Alternative Transportation Technologies: Hydrogen, Biofuels, Advanced Efficiency, and Plug-in Hybrid Electric Vehicles

Results of two Reports from the National Research Council

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COMMITTEE ON ASSESSMENT OF RESOURCE NEEDS FOR FUEL CELL AND HYDROGEN TECHNOLOGIES

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Presentation Outline

• Study Methodology and Scenarios
• Market Penetration Rates
• Oil and CO$_2$ Savings
• Fuel, Fuel Cell, Battery and Vehicle Costs
• Timing and Transition Costs to Achieve Market Competitiveness for FCVs and PHEVs
• Infrastructure Issues
• Conclusions
Goals of 2 Studies

- Establish as a goal the *maximum practicable number* of vehicles that can be fueled by hydrogen by 2020 and potential fuel and CO2 savings
- Determine the *funding*, public and private, to reach that goal
- Establish a *budget roadmap* to achieve the goal
- Determine the *government actions* required to achieve the goal
- Consider whether *other technologies* could achieve significant CO2 and oil reductions by 2020
- Completed July 2008

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- Determine the *maximum practicable* penetration rate for PHEVs and estimate the potential fuel and CO2 savings, and required funding
- Completed December 2009
Vehicle Penetration Rates and Potential Fuel and CO2 Reductions
SCENARIOS

1) **H2 SUCCESS**  H2 & fuel cells play a major role beyond 2025

2) **EFFICIENCY**  Currently feasible and projected improvements in gasoline internal combustion engine technology are introduced rapidly

3) **BIOFUELS**  Large scale use of biofuels, including ethanol and biodiesel

4) **PLUG-IN HYBRID SUCCESS**  PHEVs play a major role beyond 2025

5) **PORTFOLIO APPROACH**  More efficient ICEVs + biofuels + FCVs or PHEVs introduced
CASE 1: H2 SUCCESS Scenario

Fuel cell @ $30/kW and H2 storage @ $10/kWh by 2025)

A Partial Success Case was also studied (FC @ $50/kW and H2 storage @ $15/kWh)
Case 2: ICEV Efficiency

- Currently available and projected improvements in conventional vehicle technology used to increase efficiency
- The fuel economy of gasoline vehicles assumed to improve
  - 2.7%/year from 2010-2025
  - 1.5%/year from 2026-2035
  - 0.5%/year from 2036-2050
- Gasoline HEVs dominate; no FCVs or PHEVs

**Graphs:**
1. Number of Light Duty Vehicles (millions)
2. Fuel Economy of New Light Duty Vehicles (mpg)

**Case 2 (ICEV Efficiency): Number of Light Duty Vehicles (millions)**
- Gasoline ICEV
- Gasoline HEV
- TOTAL

**Case 2 (ICEV Efficiency): Fuel Economy of New Light Duty Vehicles (mpg)**
- Gasoline ICEV
- Gasoline HEV

**Yearly Trends:**
- 2000-2025: 2.7%/year improvement
- 2026-2035: 1.5%/year improvement
- 2036-2050: 0.5%/year improvement
CASE 3: BIOFUEL SUCCESS

- Grain and Sugar based ethanol - maximum potential 12 billion gallons/year
- Sustainable biomass (million dry tons per year)*
  300 mtpy current, 500 mtpy 2030, 700 mtpy 2050
- Cellulosic ethanol has greater potential, 16 billion gallons/year by 2020 and 63 billion by 2050 **
- Potential for a much larger % of biomass to be converted to biobutanol or other advanced biofuels after 2020

*crop residues, energy crops, forest residues   ** maximum practicable case
CASE 3: BIOFUEL SUCCESS

Biofuel production (Billion gallons fuel per year)

- Corn Ethanol
- Cellulosic EtOH
- Biobutanol
- Biodiesel

Year

2000 2010 2020 2030 2040 2050
CASE 4: PHEV SUCCESS

- 2 mid-size vehicle types: PHEV-10s, PHEV-40s
- 2 market penetration rates:
  - Maximum Practical (same as H2 FCVs but start earlier (2010))
  - Probable
- 2 electricity grid mixes (business as usual and EPRI/NRDC scenario for de-carbonized generation in a 2007 study)
- PHEV gasoline and electricity use based on estimates by MIT, NREL, ANL
CASE 4: PHEV Market penetration

- Maximum Practical (with optimistic tech development estimates): 4 million PHEVs in 2020 and 40 million in 2030
- Probable (with probable technical development): 1.8 million PHEVs in 2020 and 13 million in 2030

- Many uncertainties, especially willingness and ability of drivers to charge batteries almost every day.
CASE 4: PHEV Fuel Savings Relative to Efficiency Case

Gasoline use (million gallons/yr)

Year

Reference Case
Efficiency Case
PHEV-10 (maximum) + Efficiency
PHEV-40 (maximum) + Efficiency
CASE 5: PORTFOLIO APPROACH
Vehicles (millions)

ICEVs and HEVs assumed to use advanced biofuels and gasoline
Case 5: Portfolio Fuel Savings

Efficiency + Biofuels: ICEVs and HEVs assumed to use advanced biofuels and gasoline.
Case 5: Portfolio GHG Emissions
BAU Electric Grid

- Ref Case
- Efficiency + Biofuels
- PHEV-10 (max) + Efficiency + Biofuels
- PHEV-40 (max) + Efficiency + Biofuels
- HFCV + Efficiency + Biofuels

