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

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

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

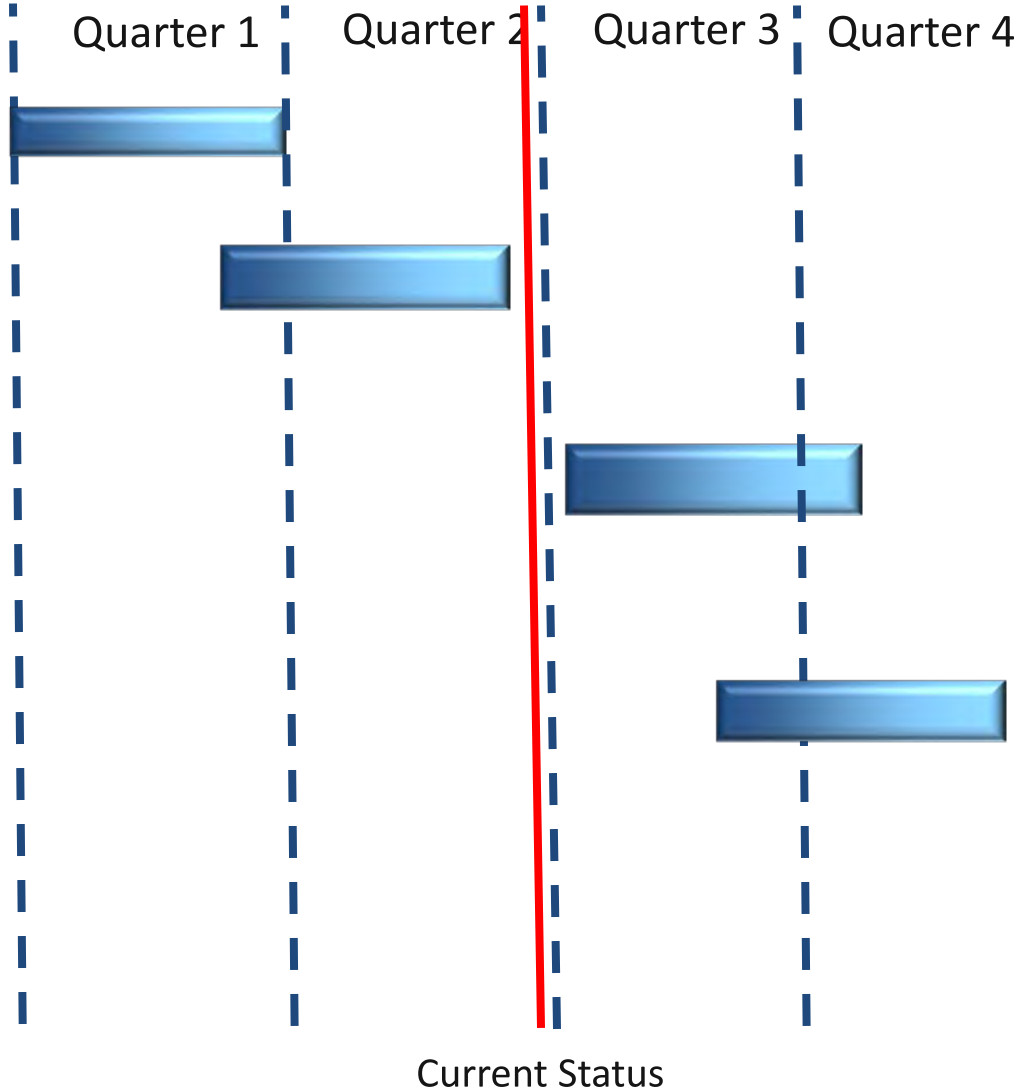
Milestones

EIL testing of conv. vehicle for gasoline, E50 and E85

EIL testing of a series PHEV for Gasoline, E50,and E85

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

Identify potential areas of improvement through steady state maps and simulation

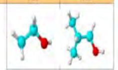


Approach: Leverage Existing Engine-in-the-Loop Set-up, Expertise with Bio-fuels Combustion and PHEV Modeling

