What consumers teach us about PHEVs, electric-drive and fuel economy

Ken Kurani, Jonn Axsen
Tom Turrentine, Andy Burke

Prepared for: University of Michigan
Developing New Powertrain Technologies for Drivers: What Are They Willing To Buy and How Do We Know?
Monday, November 10, 2008
Consumer Behavior Studies

- 1980s: Diesel LDVs, CNG
- 1990s: EV, PHEV, AFV
- 2000 to 2006: HEV, FCV
- 2007 to present: PHEV
  - First Stage was a study of PHEV “pioneers”: interviews of early converters and drivers
  - Second stage was a national internet-based survey of new car-buyers’ knowledge and priorities regarding PHEVs
  - Third stage is placing 12 converted PHEVs in ~75 households in northern California
    - 4 weeks each
    - GPS data on driving, fueling, and recharging
    - Household interviews and questionnaires
  - Fourth stage will add improved energy feedback displays of cost, integrated feedback on electricity and gasoline use, emissions etc.
  - Fifth, another large sample survey built on prior stages
PHEV vocabulary

Charge-deplete: All Electric or Blended

Charge Sustain: Gasoline Only

Distance
Conversations with PHEV Pioneers

Excited by two ideas

1. Where’s my EV?
   - PHEVs are a means to get (back) to EVs.
     • More all-electric range and higher all-electric speed

2. “100 miles per gallon!”
   “Double your MPG!”
   - Fuel economy discussed without accounting for electricity use and only considering MPG during electric assist (CD-operation)
Electric-drive (PHEV) Survey

Research Questions: From the perspective of a “new now”…

1. How many households could plug-in regularly?
   A. Where and when?

2. What kind of PHEV would they design?
   A. All-electric or high MPG?
Electric-drive (PHEV) Survey

• Samples of US households who buy new vehicles
  – United States: \( n_1 \approx 4,242; \) \( n_3 \approx 2,664 \)
  – California: \( n_1 \approx 1,738; \) \( n_3 \approx 985 \)
  – northern CA: \( n_1 \approx 464; \) \( n_3 \approx 247 \)

• On-line and Paper Questionnaires
  – Survey designed and conducted by ITS-Davis
  – Harris Interactive, Inc. sub-contracted to provide samples
  – First three weeks of December 2007
Questionnaire Design

Part 1: Baseline Information
  – Vehicle ownership, fuel and electricity use, technology knowledge, environmental beliefs, household composition, etc.
  – ~30 minutes online

Part 2: PHEV tutorial and 24-Hour vehicle diary
  – One day

Part 3: Diary data review and PHEV Design exercises
  – ~30 minutes online
PHEV demand survey
Recharging
Paper Diary to Interactive Data Display

<table>
<thead>
<tr>
<th>Trip #:</th>
<th>Location:</th>
<th>Vehicle Status:</th>
<th>How Many Hours Parked Here?</th>
<th>Details</th>
</tr>
</thead>
</table>
| 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 |

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
Potential to Recharge: Location

Higher Home Potential Segment:

*Home recharge outlet within 25 feet of vehicle (~52% of Respondents)*

(All respondents, n = 2,373)
What PHEVs do new car buyers design in our “new now”?
Whose Designs do We Consider?

- Selected *Early Market* Respondents
  - 52% *Higher Home Recharge Potential* segment
  - Of these, 64% chose the proffered PHEV or designed a more capable (and expensive) PHEV in “high” price design game
  - These 827 respondents (34% of total sample) are our *Early Market*
PHEV Design Games

- Tutorial: “Plug-in Buyers’ Guide”
- Two Design Games
  - Common design space:
    - Recharging rate; CD mode; CD fuel economy; CD range; CS fuel economy
  1. Development Priority: What is interesting and valuable to you about PHEVs?
    - Free PHEV upgrade to current reference vehicle
    - Respondent must assign points to improve base PHEV offering
  2. Purchase Design: How do you value PHEVs and their potential performance relative to conventional vehicles?
    - Next new vehicle purchase
    - Solicit plausible make, model, and price
      - Offer this vehicle, a base PHEV version of this car, and the option to upgrade PHEV performance
      - “High” and “Low” price scenarios
    - Respondent did not have to choose PHEV or any upgrades
PHEV Design Space

Distance

CD Type:
- 75 MPG
- 100 MPG
- 125 MPG
- All Electric

CS MPG:
- +10 MPG
- +20 MPG
- +30 MPG

CD Range:
- 10 miles
- 20 miles
- 40 miles

Recharge:
- 8 hours
- 4 hours
- 2 hours
- 1 hour

Figure adapted from Kromer and Heywood (2007)
Design Game 1: Development Priority

