Advanced Plug-in Electric Vehicle Travel and Charging Behavior Final Report
(CARB Contract 12-319 – Funding from CARB and CEC)

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Outline

• Background and Motivations
• Research Methods and Design
• VMT: PEV usage
• Charging Behavior and Performance
• PHEV Performance and Utility Factors
• Household Level Analysis
• Drivers Interviews
• PHEVs Engine Starts
• Conclusions
Background and Motivations

• The purpose of this project is to:
  • Understand the emissions potential of plug-in electric vehicles (PEVs) under real world conditions
  • Highlight benefits and challenges
  • Present needs for improving and regulating future electric vehicles.

• The project provides a platform to monitor how new PEVs are being used on a day-to-day and month-to-month basis within the household travel context, by placing data monitoring devices (loggers) in all vehicles of the participant households for a period of one year.
Additional Research Analysis

The project included very limited resources for analysis of the data collected and final results—for example for causality analysis to address the impact of charging infrastructure, vehicle size, and other factors that are not included in this report.

Published:

Publications under review:
## Main Project Components

<table>
<thead>
<tr>
<th>Recruitment Survey</th>
<th>Vehicle Data Logging</th>
<th>Data Analysis</th>
</tr>
</thead>
</table>
| **Detailed survey:** including purchase, travel, and charging behavior and sociodemographics | **264 households, 4 waves**  
High-resolution data: on-board data collection  
**PEV parameters:** battery SOC/tank level, speed, RPM, GPS, charging level and kWh, etc.  
**ICE parameters:** speed, RPM, GPS, fuel economy variables, refueling, etc. | **Data Cleaning**  
**Basic Data Analysis** |
| **2015-2017 samples**  
~11,000 completed surveys |                       |              |
| **Invited random PEV owners:** CVRP recipients and DMV registered |                       |              |

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Study Evolved to Match Changing Vehicle Technology

<table>
<thead>
<tr>
<th>Year</th>
<th>First-Generation and Short-Range</th>
<th>Second-Generation, Longer-Range, and Fuel Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>Plug in Prius (11), Fusion/C-Max Energi (20), Volt (36), Leaf (80)</td>
<td>Volt (53), Leaf (105), Tesla (200+), i3 REx (73), Prius Prime (22), Pacifica Hybrid (33), Bolt (236), Mirai (300+)</td>
</tr>
</tbody>
</table>
Recruitment Surveys

• 2015, 2016, 2017 N=~70,000
  • New PEV Owners CVRP
  • USED PEVs based on DMV address
  • NEW FCVs

• Finished surveys N=~14,000

• Finished with valid email for recruitment 7,800

Survey size varies by question based on analysis needs including vehicle type and unanswered questions

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Vehicle Logging

Loggers issues and limitations:
• Vehicle must be model year 1996 or newer
• Inconsistent data
• Port location is not conducive to holding a logger
• Logger unable to get signal where the port is located

Households Issues and limitations
• 60% of households required contact before the end of the study (changes in home, work, people, or vehicles)

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## Challenges with Logger Raw Data

<table>
<thead>
<tr>
<th>Data</th>
<th>Missing/Changed</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Timestamps</strong>: Some are absolute while others are relative.</td>
<td><strong>Changed Files</strong>: Some files are updated to report previously missing data.</td>
<td><strong>GPS Data</strong>: Acquisition of GPS signal takes time so GPS data values are zeroed out in the beginning of files.</td>
</tr>
<tr>
<td><strong>Column Names</strong>: Different across deployments.</td>
<td><strong>Missing Files</strong>: Some files that have been processed and added to the time series database were removed by FleetCarma.</td>
<td><strong>Other</strong>: Critical Data such as vehicle speed and fuel level are not reported for many vehicles.</td>
</tr>
<tr>
<td><strong>Null Values</strong>: Reported as extremely large or small numbers.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Logged Households are Representative of Surveyed Households

Source = Recruitment Survey
VMT
BEVs PHEVs and ICEs usage
Annual VMT of PEVs in Our Data is Higher than Other Samples

Using the study vehicles and the NHTS 2017 California Add-On Data (N=10,447 including: 9,391 gasoline and diesel vehicles, 207 BEVs, 196 PHEVs, and 653 conventional hybrids)