GHG emissions (million tonnes CO2e per year)

Year

2010 2020 2030 2040 2050
GHG Emissions from Future Electric Grid (gCO2eq/kWh)

Case 5: Portfolio GHG Emissions
De-carbonized Electric Grid

- Reference Case
- Efficiency + Biofuels
- PHEV-10 (max) + Efficiency + Biofuels
- PHEV-40 (max) + Efficiency + Biofuels
- HFCV + Efficiency + Biofuels

GHG emissions (million tonnes CO2e per year)

Year
2010 2020 2030 2040 2050
PHEV Cost Analysis: Batteries are Key

Need acceptable cost for reasonable range, durability, and safety
Batteries

• Looked at 10 and 40 mile midsize cars
  - PHEV-10s and PHEV-40s

• Battery packs with 2 and 8 kWh useable or 4 and 16 kWh nameplate energy
  – Start of life, not after degradation
  – 200 Wh/mile
  – 50% State of Charge range (increases to compensate for degradation)
Current PHEV Battery Pack Cost* Estimates Compared ($/kWh nameplate)

- $700-1500/kWh (McKinsey Report)
- $1000/kWh (Carnegie Mellon University)
- $800-1000/kWh (Pesaran et al)
- $500-1000/kWh (NRC: America’s Energy Future report)
- $875/kWh (probable) NRC PHEV Report
- $625/kWh (optimistic) NRC PHEV Report
- $560/kWh (DOE, adjusted to same basis)
- $500/kWh (ZEV report for California)

*Unsubsidized costs
Future Cost* Estimates Compared
($/kWh nameplate)

- $600/kWh (Anderman)
- $400-560/kWh in 2020 (NRC PHEV)
- $360-500/kWh in 2030 (NRC PHEV)
- $420/kWh in 2015 (McKinsey)
- $350/kWh (Nelson)
- $168-280/kWh by 2014 (DOE goals adj.)

- NRC estimates higher than most but not all
- Assumed packs must meet 10-15 year lifetime
- Dramatic cost reductions unlikely; Li-ion technology well
developed and economies of scale limited

*Unsubsidized costs
Vehicle Costs

PHEV-40
- Total Pack cost now $10,000 - $14,000
- Total PHEV cost increment over current conventional (non-hybrid) car: $14,000 - $18,000
- PHEV cost increment in 2030: $8,800 - $11,000

PHEV-10
- Total Pack cost now $2500 - $3,300
- Total PHEV cost increment over current conventional (non-hybrid) car: $5,500 - $6,300
- PHEV cost increment in 2030: $3,700 - $4,100
Electric Infrastructure

• No major problems are likely to be encountered for several decades in supplying the power to charge PHEVs, as long as most vehicles are charged at night.
• May need smart meters with TOU billing and other incentives to charge off-peak.
• Charging time could be 12 hours for PHEV-40s at 110-V and 2-3 hours at 220-V. Thus home upgrade might be needed.
• If charged during hours when power demand is high, potential for significant issues with electric supply in some regions.
Potential Transition Costs for HFCV and PHEVs
## TRANSITION COSTS: PHEVs and H2 FCVs

<table>
<thead>
<tr>
<th></th>
<th>PHEV-10</th>
<th>PHEV-40</th>
<th>PHEV-40 Sensitivity Cases</th>
<th>HFCV Success</th>
<th>HFCV Partial Success</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakeven Year</td>
<td>2024</td>
<td>2040</td>
<td>2025</td>
<td>2023</td>
<td>2033</td>
</tr>
<tr>
<td>Cum. Cash flow to breakeven ($billion)</td>
<td>24</td>
<td>408</td>
<td>41</td>
<td>22</td>
<td>46</td>
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<tr>
<td>Cum. Vehicle Retail Price Diff to breakeven ($ billion)</td>
<td>82</td>
<td>1639</td>
<td>174</td>
<td>82</td>
<td>40</td>
</tr>
<tr>
<td># Vehicles at breakeven (million)</td>
<td>10</td>
<td>132</td>
<td>13</td>
<td>10</td>
<td>5.6</td>
</tr>
<tr>
<td>Infrastructure Cost at breakeven ($ Billion)</td>
<td>10 (in-home charger @$1000)</td>
<td>132 (in-home charger @$1000)</td>
<td>13 (in-home charger @$1000)</td>
<td>10 (in-home charger @$1000)</td>
<td>8 (H2 stations for first 5.6 million FCVs)</td>
</tr>
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1-3 decade transition time; Transition cost $10s-100s Billions; Results very sensitive to oil price and vehicle (battery & fcell) costs.
Major Findings

• Significant fuel and CO2 reductions can be achieved over next 20 years with efficient ICE/HEV technologies and biofuels.

• PHEVs and HFCVs have greater long-term potential for fuel savings. HFCVs can greatly reduce CO2 emissions, but savings from PHEVs dependent on grid fuel source.

• A portfolio of technologies has potential to eliminate oil and greatly reduce CO2 from US light duty transportation by 2050.

• The U.S. could have tens of millions of H2 FCVs and PHEVs on the road in several decades, but that would require tens or hundreds of billions in subsidies.

• Technology breakthroughs are essential for both fuel cells and batteries; cost reductions from manufacturing economies of scale will be much greater for fuel cells than batteries.