Environmental Assessment of Plug-In Hybrid Electric Vehicles (PHEVs)

Greenhouse Gas Emissions and Air Quality Impacts of PHEVs

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Electric Power Research Institute
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
  - Temporal and geographic locations
- Electricity supplied by diverse mix of fuels, plant technologies
- New technologies take time to penetrate nationwide vehicle fleet
- Generation capacity and economics evolve over time
  - Must go beyond energy pathway analysis to model these changes
Approach

• Electric Sector Modeling:
  – Evolve over time
  – Least-cost economics
    – Monetization of right to emit
    – Capital, O&M costs for power plant technologies
  – Capacity expansion/retirement
  – Production simulation (dispatch modeling)
• Transportation Sector:
  – Fleet evolution of technologies (HEV, PHEV, etc) over time
• Air Quality Modeling:
  – 3D air quality model of all emissions sources
The Future of the Electric Sector
Three Possible Scenarios

Key Parameters
- Value of CO₂ emissions allowances
- Plant capacity retirement and expansion
- Technology availability, cost and performance
- Electricity demand

<table>
<thead>
<tr>
<th>Scenario Definition</th>
<th>High CO₂</th>
<th>Medium CO₂</th>
<th>Low CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of CO₂ Emissions Allowances</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Power Plant Retirements</td>
<td>Slower</td>
<td>Normal</td>
<td>Faster</td>
</tr>
<tr>
<td>New Generation Technologies</td>
<td>Unavailable: Coal with CCS New Nuclear New Biomass</td>
<td>Normal Technology Availability and Performance</td>
<td>Available: Retrofit of CCS to existing IGCC and PC plants</td>
</tr>
<tr>
<td></td>
<td>Lower Performance: SCPC, CCNG, GT, Wind, and Solar</td>
<td></td>
<td>Higher Performance: Solar</td>
</tr>
<tr>
<td>Annual Electricity Demand Growth</td>
<td>1.56% per year on average</td>
<td>1.56% per year on average</td>
<td>2010 - 2025: 0.45% 2025 - 2050: None</td>
</tr>
</tbody>
</table>

SCPC – Supercritical Pulverized Coal
CCNG – Combined Cycle Natural Gas
GT – Gas Turbine (natural gas)
CCS – Carbon Capture and Storage
Value of CO₂ Emission Allowances

- CO₂ emissions in model controlled by applying a cost to emit on power plant fuel and stack emissions
- Higher CO₂ costs increase cost of power from higher emitting technologies
- Model calculates CO₂e includes CO₂, N₂O, and CH₄ emissions from upstream fuels

Carbon Dioxide Equivalents:

$$\text{CO}_2\text{e} = \text{CO}_2 + 23 \times \text{CH}_4 + 296 \times \text{N}_2\text{O}$$

Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis*
PHEV Assumptions

• Base vehicles derived from EPRI 2001 and 2002 consensus studies on benefits and impacts of HEVs
• PHEVs available up to Class 5 vehicles (19,500 lb GVW)
• Technology options include PHEV 10, 20 and 40 (no PHEV 60, no EVs or fuel cell vehicles).
• Vehicle assumptions coordinated with MOBILE6 and EMFAC mobile emissions databases
  – PHEV and HEV have same fuel economy on gasoline
  – PHEV electricity usage dependent on battery size, annual vehicle miles travelled (VMT)
  – PHEV has electric VMT (eVMT), reducing emissions, gasoline consumption
PHEV Market Share and Electric VMT Fraction
Medium Scenario

- Low, Medium, High PHEV market penetration scenarios
- Corresponds to 20%, 60%, and 80% peak market share
- New vehicles take time to penetrate nationwide fleet

New Vehicle Market Share: Medium PHEV Scenario
Growth of PHEVs and eVMT in Nationwide Fleet
PHEV Charging Profile Assumptions

- Base Case represents 74% of energy delivered from 10:00 pm to 6:00 am, 26% between 6:00 am and 10:00 pm
- Vehicle charged primarily, but not exclusively, at each vehicle’s “home base”
- Owners incentivized or otherwise encouraged to use less expensive off-peak electricity
- Charge onset delays built into near-term vehicles—allow battery system rest and cooling before recharge
- Long-term with large PHEV fleets, utilities will likely use demand response or other programs to actively manage the charging load
Power Plant-Specific PHEV Emissions in 2010

PHEV 20 – 12,000 Annual Miles

Graph showing Well-to-Wheels greenhouse gas emissions (g CO₂e/mile) for different power plants and PHEV models.

