Plug-In Hybrid Electric Vehicles

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Manager, Technology Development
Electric Transportation
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Status
Plug-In Hybrid Electric Vehicles
Status 2001 – 2007

2001 – 2005
• EPRI/Utilities support most PHEV Research

2006
• Pres. Bush endorses PHEV technology—DOE initiates it first PHEV R&D Program
• First PHEV prototypes from major automaker begin U.S. fleet testing (DCX PHEV Sprinter)

2007
• GM announces Chevy Volt, a PHEV with ~40 miles of EV range
  – GM has 2010 market intro goal
• Toyota announces significant internal program for PHEV development
• DaimlerChrysler developing 2nd generation plug-in hybrid Sprinter Van
• Nissan & Ford announce PHEV development programs
“...we are pursuing a "plug-in" hybrid vehicle that can travel greater distances without using its gas engine...conserving more oil AND slicing smog and greenhouse gases to nearly imperceptible levels.”
– Jim Press, Toyota

"More than half of all Americans live within 20 miles of where they work (40 miles round trip). In that case, you might never burn a drop of gas during the life of the car."
– Bob Lutz, GM

"Develop advanced battery technologies that allow a plug-in hybrid-electric vehicle to have a 40-mile range operating solely on battery charge."
– President Bush’s Advanced Energy Initiative
Plug-In Hybrid Electric Vehicles
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Technology
PHEV Dodge Sprinter Program

• Plug-in hybrid commercial van
• 20 miles all-electric range (urban)
• Li Ion battery
• EPRI/DCX collaboration (Utility & public support)
• Several locations (CA, NY, TX, NJ, AL, KC, etc)
• Extensive vehicle test, data collection and analysis program
Source: DaimlerChrysler
The graph illustrates the vehicle speed (kph) and current (Amps) over time. It distinguishes between ZEV (Zero-Emission Vehicle) Mode and HEV (Hybrid Electric Vehicle) Mode. The graph also shows the battery voltage, with a separate legend for High SOC Battery Current, Vehicle Speed (NEFZ), and High SOC Voltage.
Advanced Battery Challenge

• Key questions are cycle life, and cost/availability of energy batteries for PHEVs.
• Current durability test data shows potential for current advanced batteries to meet cycle and calendar life requirements.
• Need to understand recent innovations in Li Ion field on cycle life durability, wide-temperature range operation, low cost materials.
• Ongoing sub-pack testing augmented by full pack tests of JCS (DOE-provided).
Actual Test Profile

Source: Southern California Edison
Li Ion Capacity Test Results

Source: Southern California Edison
Potential Areas for Nanotechnology Impact

1. Battery life—deep cycle durability
2. Specific power—reduce cell impedance
3. Environmental performance
   • Greater temperature range
   • Lower cooling requirements
4. Safety
5. Facilitate adoption of new materials/chemistries
6. Lower cell cost

<table>
<thead>
<tr>
<th>Electrode Thickness</th>
<th>Standard Li Ion</th>
<th>A123 Doped Nanophosphate Li Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin (20 micron particles)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thick (100nm particles)</td>
<td></td>
<td></td>
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</tbody>
</table>
Environmental Impact
Understanding Environmental Impacts of Plug-In Hybrid Electric Vehicles

- Environmental impacts of shifting vehicle energy supply from petroleum to electricity not well understood
- Location and characteristics of vehicle and power plant emissions are different
- Electricity supplied by diverse mix of fuels, plant technologies
- New technologies take time to penetrate nationwide vehicle fleet
Technologies for New Generation in 2010-2015

Levelized Cost of Electricity, $/MWh

- IGCC
- Wind@29% CF
- NGCC@$6
- PC
- Biomass
- Nuclear

Cost of CO₂, $/metric ton
Technologies for New Generation in 2020-2025

Levelized Cost of Electricity, $/MWh

Cost of CO₂, $/metric ton

Solar (CSP)

NGCC@$6

Wind@40%CF

PC w/cap

IGCC w/cap

Biomass

Nuclear
Power Plant-Specific PHEV Emissions in 2010
PHEV 20 – 12,000 Annual Miles
Electric Sector Simulation Results (2050)
PHEV 10, 20, & 40 – 12,000 Annual Miles
Greenhouse Gas Emissions

- Electricity grid evolves over time
- Nationwide fleet takes time to renew itself or “turn over”
- Impact would be low in early years, but could be very high in future
- Potentially a 400-500 million metric ton annual reduction in GHG emissions

Annual Reduction in Greenhouse Gas Emissions From PHEV Adoption
### Overall CO$_2$e Results

- All nine scenarios resulted in CO$_2$e reductions from PHEV adoption
- Every region of the country will see reductions
- In the future, PHEVs charged from new coal (highest emitter) w/o CCS roughly equivalent to HEV, superior to CV
  - There is unlikely to be a future electric scenario where PHEVs do not return CO$_2$e benefit

<table>
<thead>
<tr>
<th>PHEV Fleet Penetration</th>
<th>2050 Annual CO$_2$e Reduction (million metric tons)</th>
<th>Electric Sector CO$_2$ Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Low</td>
<td>163</td>
<td>177</td>
</tr>
<tr>
<td>Medium</td>
<td>394</td>
<td>468</td>
</tr>
<tr>
<td>High</td>
<td>474</td>
<td>517</td>
</tr>
</tbody>
</table>
U.S. Power Plant Emissions Trends

- Power plant emissions of $\text{SO}_2$ and $\text{NOx}$ will continue to decrease due to tighter federal regulatory limits (caps) on emissions
- Other local and national regulations further constrain power plant emissions
- Air quality is determined by emissions from all sources undergoing chemical reactions within the atmosphere
Net Changes in Criteria Emissions Due to PHEVs

