Challenges and opportunities, Invited paper presented at the International Conference on Improving Surveys, Copenhagen, August.

Couper, M., Kapteyn, A., Schonlau, M., Winter, J., 2007. Noncoverage and nonresponse in an Internet survey, Social Science Research 36, 131-148.

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

Duvall, M., *et al*, 2007. Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 1: Nationwide Greenhouse Gas Emissions, EPRI, Palo Alto, CA: 2002, Report #1015325.

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

Gondor, J., Markel, T. Simpson, A., Thornton, M., 2007. Using GPS Travel Data to Assess the Real World Driving Energy Use of Plug-In Hybrid Electric Vehicles (PHEVs), Presented at the Transportation Research Board (TRB) 86th Annual Meeting, Washington, D.C., January 21-25, 2007.

Graham, R., *et al*, 2001. Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options, EPRI, Palo Alto, CA: 2001, Report #1000349.

Groves, R., 2007. Nonresponse rates and nonresponse bias in household surveys, Public Opinion Quarterly 70(5), 646-675.

Hadley, S. and Tsvetkova, A., 2008. Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation, Prepared for the U.S. Department of Energy, Oak Ridge National Laboratory, January 2008.

Heffner, R., 2007. Semiotics and Advanced Vehicles: What Hybrid Electric Vehicles (HEVs) Mean and Why it Matters to Consumers, PhD Dissertation, Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-07-30.

Heffner, R., Kurani, K., Turrentine, T., 2007. Symbolism in California's early market for hybrid electric vehicles. Transportation Research Part D 12, 396-413.
Internet World Stats, 2007. United States of America: Internet Usage and Broadband Usage Report, July 2007, http://www.internetworldstats.com/am/us.htm (accessed January 27, 2008).
Kalhammer, F., Kopf, B., Swan, D., Roan, V., Walsh, M., 2007. Status and Prospects for Zero Emissions Vehicle Technology: Report of the ARB Independent Expert Panel 2007, Prepared for State of California Air Resources Board, Sacramento, California, April 13 2007.
Kromer, M., Heywood, J., 2007. Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet. LFEE 2007-03 RP. Sloan Automotive Laboratory, Massachusetts Institute of Technology, Cambridge, MA.
Kurani, K., Heffner, R. Turrentine, T., 2007. Driving plug-in hybrid electric vehicles: Reports from U.S. drivers of HEVs converted to PHEVs, circa 2006-07, 23rd International Electric Vehicle Symposium and Exposition (EVS-23), Anaheim, California, December 2-5, 2007.
Kurani, K., Turrentine, T., Sperling, D., 1994. Demand for electric vehicles in hybrid households: an exploratory analysis, Transport Policy, 1(4), 244-256.
Kurani, K., Turrentine, T., Sperling, D., 1996. Testing electric vehicle demand in 'hybrid households' using a reflexive survey, Transportation Research Part D 1(2), 131-150.
Kurani, K., Turrentine, T., Wright, J. 1997. Where, when, how fast and how much? Questions about consumer demand for home, away from home, time of day, and speed of recharging for electric vehicles, 14th International Electric Vehicle Symposium and Exposition (EVS-14), Palm Beach, Florida, October, 1997.
Lemoine, D., Kammen, D., Farrell, A., 2008. An innovation and policy agenda for commercially competitive plug-in hybrid electric vehicles, Environmental Research Letters 3, 1-10
Markel, T., 2006. Plug-in hybrid-electric vehicles: Current status, long-term prospects and key challenges, University of Colorado Sustainable Energy Course Lecture, November 16th, 2006.
Nesbitt, K., Kurani, K., DeLuchi, M., 1992. Home recharging and the household electric vehicle market: A constraints analysis, Transportation Research Record 1366, 11–19.
Pesaran, A., Market, T., Tataria, H., Howell, D., 2007. Battery requirements for plug-in hybrid electric vehicles: Analysis and rationale, 23rd International Electric Vehicle Symposium and Exposition (EVS-23), Anaheim, California, December 2-5, 2007.
Potoglou, D., Kanaroglou, P., 2007. Household demand and willingness to pay for clean vehicles, Transportation Research Part D 12, 264-274.
Rhodes, S., Bowie, D., Hergenrather, K., 2003. Collecting behavioural data using the world wide web: Considerations for researchers, Journal of Epidemiology and Community Health 57, 68-73.
Samaras, C.,Meisterling, K., 2008. Life cycle assessment of greenhouse gas emissions from plug-in hybrid vehicles: Implications for policy, Environmental Science and Technology, 42(9), 3170-3176.

Vyas, A., Santini, D., Duoba, M., Alexander, M., 2007. Plug-in hybrid electric vehicles: How does one determine their potential for reducing U.S. oil dependence?, 23rd International Electric Vehicle Symposium and Exposition (EVS-23), Anaheim, California, December 2-5, 2007.