- Gasoline Well-to-Tank
- Gasoline Tank-to-Wheels
- Electricity Well-to-Wheels
Electric Sector Simulation Results (2050)
PHEV 10, 20, & 40 – 12,000 Annual Miles

- Conventional Vehicle
- Hybrid Vehicle
- PHEV 10 - High CO2
- PHEV 20 - High CO2
- PHEV 40 - High CO2
- PHEV 10 - Med CO2
- PHEV 20 - Med CO2
- PHEV 40 - Med CO2
- PHEV 10 - Low CO2
- PHEV 20 - Low CO2
- PHEV 40 - Low CO2

Well-to-Wheels Greenhouse Gas Emissions (g CO₂e/mile)

- Gasoline Well-to-Tank
- Gasoline Tank-to-Wheels
- Electricity Well-to-Wheels

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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
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>Low</td>
<td>163</td>
<td>High 163</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium 177</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low 193</td>
</tr>
<tr>
<td>Medium</td>
<td>394</td>
<td>High 474</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium 517</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low 612</td>
</tr>
<tr>
<td>High</td>
<td>474</td>
<td>High 474</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium 517</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low 612</td>
</tr>
</tbody>
</table>

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• 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)
Scope and Methodology Air Quality Task

• National Analysis
  – Phase I:
    • Consistent with U.S. Department of Energy’s 2006 Annual Energy Outlook (AEO)
    • Also considers California Electricity Commission’s 2005 Integrated Energy Policy Report (IEPR)
    • Reflects a generation mix in the absence of any national or state greenhouse gas policies
  – Phase II:
    • Combined Air Quality/Climate Study
• National Analysis
• Two Scenarios in 2030:
  – 0% and 50% PHEV (new-vehicle) market penetration
  – Model power-plant capacity expansion, generation and emissions using North American Electricity and Environment Model (NEEM)
    • Renewable Portfolio Standards (RPS)
    • California Million Solar Roofs Initiative
    • Includes all current EPA regulations:
      – Clean Air Interstate Rule, Clean Air Mercury Rule, Clean Air Visibility Rule
  – Full-year air quality analysis using three-dimensional air quality model
U.S. Power Plant Emissions Trends

- Power plant emissions of $\text{SO}_2$ and 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

Source: U.S. Environmental Protection Agency
Scope and Methodology Air Quality Task
Transportation Sector (Phase I)

- **Key Transportation Assumptions**
- 2030 Base Case (no-PHEV) scenario
  - EIA-consistent assumptions
    - Vehicle growth in vehicles miles traveled (VMT)
    - Fleet turnover
  - Includes all current EPA regulations:
    - Clean Air Non-Road Diesel Rule, Clean Highway (Heavy Duty) Diesel Rule, Tier II Gasoline Program
- 2030 PHEV scenario
  - Estimate vehicle Penetration by 2030
    - Estimate VMT provided in all-electric mode
    - 76/24 off-peak/on-peak charging profile
    - Additional benefits from lower upstream (refinery, transport, storage, refueling evaporative, spillage) emissions per VMT
PHEV Market Penetration

- All-Electric VMT Fraction
- Fraction of Vehicles On Road
- Fraction of New Vehicle Sales

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Results Shown Mapped to NEMS EMM Regions
## Incremental Load Growth due to PHEV