**Power Plant Emissions**
- Emissions capped under law (SO₂, NOₓ, Hg) are essentially unchanged
- Primary PM emissions increase (defined by a performance standard)

**Vehicle Emissions**
- NOₓ, VOC, SO₂, PM all decrease
- Significant NOₓ, VOC reductions at vehicle tailpipe
- Reduction in refinery and related emissions
PHEVs Improve Overall Air Quality
Reduced Formation of Ozone

- Air quality model simulates atmospheric chemistry and transport
- Lower NOx and VOC emissions results in less ozone formation particularly in urban areas

Change in 8-Hour Ozone Design Value (ppb)
PHEV Case – Base Case
PHEVs Improve Overall Air Quality
Reduced Formation of Secondary PM$_{2.5}$

- PM$_{2.5}$ includes both direct emissions and secondary PM formed in the atmosphere
- PHEVs reduce motor vehicle emissions of VOC and NOx.
- VOCs emissions from power plants are not significant
- Total annual SO$_2$ and NOx from power plants capped by federal law
- The net result of PHEVs is a notable decrease in the formation of secondary PM$_{2.5}$

Change in Daily PM$_{2.5}$ Design Value (µg m$^{-3}$)
PHEV Case – Base Case
PHEVs Improve Overall Air Quality
Reduced Deposition of Sulfates, Nitrates, Nitrogen, Mercury

<table>
<thead>
<tr>
<th></th>
<th>Sulfate (ton)</th>
<th>Nitrate (ton)</th>
<th>Nitrogen (ton N)</th>
<th>Mercury (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefit above Threshold</td>
<td>-41,472</td>
<td>-45,490</td>
<td>-32,413</td>
<td>-146,370</td>
</tr>
<tr>
<td>Benefit below Threshold</td>
<td>-12,416</td>
<td>-20,995</td>
<td>-22,784</td>
<td>-90,202</td>
</tr>
<tr>
<td>Disbenefit above Threshold</td>
<td>27,769</td>
<td>4,973</td>
<td>233</td>
<td>48,377</td>
</tr>
<tr>
<td>Disbenefit below Threshold</td>
<td>4,562</td>
<td>3,396</td>
<td>233</td>
<td>28,693</td>
</tr>
</tbody>
</table>

|                | -26,114 | -61,508 | -54,963 | -188,166 |

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Impacts to Energy 
Electricity and Petroleum

• Moderate electricity demand growth
• Capacity expansion 19 to 72 GW by 2050 nationwide (1.2 – 4.6%)
• 3-4 million barrels per day in oil savings (Medium PHEV Case, 2050)
Advanced Infrastructure
Charging Infrastructure

- Plug-in hybrids require relatively low power charging
- Wide availability of infrastructure
  - Initial focus on private chargers
- Array of options
  - 120 VAC, 15 amp (~1.4 kW)
  - 120 VAC, 20 amp (~2.0 kW)
  - 208/240 VAC, 30 amp (~6 kW)
- 120 VAC strongly preferred due to cost, availability

<table>
<thead>
<tr>
<th>PHEV 20 Vehicle</th>
<th>Pack Size</th>
<th>Charger Circuit</th>
<th>Charging Time 20% SOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact Sedan</td>
<td>5.1 kWh</td>
<td>120 VAC / 15 A</td>
<td>3.9 – 5.4 hrs</td>
</tr>
<tr>
<td>Mid-size Sedan</td>
<td>5.9 kWh</td>
<td>120 VAC / 15 A</td>
<td>4.4 – 5.9 hrs</td>
</tr>
<tr>
<td>Mid-size SUV</td>
<td>7.7 kWh</td>
<td>120 VAC / 15 A</td>
<td>5.4 – 7.1 hrs</td>
</tr>
<tr>
<td>Full-size SUV</td>
<td>9.3 kWh</td>
<td>120 VAC / 15 A</td>
<td>6.3 – 8.2 hrs</td>
</tr>
</tbody>
</table>

1.2 – 1.4 kW power, 1 or 2 hours conditioning
Intelligent Electricity Delivery Infrastructure

Four Building Blocks

- Communications Infrastructure
- Innovative Regulation and Rates
- Efficient and Smart End-use Devices
- Innovative Markets
Intelligent Electricity Delivery Infrastructure

Smart Thermostat Example

- Consumer has hourly day-ahead electricity rates
- Consumer’s thermostat receives hourly day-ahead electricity prices and day-ahead weather forecast through a network connection
- Consumer sets thermostat within a “comfort” range
- Thermostat “learns” rate of house cool-down/heat-up based on consumer habits, outside temperature, time of year, etc.
- Thermostat optimizes air-conditioner operation within the comfort range to minimize consumers electricity costs

“Prices to Devices” sm
Intelligent Electricity Delivery Infrastructure

PHEV’s: Mobile Smart End-Use Devices

• Convenient Re-charging… Anytime and Anywhere
  – Vehicle meter “handshakes” with network-connected “socket” to identify vehicle and billing information
  – Re-charges with kWh measured by vehicle meter
  – Electronic billing transaction debits vehicle owner’s account and credits “socket” owner’s account

• Distributed Energy Storage
  – Sell stored battery energy to the grid
  – Utilize stored battery energy for short-term back-up power

• Distributed Generation
  – Utilize internal combustion engine for longer-term backup power

Will Require Close Vehicle-to-Grid System Integration
Future Intelligent Infrastructure Enabling PHEV and Consumer Choice

Interoperability and Functionality is Key