Williams, B., Kurani, K., 2006. Estimating the early household market for light-duty hydrogen-fuel-cell vehicles and other "Mobile Energy" innovations in California: A constraints analysis, Journal of Power Sources 160, 446-453.

Winkel, R. *et al*, 2006. Global prospects of plug-in hybrids, 22nd International Battery, Hybrid, and Fuel Cell Electric Vehicle Symposium and Exhibition (EVS-22), Yokohama, Japan, October 23-28.

Appendix A: Vehicle Diary Example

Trip #:	Location:	Vehicle Status:	How Many Hours Parked Here?		Details
Starting Point	Home	Parked	11 hours		1. Electrical Outlet Within Sight (50 ft)? (Circle one) (Yes) / No 2. If Yes, Distance (Feet): 45 feet 3. Starting Odometer: 6,127
Trip #:	**Destination/ Location:**	**Vehicle Status:**	**Start Time:**	**End Time:**	**Details**
Trip #1	Work	Driving	8:05am	8:50am	1. Ending Odometer: 6,148 2. Total Distance (Miles): 21 3. Highway Distance (Miles): 18
		Parked	8:50am	5:10pm	1. Electrical Outlet Within Sight (50 ft)? (Circle one) Yes / (No) 2. If Yes, Distance (Feet): ______
Trip #2	Grocery Store	Driving	5:10pm	6:00pm	1. Ending Odometer: 6,167 2. Total Distance (Miles): 19 3. Highway Distance (Miles): 18
		Parked	6:00pm	6:25pm	1. Electrical Outlet Within Sight (50 ft)? (Circle one) Yes / (No) 2. If Yes, Distance (Feet): ______
Trip #3	Home	Driving	6:25pm	6:30pm	1. Ending Odometer: 6,169 2. Total Distance (Miles): 2 3. Highway Distance (Miles): 0
		Parked	6:30pm	8:00am	1. Electrical Outlet Within Sight (50 ft)? (Circle one) (Yes) / No 2. If Yes, Distance (Feet): 10 feet

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1) The last "Trip #" is equal to the total number of trips (e.g. 3).

2) Each Trip includes a 'Driving' and 'Parked' entry.

3) The 'End Time' for each entry is the 'Start Time' of the next entry.

4) The 'End Time' of the last trip is about 24-hours after the 'Start Time' of the first trip.

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Appendix B: Plug-in Vehicle Guide

Your *Plug-In Vehicle Guide*

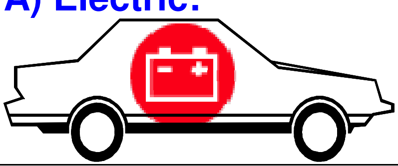
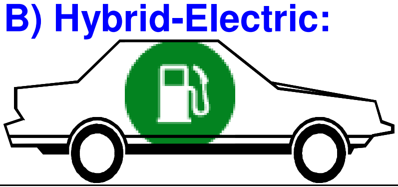
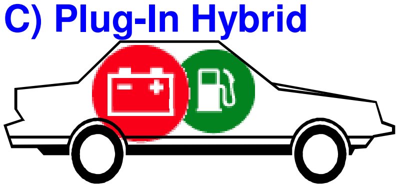
Your Plug-In Hybrid Guide:

Why read this guide?

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

This Guide Focuses on Plug in Hybrid Vehicles ONLY

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

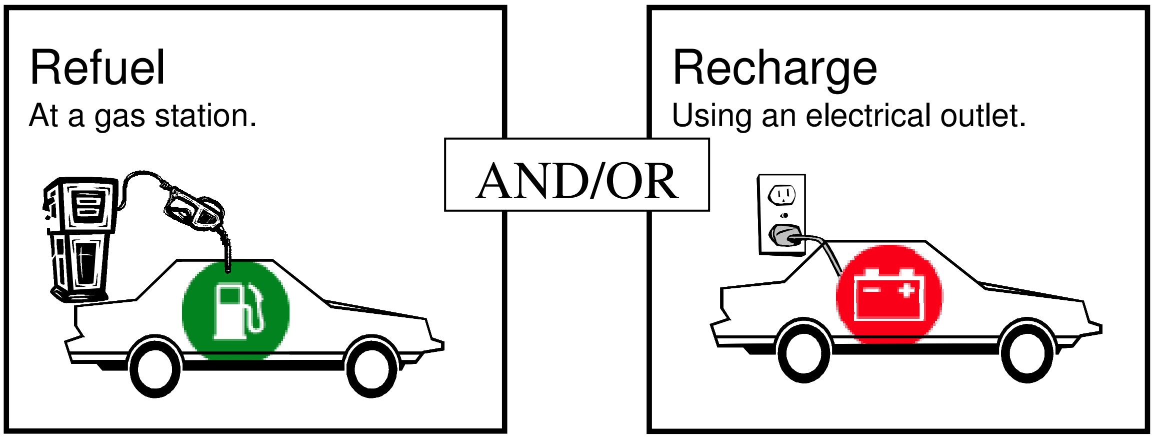
Vehicle Type	Description
A) Electric: 	An electric vehicle is fueled by **electricity only**. It is charged by plugging in to an electric outlet. The electricity is stored in the vehicle until it is used to power the vehicle. This technology is not currently produced by any major car companies, but a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

