Fuel Displacement & CO2 Benefits of Vehicle Electrification

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Electrification enables ...
Important Questions

• What are the CO₂ effects of electrically powered transportation?
• How do PHEV compare with E-REVs for Petroleum displaced and for CO₂ generated?
• How does fleet petroleum consumption and CO₂ generation vary with battery pack size?
• How useful are multiple charges per day?
• How useful is higher power charging?
<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Electric Power</th>
<th>Onboard Electric Storage</th>
<th>Grid Recharge</th>
<th>Electric Driving Capability</th>
<th>Preferential Electric Driving</th>
<th>Range Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild HEV</td>
<td>low</td>
<td>low</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>Gasoline</td>
</tr>
<tr>
<td>Full HEV</td>
<td>med</td>
<td>low</td>
<td>no</td>
<td>very limited</td>
<td>no</td>
<td>Gasoline</td>
</tr>
<tr>
<td>PHEV</td>
<td>med</td>
<td>med</td>
<td>yes</td>
<td>Urban Only</td>
<td>no</td>
<td>Gasoline + Battery</td>
</tr>
<tr>
<td>E-REV</td>
<td>high</td>
<td>high</td>
<td>yes</td>
<td>Full</td>
<td>yes</td>
<td>Gasoline + Battery</td>
</tr>
<tr>
<td>BEV</td>
<td>high</td>
<td>highest</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>Battery</td>
</tr>
</tbody>
</table>
Vehicle Type Characterized by Energy Use

Cumulative Gasoline Energy vs. Driving Distance, km

Cumulative Electric Energy

Conventional
Full Hybrid
PHEV 4kWhr
PHEV 8kWhr
E-REV 4 kWhr
E-REV 8kWhr
BEV 12kWhr
Studies of US Vehicle Use

• Two Major Populations Studied:
  – Southern California Association of Governments Regional Travel Survey, 2003
    • Speed vs. time of day, every second, aggregated days, 621 drivers
    • Basis of single charge per day study 2007
  – National Household Travel Survey, 2001
    • Vehicle location vs. arrival times, several weeks, separated days, >50,000 vehicles, >200,000 travel days
    • Basis of multiple charge per day studies
Analysis Study Vehicles Normalized

Based upon a 2009 Malibu, Full Hybrid, PHEV and E-REV was constructed. All achieve approximately 36 mpg charge sustaining FE on US Schedules

<table>
<thead>
<tr>
<th></th>
<th>Conventional or HEV</th>
<th>PHEV</th>
<th>E-REV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Charge Sustaining Fuel Economy</strong></td>
<td></td>
<td>36 [mpg]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.53 [l/100 km]</td>
<td></td>
</tr>
<tr>
<td><strong>Charge Decreasing Electrical Energy Consumption [kw-hr/mile]</strong></td>
<td>n/a</td>
<td>0.350 [kw-hr/mi]</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.2175 [kw-hr/km]</td>
<td></td>
</tr>
<tr>
<td><strong>Charge Decreasing Energy Split</strong></td>
<td>n/a</td>
<td>0.7</td>
<td>1.0</td>
</tr>
</tbody>
</table>
ZEV Power and Speed

Distance (miles)

Net Energy per Mile (kW-hr/mile)

0 0.1 0.2 0.3 0.4 0.5 0.6

0 50 100 150 200 250 300

Urban

Mid-Sized Vehicle Simulated with SCAG Regional Transportation Survey Data
Examining the “Average Driver”

Mid-Sized Vehicle Simulated with SCAG Regional Transportation Survey Data

“Driver #231”

Distance (miles)

Net Energy per Mile (kW·hr/mile)

27.4 Miles

308 Whr/Mi

US06

Urban
Driver #231’s Driving Day

SCAG Regional Transportation Survey Data

Morning Commute

Afternoon Commute
Driver #231’s Morning Commute

Engine on
Speed exceeds urban schedule

Engine on
Power exceeds urban schedule

Engine On
Battery Energy Depleted

Urban Capable PHEV
6 engine starts
18% energy from engine

E-REV
0 engine starts
0% energy from engine

Engine off – ZEV miles
Engine on and off, – Hybrid Miles

SCAG Regional Transportation Survey Data
Driver #231’s Afternoon Commute

Urban Capable PHEV
1 initial engine start
100% energy from engine

E-REV
1 engine start
5% energy from engine

Engine off – ZEV miles
Engine on and off, – Hybrid Miles

SCAG Regional Transportation Survey Data
Differences in PHEV and E-REV Energy Usage

- SCAG survey reveals that 30% of all aggregate driving energy is used at power levels and speed levels beyond the “Urban” power and speed levels (greater than 56 mph or greater than 53 kW)
- PHEV uses a 70% EV energy fraction and a 30% gasoline fraction in Charge Depleting (CD) Mode (energy remaining in the battery)
- E-REV uses a 100% energy fraction in CD Mode
• EREV and PHEV use same fuel for all travel beyond charge-depleting operation.
Where are the Cars?