CD Type:
- 75 MPG
- 100 MPG (1pt)
- 125 MPG (2pt)
- All Electric (4pt)

CS MPG:
- +10 MPG
- +20 MPG (1pt)
- +30 MPG (2pt)

CD Range:
- 10 miles
- 20 miles (1pt)
- 40 miles (2pt)

Recharge:
- 8 hours
- 4 hours (1pt)
- 2 hours (2pt)
- 1 hour (3pt)

Development Priority
- Round One: 1 pt
- Round Two: 2 pts
- Round Three: 4 pts
- Round Four: 6 pts
- Round Five: 8 pts

Figure adapted from Kromer and Heywood (2007)
Round One: 1 pt

- 4 hours (1pt)
- 100 MPG (1pt)
- 20 miles (1pt)
- +20 mpg (1pt)

FOR THE FIRST 10 MILES

Your Car +10 mpg
Round Three: 4 pts

No Gas
All Electric
3.4%

1 Hour (3pt)
125 MPG (2pt)
40 miles (2pt)
+30 mpg (2pt)

2 hours (2pt)
100 MPG (1pt)
20 miles (1pt)
+20 mpg (1pt)

4 hours (1pt)
100 MPG (1pt)
20 miles (1pt)
+20 mpg (1pt)

Base Model=
8 Hours
75 MPG
Electric Assist

FOR THE FIRST 10 MILES

Your Car
+10 mpg
Round Four: 6 pts

- **No Gas All Electric**: 12.3%
- **1 Hour (3pt)**: 125 MPG (2pt), 40 miles (2pt), +30 mpg (2pt)
- **2 hours (2pt)**: 100 MPG (1pt), 20 miles (1pt), +20 mpg (1pt)
- **4 hours (1pt)**: 75 MPG (1pt), 10 miles (1pt), +10 mpg

**Base Model=**
- **8 Hours**: 75 MPG Electric Assist
- **FOR THE FIRST 10 MILES**: +10 mpg
Round Four: 6 pts

PHEV Type
(Recharge_CD Type_CD Range_CS MPG)

8 Hours Electric Only_40 Miles_+10 MPG
2 Hours Electric Only_10 Miles_+10 MPG
4 Hours Electric Only_10 Miles_+20 MPG
4 Hours Electric Only_20 Miles_+10 MPG
8 Hours Electric Only_10 Miles_+30 MPG
8 Hours Electric Only_20 Miles_+20 MPG

1 Hours 125 MPG_10 Miles_+20 MPG
1 Hours 125 MPG_20 Miles_+10 MPG
2 Hours 125 MPG_10 Miles_+30 MPG
2 Hours 125 MPG_20 Miles_+20 MPG
2 Hours 125 MPG_40 Miles_+10 MPG
4 Hours 125 MPG_20 Miles_+30 MPG
4 Hours 125 MPG_40 Miles_+20 MPG
8 Hours 125 MPG_40 Miles_+30 MPG

1 Hours 100 MPG_10 Miles_+30 MPG
1 Hours 100 MPG_20 Miles_+20 MPG
1 Hours 100 MPG_40 Miles_+10 MPG
2 Hours 100 MPG_20 Miles_+30 MPG
2 Hours 100 MPG_40 Miles_+20 MPG
4 Hours 100 MPG_40 Miles_+30 MPG
1 Hours 75 MPG_20 Miles_+30 MPG
1 Hours 75 MPG_40 Miles_+20 MPG
2 Hours 75 MPG_40 Miles_+30 MPG

“Volt” ≈ 5% (40 miles AER)
≈ 12%
≈ 62%, 125 CD MPG
≈ 17%, 100 CD MPG
≈ 8%, 75 CD MPG

(Primary Market, High Price Buyers, n = 801)
Design Game 2: Purchase Design

- **CD Type:**
  - 75 MPG
  - 100 MPG (+$1000)
  - 125 MPG (+$2000)
  - All Electric (+$4000)

- **CS MPG:**
  - +10 MPG (+$500)
  - +20 MPG (+$1000)
  - +30 MPG (+$1000)

- **CD Range:**
  - 10 miles
  - 20 miles (+$2000)
  - 40 miles (+$4000)

- **Recharge:**
  - 8 hours
  - 4 hours (+$500)
  - 2 hours (+$1000)
  - 1 hour (+$1500)