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

Lesson 1: Refueling and Recharging

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

Refueling and recharging your vehicle is simple:



Gasoline: Refueling

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

Electricity: Recharging

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

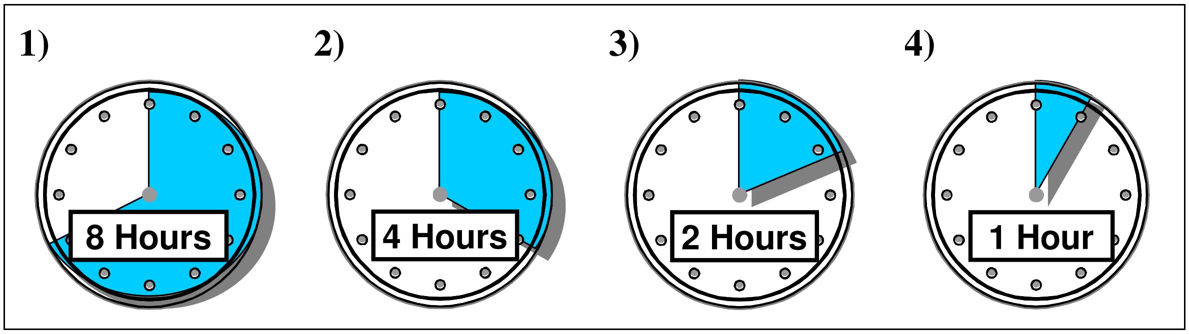
Why plug-in when I could just use gasoline?

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

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

How long does it take to recharge?

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



Can I interrupt the recharging process?

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

EXAMPLES: Recharge Upgrades

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

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

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

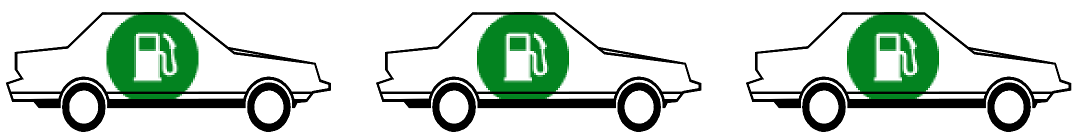
Lesson 2: Gasoline Mode (Driving Without Electricity)

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

'Gasoline' Mode: Efficiency Upgrade

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

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



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

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

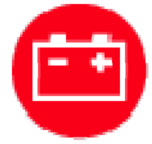
EXAMPLES: Upgrading Gasoline Mode

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

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

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

Lesson 3: Electric Mode (Driving With Electricity)



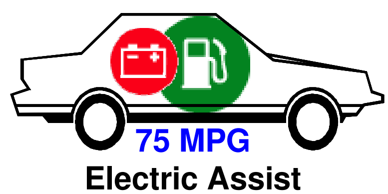
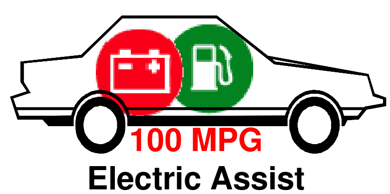
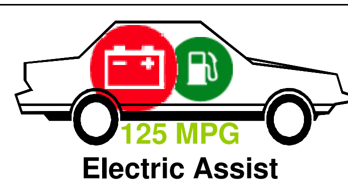
If you recharge your plug-in vehicle, you can drive for some distance using electricity. Depending on your chosen design, electricity would either *reduce* gasoline use (Electric Assist) or *replace* gasoline use (All Electric) for this limited distance.

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

Electric Assist: Reducing Gasoline Use

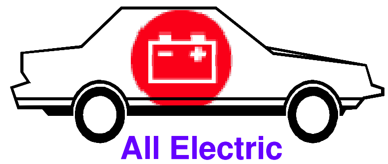
When recharged, a vehicle that is 'Electric Assist' capable will use both electricity and gasoline at the same time. The electricity *helps* the gasoline engine, offsetting the gasoline required to drive. For instance, an average car can travel 27 miles with a gallon of gasoline (27 MPG). However, a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

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

Type #1: Electric Assist (75 MPG) Where electricity *helps* the gasoline engine, improving your gas mileage to **75** miles per gallon (MPG). *Some* gasoline is always required to drive.	
Type #2: Electric Assist (100 MPG) Same as above, but improving your gas mileage to **100** miles per gallon (MPG). *Some* gasoline is always required to drive	
Type #3: Electric Assist (125 MPG) Same as above, but improving your gas mileage to **125** miles per gallon (MPG). *Some* gasoline is always required to drive	

All Electric: Temporarily Replacing Gasoline Use

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

Type #4: All Electric Where electricity is temporarily used *instead* of gasoline. As long as the vehicle is charged up, no gasoline is required to drive.	