<table>
<thead>
<tr>
<th>NEMS EMM Region</th>
<th>Base Case Generation 000 MWh</th>
<th>Δ Generation PHEV Case 000 Mwh</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>315,837</td>
<td>-26,583</td>
<td>-8.4%</td>
</tr>
<tr>
<td>ECAR</td>
<td>864,261</td>
<td>14,492</td>
<td>1.7%</td>
</tr>
<tr>
<td>ERCOT</td>
<td>468,901</td>
<td>26,469</td>
<td>5.6%</td>
</tr>
<tr>
<td>FL</td>
<td>366,602</td>
<td>7,769</td>
<td>2.1%</td>
</tr>
<tr>
<td>MAAC</td>
<td>364,747</td>
<td>35,127</td>
<td>9.6%</td>
</tr>
<tr>
<td>MAIN</td>
<td>447,458</td>
<td>38,866</td>
<td>8.7%</td>
</tr>
<tr>
<td>MAPP</td>
<td>251,952</td>
<td>22,384</td>
<td>8.9%</td>
</tr>
<tr>
<td>NE</td>
<td>179,915</td>
<td>11,476</td>
<td>6.4%</td>
</tr>
<tr>
<td>NWP - WY</td>
<td>375,295</td>
<td>86,170</td>
<td>23.0%</td>
</tr>
<tr>
<td>NY</td>
<td>189,994</td>
<td>8,039</td>
<td>4.2%</td>
</tr>
<tr>
<td>RA + WY</td>
<td>468,337</td>
<td>14,762</td>
<td>3.2%</td>
</tr>
<tr>
<td>SERC</td>
<td>1,307,279</td>
<td>85,859</td>
<td>6.6%</td>
</tr>
<tr>
<td>SPP</td>
<td>274,571</td>
<td>13,883</td>
<td>5.1%</td>
</tr>
<tr>
<td><strong>Total US</strong></td>
<td><strong>5,875,149</strong></td>
<td><strong>338,713</strong></td>
<td><strong>5.8%</strong></td>
</tr>
</tbody>
</table>
Net Changes in Criteria Emissions Due to PHEVs

**Power Plant Emissions**
- Emissions capped under law ($SO_2$, NOx, Hg) are essentially unchanged
- Primary PM emissions increase (defined by a performance standard)

**Vehicle Emissions**
- NOx, VOC, SO$_2$, PM all decrease
- Significant NOx, VOC reductions at vehicle tailpipe
- Reduction in refinery and related emissions

<table>
<thead>
<tr>
<th>Emissions (tons)</th>
<th>SOx</th>
<th>NOx</th>
<th>VOC</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-Road Vehicle</td>
<td>-7,716</td>
<td>-236,292</td>
<td>-234,342</td>
<td>-9,255</td>
</tr>
<tr>
<td>Refinery and Other Stationary</td>
<td>-23,549</td>
<td>-20,076</td>
<td>-17,804</td>
<td>-3,282</td>
</tr>
<tr>
<td>Distributed Upstream</td>
<td>0</td>
<td>-1,293</td>
<td>-103,323</td>
<td>-101</td>
</tr>
<tr>
<td>Power Plant</td>
<td>-16,284</td>
<td>58,916</td>
<td>0</td>
<td>49,434</td>
</tr>
</tbody>
</table>

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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
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$_{2.5}$
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>

| Sum              | -26,114       | -61,508       | -54,963          | -188,166    |
Nitrogen Deposition Impacts

Annual: Difference in Nitrogen deposition kg/hectare
PHEV - Base, 2030 - 36km domain
Mercury Deposition Impacts

Difference in Annual Total Hg deposition mg/hectare
PHEV - Base, 2030 - 36km domain
Regional Visibility Impacts

Difference in 98 percentile of visibility degradation (deciviews - dv) at Class I areas

PHEV - Base case: 2030
Results

• Most comprehensive nationwide environmental assessment of electric transportation to date.
  – First nationwide air quality study for electric transportation
  – First greenhouse gas study to account for simultaneous evolution of electric and transport sectors
• Capacity expansion/retirement, production simulation
• PHEV adoption results in modest air quality benefits
• PHEV adoption generates significant reductions in greenhouse gas emissions in the transport sector in all scenarios
  – PHEV 40 – up to 45% reduction in GHG emissions vs. HEV
• Petroleum reduction: 3-4 million barrels per day in Medium PHEV scenario (2050)
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