**Purchase Design:**
High Price Scenario, base PHEV (car): $3,000
High Price Scenario

<table>
<thead>
<tr>
<th>Recharge</th>
<th>CD MPG</th>
<th>CD Range</th>
<th>CS MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Hour</td>
<td>125 MPG</td>
<td>40 miles</td>
<td>+30 mpg</td>
</tr>
<tr>
<td>2 hours</td>
<td>100 MPG</td>
<td>20 miles</td>
<td>+20 mpg</td>
</tr>
<tr>
<td>4 hours</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Base Model=

- 8 Hours
- 75 MPG Electric Assist
- 36% stayed with base
- FOR THE FIRST 10 MILES
- Your Car +10 mpg
PHEV Designs in CD-space

- All-electric
- 125 mpg
- 100 mpg
- 75 mpg

CD Range, miles:
- 10 miles
- 20 miles
- 40 miles
Powertrain design:
Using batteries as a surrogate for the rest of the powertrain and consumers’ PHEV designs
## PHEV Vehicle “goals”

<table>
<thead>
<tr>
<th>Performance goals</th>
<th>Design space</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Units</strong></td>
<td><strong>USABC</strong></td>
</tr>
<tr>
<td>Body type</td>
<td>type</td>
</tr>
<tr>
<td>CD range</td>
<td>miles</td>
</tr>
<tr>
<td>CD operation</td>
<td>type</td>
</tr>
<tr>
<td>Electricity use</td>
<td>kWh/mile</td>
</tr>
<tr>
<td>Depth of discharge</td>
<td>percent</td>
</tr>
<tr>
<td>Drive schedule</td>
<td>type</td>
</tr>
<tr>
<td>Battery mass</td>
<td>kg</td>
</tr>
<tr>
<td>Vehicle mass</td>
<td>kg</td>
</tr>
</tbody>
</table>
Energy Density, Wh/kg

UCD Cars
EPRI AE20 (car)
USABC AE10 (car)
USABC AE40 (truck)
MIT B30 (car)

Battery Size, ≤ 2KwH

Consumer and expert cell requirements

UCD Trucks
EPRI AE60 (car)

Li-Ion
To Conclude…
How many US new car buyers can recharge a vehicle? Where? When?

53 percent; at home; at night

• Recharge potential:
  • We select these 53% as higher home recharge potential segment
    • Park vehicle at home within 25 feet of an outlet
      • 36-61% depending on outlet distance
        » Detached houses and garages helpful, but neither necessary nor sufficient
  • Respondents presently see little potential for work and “opportunity” recharging
  • Weekday home recharging:
    • Highest potential (~50%) at night (9pm-6am)
    • Lowest potential (<20%) midday (10am-4pm)
  • Less potential for weekend home recharging
    • Highest potential (~40%) at night (9pm-6am)
What is exciting to households about PHEVs?

MPG, within *Early Market* respondents (~34% of total)

1. Most frequent upgrades: CS fuel economy
   - Little inherent interest in All-Electric operation
     - ~12% designed a PHEV with AER in Round 4 of the development priority game
     - ~1 to 6% design a PHEV with AER in design purchase game
   - In design purchase game, many (27 to 36%) stayed with proffered base PHEV model
     - 8 hours; 75mpg (blended) for 10 miles; +10mpg
   - About one-third design higher-capability PHEVs
     - Most respondents’ PHEV designs are radically different than assumed by experts
What is exciting to households about PHEVs?

2. Don’t take any individual design too seriously; but the overall direction is unassailable
   • All-electric driving may not be a bad idea; it may be a good idea most consumers don’t yet value (or understand)
   • Different messages may create different market outcomes about the same technology: All-electric, or Zero-gasoline?

3. Overall, wide variety of PHEV designs across respondents.
   • Distribution of PHEV designs to be compared to those of households in our ongoing PHEV demonstration.
To start a market for PHEVs…

…and to design policies to start a market for PHEVs…

• …the problem is not just that batteries don’t meet USABC and others goals.

• The problem is also a lack of attention to consumers.
  – We don’t need just an All-electric, long CD-range PHEV end design.
  – We need a trajectory, and designs from which to start.
  – Those starting designs would appear to be PHEVs operating in blended-mode, providing a large increase in MPG over “short” CD-range, and providing a more modest increase in fuel economy during CS operation.
Potential to Recharge: Timing

(Weekdays, n = 1,650)
Potential to Recharge: Timing

≤25 feet to Outlet

Driving

Home
Work
Other
Drive

(Weekends, n = 493)