How long does the Electric Charge last?

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

When Fully Charged
Drive in 'Electric Assist' or 'All Electric' Mode:

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

EXAMPLES: Upgrading Electric Mode and Electric Distance

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

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

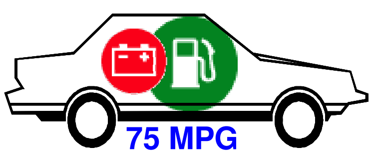
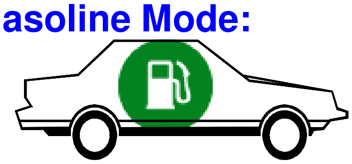
Sarah does not care if she uses gasoline or electricity; she just wants to save money. She chose the 'Electric Assist' capability, as she doesn't think 'All-Electric' mode is worth the extra cost. She chose **'Type #2: Electric Assist (100 MPG)'** so she can drive at a rate of 100 miles per gallon of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

Lesson 4: Upgrading Your Plug-In Vehicle

Minimum Upgrade Package

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

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

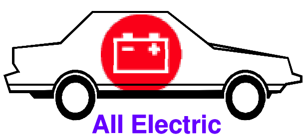
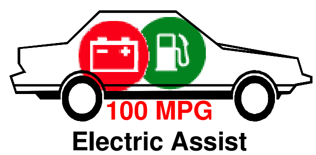
Your Plug-In Hybrid Vehicle	Upgrades
Recharge Time: 	**Time to Fully Recharge:** ● 8 Hours ○ 4 Hours ○ 2 Hours ○ 1 Hour
Electric Mode:  75 MPG Electric Assist **For the First 10 Miles**	**Electric Capability:** ● Type #1: Electric Assist (75 MPG) ○ Type #2: Electric Assist (100 MPG) ○ Type #3: Electric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

EXAMPLES:

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

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

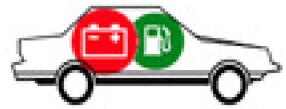
Sarah chose a plug-in vehicle that takes only 1 hour to recharge. The fully charged vehicle can drive with Electric Assist (Type #2) for 40 miles, using electricity to boost fuel economy up to 100 miles per gallon. After 40 miles, the vehicle switches to gasoline only, where her vehicle can travel an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

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

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

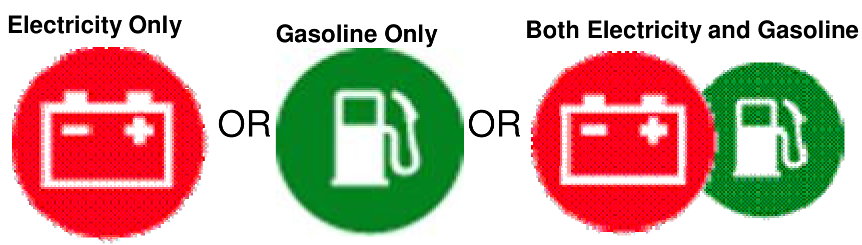
Appendix C: PHEV Design Games

Section 3: Designing Your Plug-In Vehicle



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

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



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

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

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

Next

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

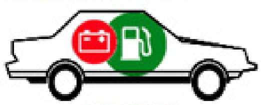
Each upgrade requires a certain number of �points�. We want to know what upgrades you consider to be most important. You will be shown 5 scenarios. Each scenario will give you a different number of �points� to make upgrades. Each scenario is independent, so you can choose different upgrades each time.

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

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

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

Your choice is visually represented in the left column.

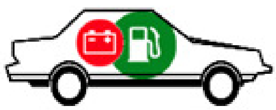
Your Plug-In Hybrid MINI COOPER	Upgrades	Upgrades Points
Recharge Time:  8 Hours required to fully recharge vehicle.	**Time to Fully Recharge:** ◉ 8 Hours ○ 4 Hours (1 pt)	**Total Points: 1 pts** **Points Used: 0 pts** **Points Left: 1 pts**
↓		
Electric Mode:  75 MPG Electric Assist For the First 10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

Description of Your Choice:

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

This is My Choice

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

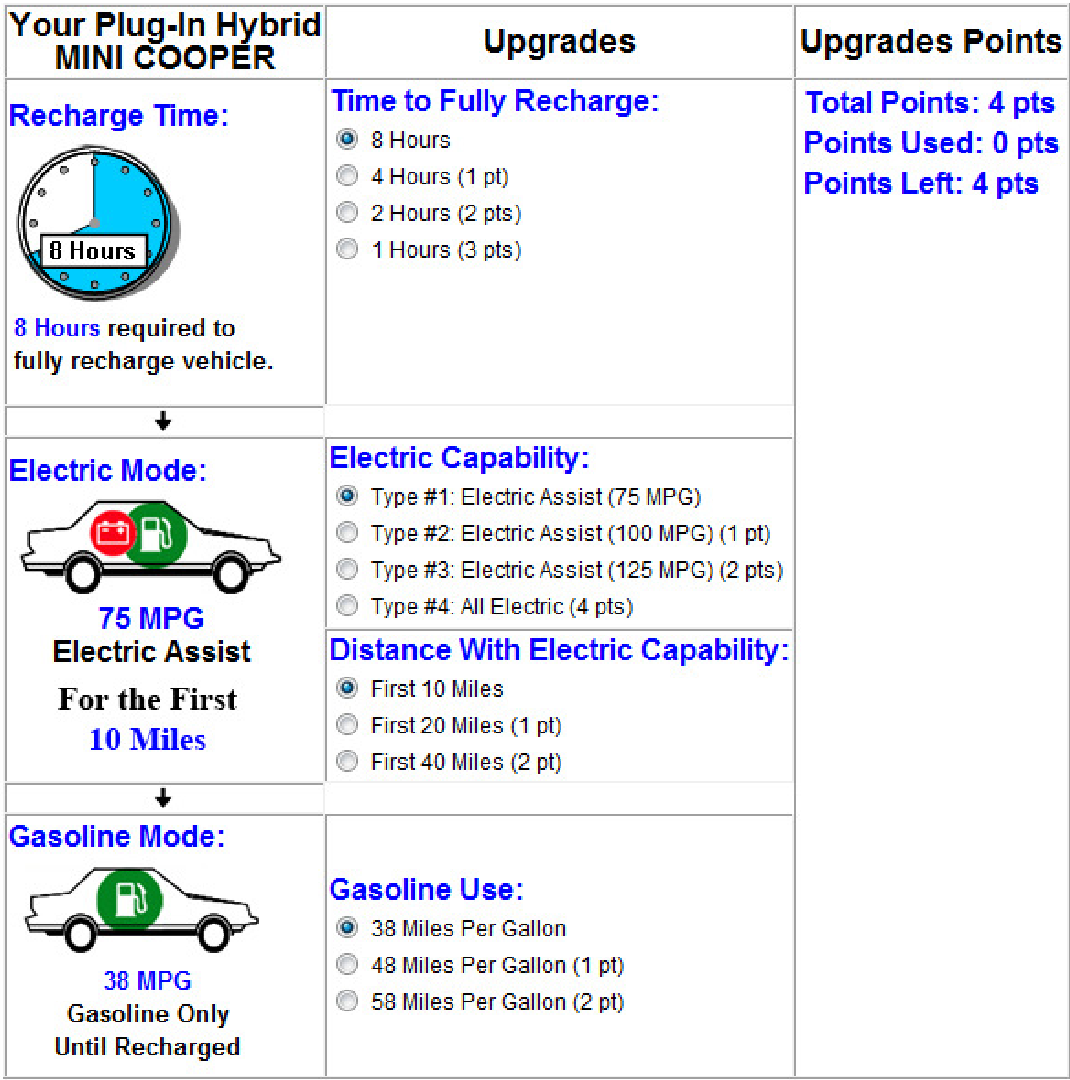
Your Plug-In Hybrid MINI COOPER	Upgrades	Upgrades Points
Recharge Time:  8 Hours required to fully recharge vehicle.	**Time to Fully Recharge:** (•) 8 Hours ( ) 4 Hours (1 pt) ( ) 2 Hours (2 pts)	**Total Points: 2 pts** **Points Used: 0 pts** **Points Left: 2 pts**
↓		
Electric Mode:  75 MPG Electric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

Description of Your Choice:

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

[This is My Choice]

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

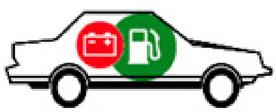
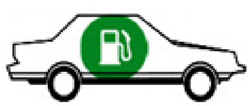


Description of Your Choice:

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

This is My Choice

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

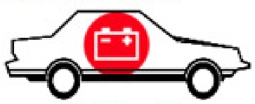
Your Plug-In Hybrid MINI COOPER	Upgrades	Upgrades Points
Recharge Time:  8 Hours required to fully recharge vehicle.	**Time to Fully Recharge:** ◉ 8 Hours ○ 4 Hours (1 pt) ○ 2 Hours (2 pts) ○ 1 Hours (3 pts)	**Total Points: 6 pts** **Points Used: 0 pts** **Points Left: 6 pts**
↓		
Electric Mode:  75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

