Evaluation of Ethanol Blends for PHEVs using Simulation and Engine-in-the-Loop

2011 DOE Hydrogen Program and Vehicle Technologies
Annual Merit Review
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Sponsored by David Anderson

Project ID # VSS049
Project Overview

Timeline
- Start: September 2010
- End: September 2011
- Status: 50% complete

Barriers
- Energy density of ethanol blends
- Cold start issues

Budget
- FY11 -$100K (ANL)

Partners
- Engine and Emissions Research Program at ANL
- OEM for ECU calibration
# Research Objective

## Technical Challenges with Ethanol Gasoline Blends

<table>
<thead>
<tr>
<th>Fuel Property of ethanol-gasoline blends (in comparison to gasoline)</th>
<th>Engine level impact</th>
<th>Vehicle level impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower energy density</td>
<td>Higher volumetric fuel flow for same shaft power</td>
<td>Higher fuel consumption</td>
</tr>
<tr>
<td>Higher latent heat of vaporization</td>
<td>Unreliable cold start, especially for higher blend ratios&lt;br&gt;Low combustion temperature</td>
<td>Higher emissions due to low temperature of combustion or failed combustion. The issue might be aggravated for PHEVs with multiple cold start events</td>
</tr>
<tr>
<td>Better knock properties</td>
<td>Efficient high load operation</td>
<td>Lower fuel consumption at high loads, which can be advantageous for hybrid operation</td>
</tr>
</tbody>
</table>
Research Objective

Impact of different levels of ethanol gasoline blends on conventional and PHEV vehicle fuel consumption

- Evaluate the performance of advanced powertrain components in a systems context
- Use modeling, simulation and component-in-the-loop techniques to provide system optimization for advanced powertrain components
- Use of alternative fuels to decrease U.S. reliance on petroleum
Milestones

Quarter 1
- EIL testing of conv. vehicle for gasoline, E50 and E85
- EIL testing of a series PHEV for Gasoline, E50, and E85

Quarter 2
- EIL testing of a power-split PHEV for gasoline, E50 and E85

Quarter 3
- Identify potential areas of improvement through steady state maps and simulation

Quarter 4

Current Status
Approach: Leverage Existing Engine-in-the-Loop Set-up, Expertise with Bio-fuels Combustion and PHEV Modeling

1. Quantify impact of ethanol / gasoline blends on FC
2. Assess sensitivity of different configurations to blend ratios

* A.Ickes, T.Wallner et al, ‘Impact of ethanol and butanol as oxygenates on SIDI engine efficiency and emissions using steady-state and transient test procedures’ presented at DEER 2010
Approach - Design of Experiment

Evaluation of ethanol blends for PHEVs

Fuels:
Gasoline, E50, E85

Vehicle configurations:
Conventional, Series PHEV, Power split PHEV

Drive cycle:
Conventional: UDDS
PHEVs: UDDS X5

The vehicle energy management remains the same for the three fuel blends
Technical Accomplishments
EIL Evaluation of Gasoline, E50 and E85 Complete for Conventional Vehicle

**Fuel Consumption Increase**

<table>
<thead>
<tr>
<th></th>
<th>E50</th>
<th>E85</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot</td>
<td>18.6%</td>
<td>37.2%</td>
</tr>
<tr>
<td>Cold</td>
<td>18.4%</td>
<td>35.9%</td>
</tr>
</tbody>
</table>

**Engine cold start penalty over an entire UDDS**

<table>
<thead>
<tr>
<th></th>
<th>E50</th>
<th>E85</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>5.1%</td>
<td></td>
</tr>
<tr>
<td>E50</td>
<td>5.0%</td>
<td></td>
</tr>
<tr>
<td>E85</td>
<td>4.5%</td>
<td></td>
</tr>
</tbody>
</table>

**Observations:**

- Increase in fuel consumption is similar for both hot and cold starts
- Cold start penalty is similar for all fuels
### Vehicles Have Identical Behavior for All Fuels

<table>
<thead>
<tr>
<th>Electrical consumption (Wh/mi)</th>
<th>UDDS # 1 EV</th>
<th>UDDS # 2 EV</th>
<th>UDDS # 3 transition</th>
<th>UDDS # 4 CS</th>
<th>UDDS # 5 CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>369.1</td>
<td>357.2</td>
<td>108</td>
<td>-6.5</td>
<td>-6.5</td>
</tr>
<tr>
<td>E50</td>
<td>369.1</td>
<td>357.2</td>
<td>107.3</td>
<td>-6.6</td>
<td>-6.6</td>
</tr>
<tr>
<td>E85</td>
<td>369.1</td>
<td>357.2</td>
<td>105.7</td>
<td>-6</td>
<td>-6.5</td>
</tr>
</tbody>
</table>

PHEV Series Test Cycle and Electrical Consumption
PHEV Fuel Consumption Increases with Higher Ethanol Content

- Hybrid operation shows lower fuel consumption penalty when compared to conventional, suggesting that the engine operates more efficiently at high loads for ethanol blends.