Existing Series and Powersplit PHEV models

Existing Expertise in bio-fuel Combustion in SIDI Engine*

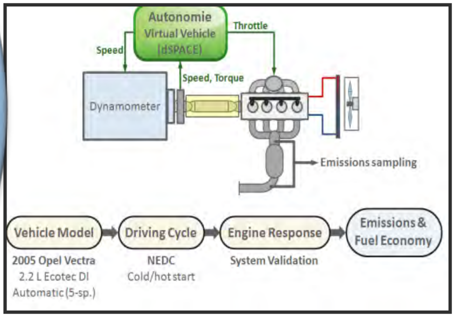
		Gasoline	Ethanol	iso-Butanol
Chemical formula		$C_4 - C_{12}$	C_2H_5OH	C_4H_9OH
Composition (C, H, O)	Mass-%	86, 14, 0	52, 13, 35	65, 13.5, 21.5
Lower heating value	MJ/kg	42.7	26.8	33.1
Density	kg/m^3	715 - 765	790	802
Octane number ((R+M)/2)	-	90	100	103
Stoichiometric air/fuel ratio	-	14.7	9.0	11.2
Latent heat of vaporization	kJ/kg	380 – 500	919	686



1. Quantify impact of ethanol / gasoline blends on FC

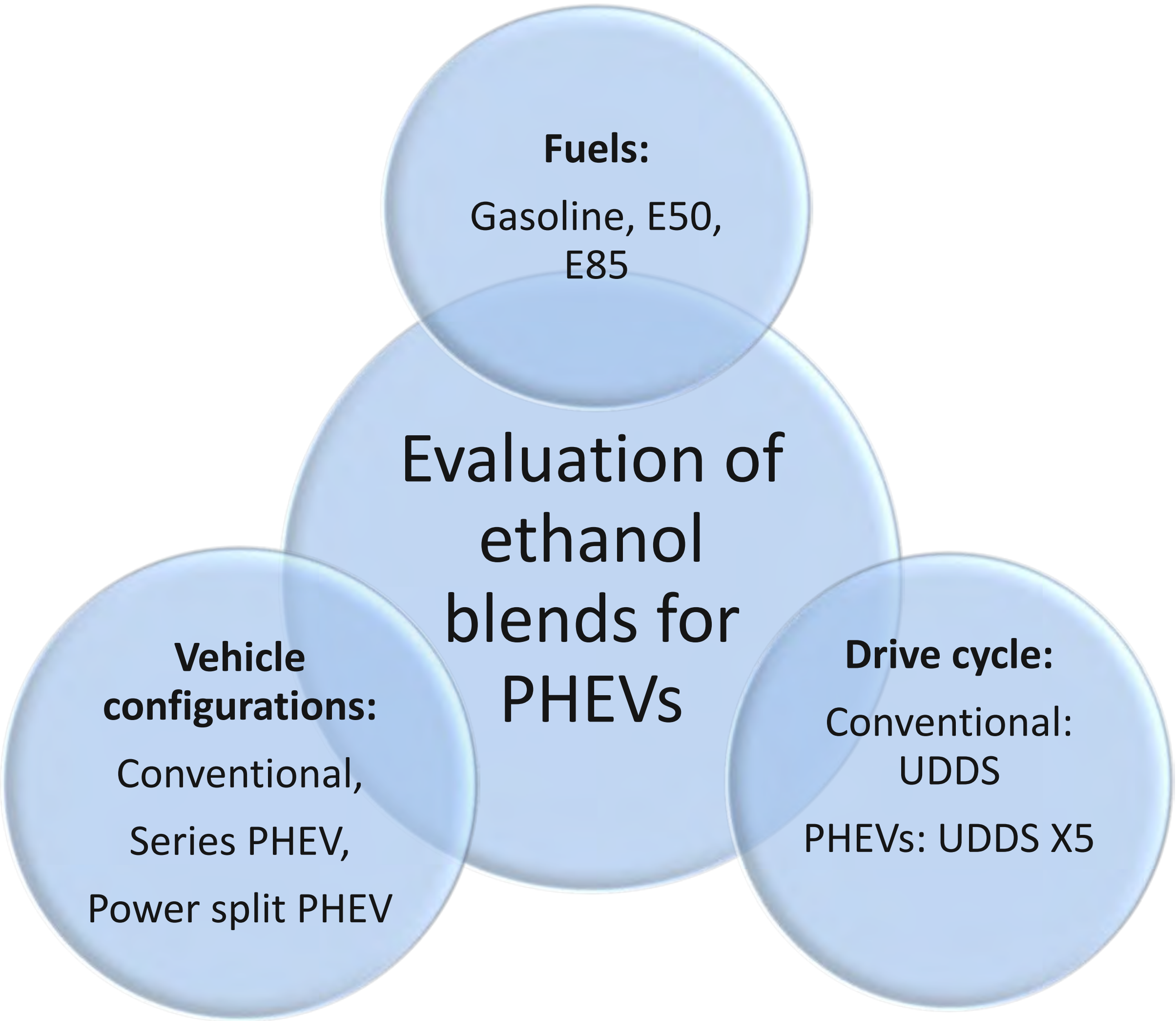
2. Assess sensitivity of different configurations to blend ratios