Description of Your Choice:

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

This is My Choice

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

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

Description of Your Choice:

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

This is My Choice

Section 4: Next Vehicle Purchase

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

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

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

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

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

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

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

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

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

Next

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

- I choose **MINI COOPER**
- (selected) I would like to select another vehicle. Please specify Make and Model:

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

Make: Make

Model: Model

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

Next

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

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

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

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

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

Next

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

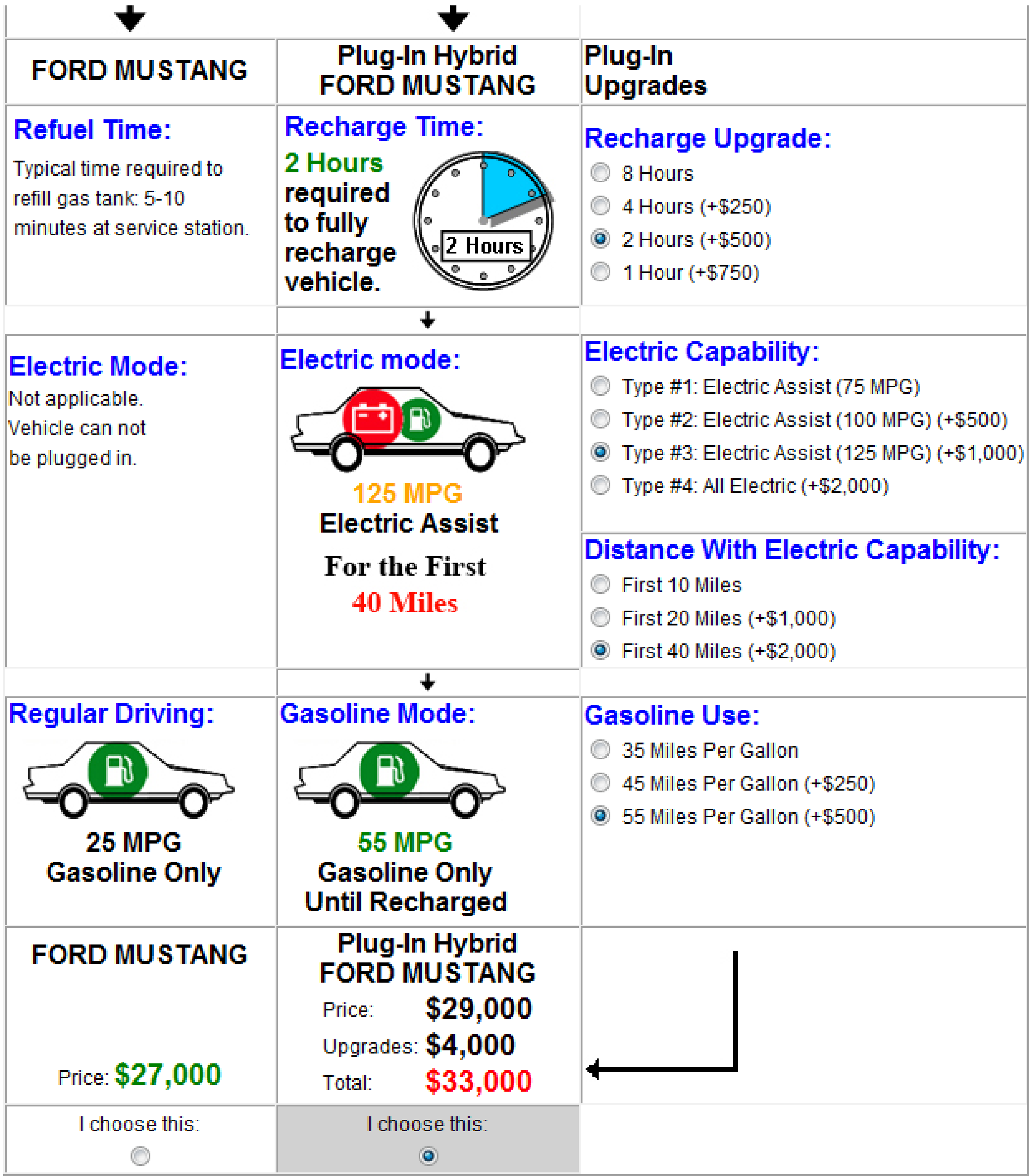
You can customize the specific features of the plug-in version, just as you did in the previous exercise. Again, refer to ***Your Plug-In Vehicle Guide*** for help in choosing upgrades, particularly the summary on **pages 7 to 8**.