Fleet Distribution during week

- Home
- Residence
- Work
- School & Church
- Commercial
- Other
- Driving
How far do people drive?

2001 USA Daily Distance vs Fraction of Driven Vehicles

Daily Driving

mi km

Fraction of vehicles
Petroleum Displacement and CO$_2$ Reduction - 3.3 kw Charging at Work & Home

For the same size battery pack
- The EREV displaces 60% of fuel versus 55% for the PHEV.
- The EREV displaces 36% of CO$_2$ versus 33% for the PHEV.
Three Charging Scenarios Examined

• 1.1 kW charging: 15 Amp, 110 volt outlet
  – Restricted to at home only
  – 9 pm to 9 am; randomized start; charge until full
  – effectively one charge per day

• 3.3 kW charging: 15 amp, 220 volt outlet
  – Restricted to home and work
  – Charge at any time; charge until full
  – effectively two charges per day

• 6.6 kW charging: 30 amp, 220 volt outlet
  – Unrestricted location; wherever you park
  – Charge at anytime; charge until full
  – effectively unlimited charges per day
E-REV Fuel Displacement Advantage Grows with Increasing Battery Size, More Charging
Powertrain and Infrastructure can replace batteries
an example

![Graph showing fuel use vs battery size for different scenarios of PHEVs and EREV. The graph indicates that adding batteries reduces fuel use.](image)

Adding batteries reduces fuel use
Powertrain and Infrastructure can replace batteries
an example

The same fuel savings is achieved with 15% less battery by using an EREV powertrain.
(PHEV-> EREV)
Powertrain and Infrastructure can replace batteries
an example

The same fuel savings is achieved with 50% less battery by a combination of an EREV powertrain and charging at work.
Powertrain and Infrastructure can replace batteries
an example

The same fuel savings can be achieved with 75% less pack if level 2 charging is available everywhere.

However, adding Level 3 charging offers only an additional 5% reduction in pack size ...
Powertrain and Infrastructure increase fuel savings
an example

![Graph showing fuel use per day vs battery size for different charging scenarios.](image-url)
Infrastructure Capacity Does not Appear to be a Constraint to Vehicle Electrification

Expected Charger Wall Power
8kW-hr EREV, 3.3kW Charger, Charge at Work & Home
Even at higher Peak Charge rates, Grid Capacity Does not Appear to be a Large Issue

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**Expected Peak Electrical Power**

- **EREV, Restricted Home Charging, 1.1 kW**
- **EREV, Charge at Home & Work, 3.3kW**
- **EREV, Unrestricted Charging Everywhere, 6.6kW**
- **0.7 PHEV, Restricted Home Charging, 1.1kW**
- **0.7 PHEV, Charge at Work & Home, 3.3kW**
- **0.7 PHEV, Unrestricted Charging Everywhere, 6.6kW**

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**Battery Size [W-hr]**

- X-axis: Battery Size [W-hr]
- Y-axis: Watts

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The graph illustrates the expected peak electrical power for different charging scenarios. The x-axis represents the battery size in W-hr, while the y-axis represents the watts. Each scenario is indicated by a different line color and symbol:
Conclusions

1. E-REVs offer an advantage over PHEVs for fuel displaced and CO2 reduced. This advantage is more pronounced with larger batteries. E.g, an 8 kWhr E-REV will give an 11% reduction in fuel consumed relative to an 8kWhr PHEV. (3.3 kW charging at home and work)

2. Since E-REVs are more likely to be produced with larger batteries than PHEVs, an 8kWhr E-REV shows an 23% reduction in fuel consumed and CO2 generated compared to a 2kWhr PHEV. (3.3 kW charging at home and at work)

3. If renewable electricity is used CO2 reduction is equal to fuel displacement.

4. The grid capacity impact of introducing PHEVs and E-REVs is not, in general, great. Considering an 8kWhr E-REV using a 3.3kW charge has an expected peak grid load roughly of roughly 800 Watts. This is equivalent to two plasma TVs.

5. Making charging available at work significantly improves the ability of an E-REV or PHEV to displace fuel. For instance, a 8 kWhr E-REV charged at 3.3 kW at home and at work will lower fuel consumption by 24% when compared to 1.1kW charging restricted to use only at home.

6. An infrastructure improvement allowing multiple charges per day is one factor that could allow a reduction in E-REV or PHEV battery size while maintaining similar levels of petroleum displacement and CO2 reduction.
Thank You!