Source = Logger Data, Recruitment Survey, External Data
Average Daily VMT: All BEVs Have Users with Short Daily Drive but More Longer Range BEVs Have High Daily Miles

Source = Logger Data

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Daily VMT is Similar for All BEVs up to 60% of Travel Days

<table>
<thead>
<tr>
<th>Model</th>
<th>Distance Bins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf-24</td>
<td></td>
</tr>
<tr>
<td>Leaf-30</td>
<td></td>
</tr>
<tr>
<td>RAV4-40</td>
<td></td>
</tr>
<tr>
<td>ModelS_60-80</td>
<td></td>
</tr>
<tr>
<td>ModelS_80-100</td>
<td></td>
</tr>
</tbody>
</table>

**Source:** Logger Data

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Charging

Exploring BEVs and PHEVs Charging behavior:
Survey and logger results

Gil Tal, UC Davis
Charging Location Mostly Home and Work

- Home (80%+)
- Work (30%-50%)
- Public DC Fast (5%-10%)
- Public L2 (2%-10%)

Source = Recruitment Survey
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Home and Home-Work are the Most Common Charging Options

Source = Recruitment Survey
Half of Drivers Who Are Not Using Home Charging Could

- No, we have no option to charge the car overnight
- No, but we can leave the car next to a public charger overnight
- Yes, but we will need to use an extension cord
- Yes, we can use a 120V regular plug
- Yes, we have a charger installed

Source = Recruitment Survey

Gil Tal, UC Davis
Most BEV Drivers Do Not Use DCFC Regularly

Source = Recruitment Survey
Gil Tal, UC Davis
Average kWh/Session is Similar For All L1 but Higher for Longer Range L2 and DCFC Events

Source = Logger Data

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No BEV Charged Every Day

Source = Logger Data
L2 Provides Most of the Energy for BEVs

<table>
<thead>
<tr>
<th>Model</th>
<th>% kWh L1 Sessions</th>
<th>% kWh L2 Sessions</th>
<th>% DCFC Sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf-24</td>
<td>6.17</td>
<td>63.90</td>
<td>29.93</td>
</tr>
<tr>
<td>Leaf-30</td>
<td>25.11</td>
<td>61.66</td>
<td>13.23</td>
</tr>
<tr>
<td>RAV4-40</td>
<td>0.26</td>
<td>99.64</td>
<td>0.10</td>
</tr>
<tr>
<td>ModelS_60-80</td>
<td>20.27</td>
<td>77.50</td>
<td>2.24</td>
</tr>
<tr>
<td>ModelS_80-100</td>
<td>1.51</td>
<td>83.03</td>
<td>15.45</td>
</tr>
</tbody>
</table>

Percentage of Total kWh by Charging Level

Source = Logger Data

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Share of Charging by Start Time: Commute Peak and Midnight Peak

Source = Logger Data
Charging Sessions More Than 1 Mile From Home: Most Public Charging Events are Within the Vehicle Range

Includes 13% of the L1 events, 29% of L2 events, and 97% of DCFC events

Source = Logger Data
DCFC Charging Also Happens near Home. Only 10% of the Tesla Charging Events are on the Road.

**BEV DCFC Charges away from Home**

- Leaf-24
- Leaf-30
- ModelS_60-80
- ModelS_80-100

**Distance from Home (miles)**

**Source = Logger Data**

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PHEVs Charging
L1 and L2 Events Provides Similar Energy for PHEVs

Source = Logger Data
L1 Is Very Dominant For Short Range PHEVs

<table>
<thead>
<tr>
<th>Source = Logger Data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percentage of Charging Sessions</strong></td>
</tr>
<tr>
<td><strong>PlugInPrius</strong></td>
</tr>
<tr>
<td>0.43</td>
</tr>
<tr>
<td><strong>CMaxFusion</strong></td>
</tr>
<tr>
<td>9.44</td>
</tr>
<tr>
<td><strong>Volt-16kWh</strong></td>
</tr>
<tr>
<td>11.97</td>
</tr>
<tr>
<td><strong>Volt-18kWh</strong></td>
</tr>
<tr>
<td>14.02</td>
</tr>
</tbody>
</table>
PHEV Performance

eVMT- electric vehicle miles travel
zVMT- miles in trips with no engine start/fuel consumption
Utility Factor – share of eVMT of all VMT
PHEV eVMT, gVMT, and VMT

eVMT: electric vehicle miles traveled

gVMT: gasoline vehicle miles traveled

Source = Logger Data
Short Range PHEVs Have Only Low UF And Long Range Have Only High UF

