Fuel Economy Potential of Advanced Configurations from 2010 to 2045

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Sponsored by Lee Slezak (U.S. DOE)
Study Objectives

CAFÉ
Fuel Economy Standards

Baseline

Additional Improvements

- What are the benefits of the FreedomCAR & Fuel Partnership in terms of petroleum displacement?
- How much additional petroleum could be displaced with additional funding?
- Assess technology potential to guide future research and development

Mandated by Congress
**Approach**

### Component & Vehicle Assumptions

<table>
<thead>
<tr>
<th>Veh Classes</th>
<th>Timeframe</th>
<th>Powertrain</th>
<th>Fuels</th>
<th>Uncertainties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td></td>
<td>Gasoline</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>2020</td>
<td></td>
<td>Diesel</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>2030</td>
<td></td>
<td>Ethanol</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>2045</td>
<td></td>
<td>Hydrogen</td>
<td>50%</td>
</tr>
</tbody>
</table>

### Vehicle Definition & Simulation

- Vehicle Technical Specifications
- Sizing
- Simulation

### Results Analysis & Validation

- Results
- Validation
Reference Vehicles Fuel Economy Compared to Entire Class

EPA 2008 Adjusted Values – Including Cold Start Penalty
Battery Power and Usable Energy Requirement as a Function of Vehicle Mass

Battery Power vs Vehicle mass for Small SUV

PHEV Battery Energy vs Vehicle mass for Midsize

- SI Split HEV
- SI Split PHEV
- FC HEV
- FC PHEV
- EV

- SI Split PHEV10
- SI Split PHEV20
- SI Split PHEV30
- SI Split PHEV40
Vehicle Mass is a Major Factor Influencing Electric Consumption

Electric Consumption vs Vehicle Mass for PHEVs

$y = 0.19537x - 87.8426$

UDDS
HEVs Fuel Consumption Remains Fairly Constant Compared to Conventional

H2 ICE only technology to show significant changes

Ratio = \frac{\text{HEV}}{\text{Conv SI}}

Input Split Configuration Used
Early years difference explained by different range assumptions (190 mi for FC). Later, with same range, FC maintains benefits due to storage improvements.
Hybridization Benefits Based on Ratio Reduced with Larger Vehicle Class

\[
\text{Ratio} = \frac{\text{SI HEV}}{\text{Conv SI}}
\]

Variable Vehicle Class

Input Split Configuration Used
Trade-off Between Cost & Fuel Efficiency
All Vehicles

Lower fuel consumption leads to increased cost.
Trade-off Between Cost & Fuel Efficiency

Conventional Vehicles

Incremental Cost vs fuel consumption for Midsize Conv

- Diesel remains more expensive
- with benefits decreasing compared to other fuels over time

Each ICE technology has different impact

<table>
<thead>
<tr>
<th>Year</th>
<th>Incremental Cost ($) Compared to Reference Conventional Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>8000</td>
</tr>
<tr>
<td>2010</td>
<td>7000</td>
</tr>
<tr>
<td>2015</td>
<td>6000</td>
</tr>
<tr>
<td>2030</td>
<td>5000</td>
</tr>
<tr>
<td>2045</td>
<td>4000</td>
</tr>
</tbody>
</table>

- Gasoline
- Diesel
- Hydrogen
- Ethanol
Trade-off Between Cost & Fuel Efficiency

ICE-HEV Vehicles

Incremental Cost vs fuel consumption for Midsize HEV

- 2008
- 2010
- 2015
- 2030
- 2045

HEVs follow similar trends independently of ICE technology

Fuel Consumption (gal/100mile)

Incremental Cost ($) Compared to Reference Conventional Gasoline

Gasoline
Diesel
Hydrogen
Ethanol
Higher efficiency ICEs offer less benefits than for HEVs and Conventional.
Trade-off Between Cost & Fuel Efficiency
FC-HEV Vehicles

Based on the test procedure used, advanced powertrain do not benefit as much of high battery energy as current technologies.
Conclusions

- More than 600 vehicles were simulated for different timeframes (up to 2045), powertrain configurations, and component technologies.
- Both their fuel economy and cost were assessed to estimate the potential of each technology. Each vehicle was associated with a triangular uncertainty.
- The discrepancy between gasoline and diesel engine for conventional vehicles is narrowing with the introduction of new technologies, such as VVT and low temperature combustion.
- From a fuel-efficiency perspective, HEVs maintain a relative constant ratio compared to their conventional vehicle counterparts. However, the cost of electrification is expected to be reduced in the future, favoring the technology’s market penetration.
- PHEVs offer significant petroleum reduction potential.
- Hydrogen engine HEVs, through direct injection, will offer significant fuel improvements and appear to be a bridging technology towards fuel cell.