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

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

Please be realistic, and consider your expected household budget constraints

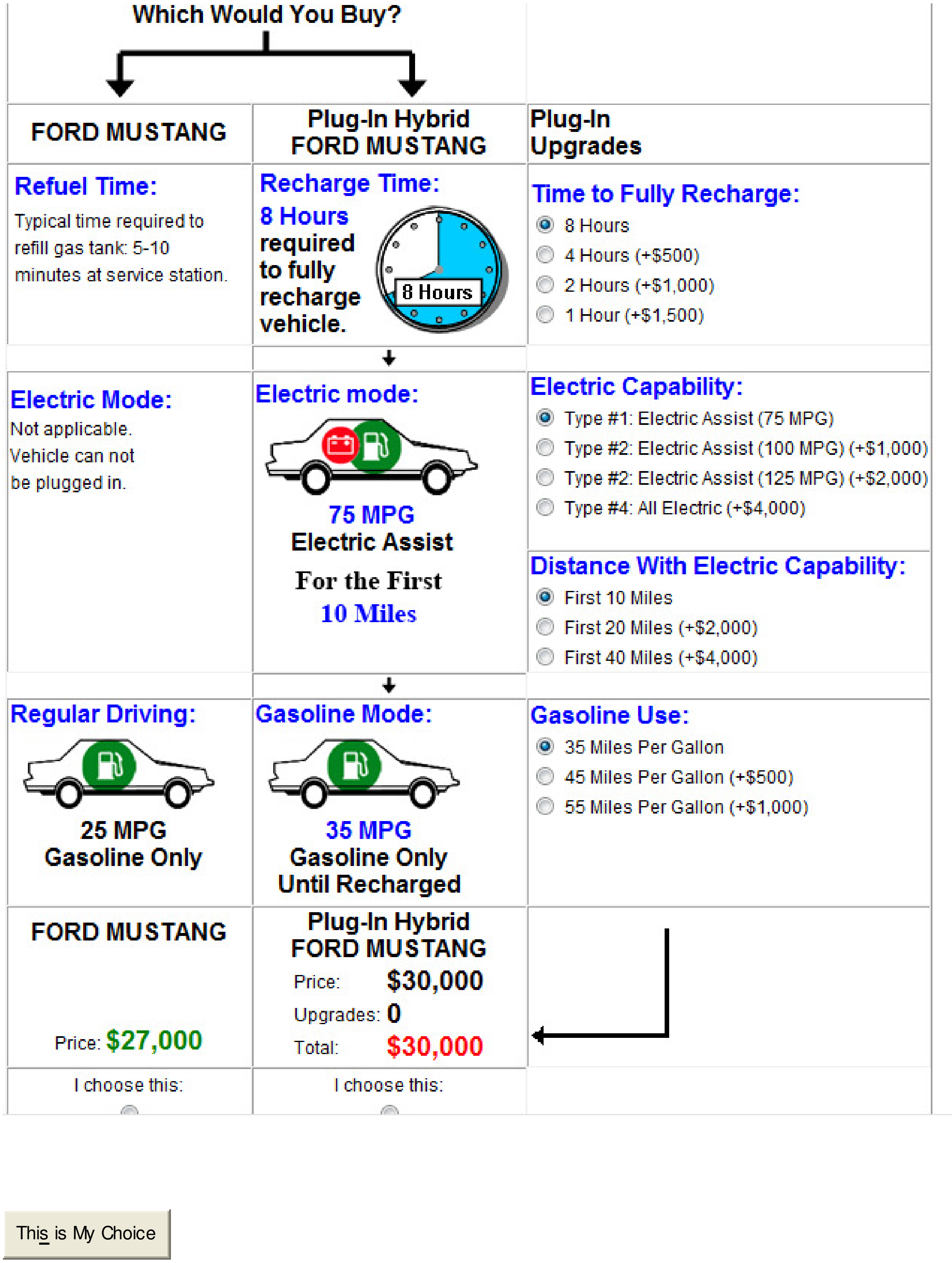
Price Scenario #1 (Low Cost Scenario – Order Randomized)