<table>
<thead>
<tr>
<th>% increase in FC compared to gasoline</th>
<th>UDDS # 4</th>
<th>UDDS # 5</th>
<th>Conventional hot start</th>
</tr>
</thead>
<tbody>
<tr>
<td>E50</td>
<td>17.7%</td>
<td>17.9%</td>
<td>18.6%</td>
</tr>
<tr>
<td>E85</td>
<td>33.1%</td>
<td>33.6%</td>
<td>37.2%</td>
</tr>
</tbody>
</table>
Impact of Ethanol on HEV Fuel Consumption is Lower than for Conventional

<table>
<thead>
<tr>
<th>% decrease in fuel energy consumption compared to gasoline</th>
<th>UDDS # 4</th>
<th>UDDS # 5</th>
<th>Conventional hot start</th>
</tr>
</thead>
<tbody>
<tr>
<td>E50</td>
<td>1.4%</td>
<td>1.4%</td>
<td>0.7%</td>
</tr>
<tr>
<td>E85</td>
<td>4.2%</td>
<td>3.8%</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

Test to test variation of +/-1% in fuel consumption for the same fuel has been observed.
E85 Engine Has Higher Efficiency than for Gasoline
Change in Engine Operating Region for E85 Could Result in Further Fuel Consumption Improvement

- There is potential for further improvements in fuel economy for ethanol blends by optimizing the vehicle level control strategy.
- E50/E85 engine and generator efficiency maps (for a series PHEV) will be used to determine high efficiency regions for series operation.
Lower Exhaust Temperature for Ethanol Blends Indicates Improved Engine Efficiency

Larger temperature difference at high load operation (which corresponds to improved efficiency regions on the efficiency map)

Insignificant temperature difference at low load operation
Future Work

On going work for FY11

- Extend the comparison of Gasoline, E50 and E85 as fuels for a power-split PHEV

- Quantify the sensitivity of fuel consumption to different fuel blend levels for the three configurations

Potential follow-up

- Incorporate bsfc maps for the ethanol-gasoline blends in simulation models, to reproduce the EIL hot operation

- Use modeling and simulation to suggest system level optimization for E50 and E85 PHEV operation

- Evaluate different fuels
Collaborations and Coordination

- Engine and Emissions group at ANL
  Dr. T. Wallner, Dr. A. Ickes,
  ‘omnivorous’ engine research

- DOE technology evaluation
  - DOE requests
  - National Lab requests

- OEM support for ECU
  Calibration for
  Ethanol blends

- AUTONOMIE
  Virtual vehicle,
  PHEV control

- USCAR, tech teams and OEMs
  Share test plans, data and
  analysis
Summary

- Several existing capabilities have been leveraged to compare the fuel consumption of different vehicles for different levels of ethanol and gasoline blends
  - Existing engine controllers tuned for different blends
  - Existing engine-in-the-loop setup
  - Existing vehicle models
- Energy density penalty of E50 and E85 has been quantified for conventional vehicle
- Hybrid operation for E50 and E85 shows lower energy density impact than conventional, suggesting improved engine efficiency for E50 and E85
- Comparison of gasoline and E85 efficiency maps suggests further improvement in E85 PHEV operation possible
Technical Back-Up Slides
Efficient engine operation with ethanol blends possible because of spark advance

High engine load

Low engine load
## Vehicle assumptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values (PHEV)</th>
<th>Values (conventional)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GVW</td>
<td>1936 kg</td>
<td>1783 kg</td>
</tr>
<tr>
<td>Engine</td>
<td>110 kW, 2.2 L SIDI engine</td>
<td>110 kW, 2.2 L SIDI engine</td>
</tr>
<tr>
<td>Electric Machine Power</td>
<td>130 kW / 13000 rpm</td>
<td>N.A.</td>
</tr>
<tr>
<td>Generator Power</td>
<td>110 kW / 6000 rpm</td>
<td>N.A.</td>
</tr>
<tr>
<td>Battery</td>
<td>41 Ah, 10 kWh Li-ion</td>
<td></td>
</tr>
<tr>
<td>Cd</td>
<td>0.37</td>
<td>0.37</td>
</tr>
<tr>
<td>FA</td>
<td>2.54 m²</td>
<td>2.54 m²</td>
</tr>
<tr>
<td>Tire</td>
<td>P225_75_R15 (0.359)</td>
<td>P225_75_R15 (0.359)</td>
</tr>
<tr>
<td>Fixed ratio</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Final drive ratio</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
PHEV Engine Operation is the Same for Gasoline and E85 - Engine Speed
PHEV Engine Operation is the Same for Gasoline and E85- Engine Torque