Source = Logger Data
Share of: ZE Days (No engine), CS Days (Mix of electric and Gas), and CDB/CS (Gas Only) Days

Long Range PHEVs can drive more than half the days as BEVs

Source = Logger Data
Average Utility Factor Of Short-range PHEVs Is Much Lower Than Expected (Including survey data on no charging)

Source = Logger Data and Recruitment Survey
Household level analysis

Utility Factor of the household – share of eVMT of all household vehicles / VMT

Introducing GHG in addition to VMT analysis
Household Level Sample

Households Logged by Type of Vehicles (Total HHs = 226)

- **ICE-PHEV**: 77
- **SingleBEV**: 51
- **BEV-PHEV**: 47
- **ICE-BEV**: 19
- **TwoICE-PHEV**: 12
- **BEV-PHEV-PHEV**: 11
- **ICE-BEV-PHEV**: 9
- **SinglePHEV**: 5
- **TwoICE-BEV**: 4

Source = Logger Data
Longer Range PHEV Households Have Higher UF than Shorter Range and Similar to BEV/ICE Households

Source = Logger Data
Utility Factor is Correlated with EV Range for Two-Car Households

Average Annualized HH VMT, eVMT, gVMT, PEV and HH UF

Source = Logger Data
BEV Households Have Lower Average GHG per Mile: But It’s Not Directly Correlated with Utility Factor

Source = Logger Data

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Interviews

22 interviews conducted with drivers of the PHEVs and BEVs in the first logged wave of this study
We make these overall observations from these interviews:

- Learning and not learning about PEVs
  - Early PEV drivers may still be learning about their PEVs, even months or years after they acquired one

- Conversely, early PEV drivers may still be operating with old ideas/information, that is, they are not learning, even months or years after they acquired a PEV

Source = Interviews
We make these overall observations from these interviews:

- Vehicle (and EVSE) purchase and use incentives shape outcomes
  - Vehicle purchase incentives are described as essential by some PEV owners;
  - Incentive for home chargers may produce home chargers, but their subsequent effect on eVMT is not straightforward

Source = Interviews
Engine Starts

Days without engine start
Cold and hot starts
High power cold start
Unlike ICEVs, PHEVs Can Finish Many Days Without Engine Start

Share of Drive Days with No Engine Starts

Percentage of Driving Days (%)

- **PlugInPrius**: 4%
- **CMaxFusion**: 21%
- **Volt-16 kWh**: 55%
- **Volt-18 kWh**: 63%
- **All PHEVs**: 38%

% ZE Only Days

Source = Logger Data
Catalyst Modeled Temperature At First (Blue) And Other (Red) Engine Start: Almost No Cold Second Start

Source = Logger Data

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Battery State of Charge at Engine Start

Source = Logger Data
Maximum Power Requirement 5 Seconds before Engine Start: Longer Range PHEVs

*E-empty SOC, M-medium SOC, H-high SOC*

Source = Logger Data
Conclusions
Selected Takeaway Points

• PHEVs with smaller capacity batteries would need to plug-in more than those with larger capacity batteries to maximize electrification of their driving but this is not what we observed. We find that charger availability and the range recovered per charging event are significant factors in the decision to plug-in.

• Blended PHEVs have a lower utility factor, limited both by the technology and the charging and driving behavior of the owners.

• Longer range BEVs have the highest utility factor, both on the vehicle level and the household level.

• Long Range PHEVs have very few cold starts and low (No?) probability for high-power cold start.
Selected Takeaway Points

• The vast majority of the charging events that are not home events occur within the vehicle range (if starting the day with a fully charged battery).

• The household analysis suggests the longer-range BEVs can improve environmental performance (by decreasing GHG emissions and cold starts).

• Future households may move to own or lease multiple PEVs, combining BEVs and PHEVs, or short- and long-range BEVs, as well as fuel cell electric vehicles (FCEVs).
Additional Research Analysis

The project included very limited resources for analysis of the data collected and final results—for example for causality analysis to address the impact of charging infrastructure, vehicle size, and other factors that are not included in this report.

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Thank you

Questions?

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