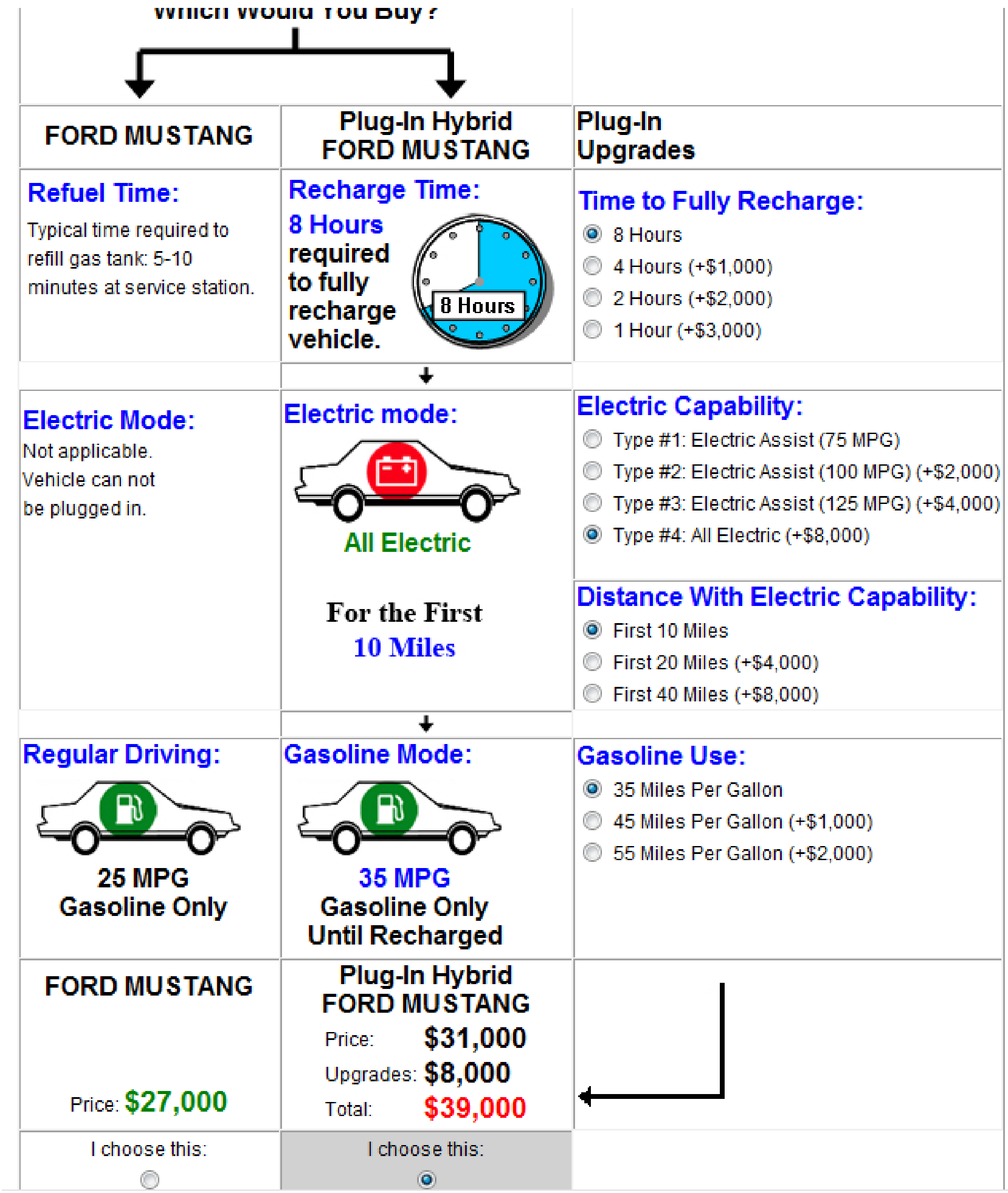
FORD MUSTANG	Plug-In Hybrid FORD MUSTANG	Plug-In Upgrades
Refuel Time: Typical time required to refill gas tank: 5-10 minutes at service station.	**Recharge Time:** 2 Hours required to fully recharge vehicle. (2 Hours)	**Recharge Upgrade:** ○ 8 Hours ○ 4 Hours (+$250) ◉ 2 Hours (+$500) ○ 1 Hour (+$750)
Electric Mode: Not applicable. Vehicle can not be plugged in.	**Electric mode:** 125 MPG Electric Assist For the First 40 Miles	**Electric Capability:** ○ Type #1: Electric Assist (75 MPG) ○ Type #2: Electric Assist (100 MPG) (+$500) ◉ Type #3: Electric Assist (125 MPG) (+$1,000) ○ Type #4: All Electric (+$2,000) **Distance With Electric Capability:** ○ First 10 Miles ○ First 20 Miles (+$1,000) ◉ First 40 Miles (+$2,000)
Regular Driving: 25 MPG Gasoline Only	**Gasoline Mode:** 55 MPG Gasoline Only Until Recharged	**Gasoline Use:** ○ 35 Miles Per Gallon ○ 45 Miles Per Gallon (+$250) ◉ 55 Miles Per Gallon (+$500)
FORD MUSTANG Price: $27,000	Plug-In Hybrid FORD MUSTANG Price: $29,000 Upgrades: $4,000 Total: $33,000	
I choose this: ○	I choose this: ◉	

This is My Choice

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



Price Scenario #3 (High Cost Scenario – Order Randomized)



This is My Choice