Existing Operational Engine in the Loop Set-up



* 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

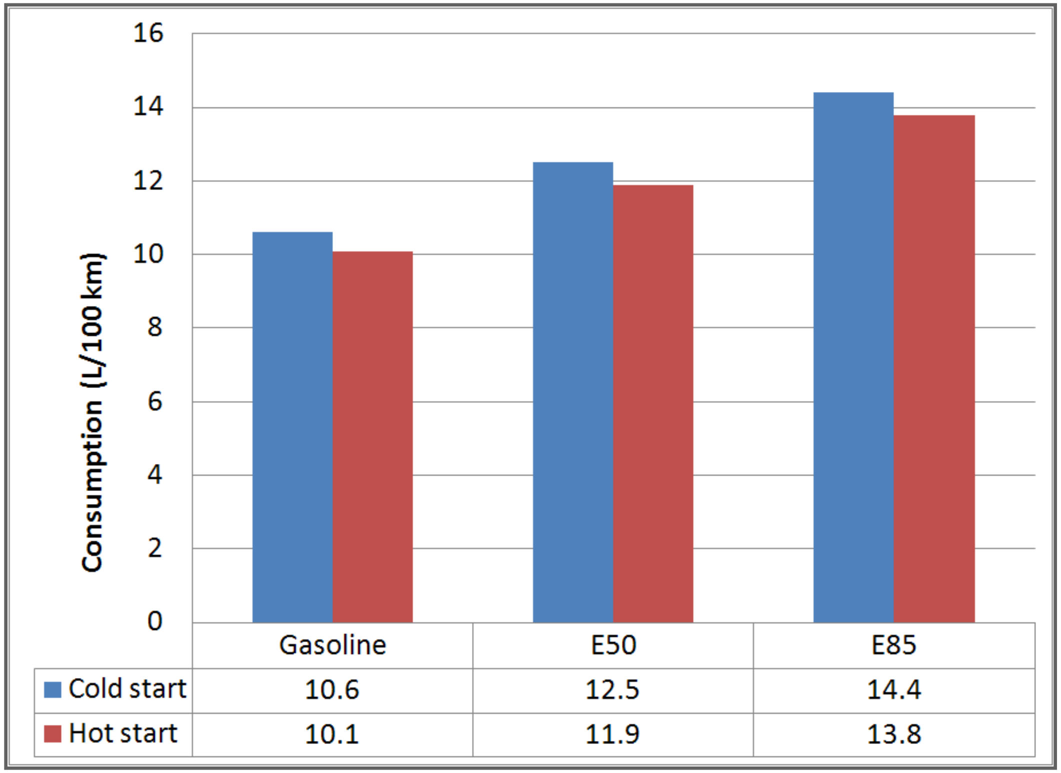
Approach - Design of Experiment



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



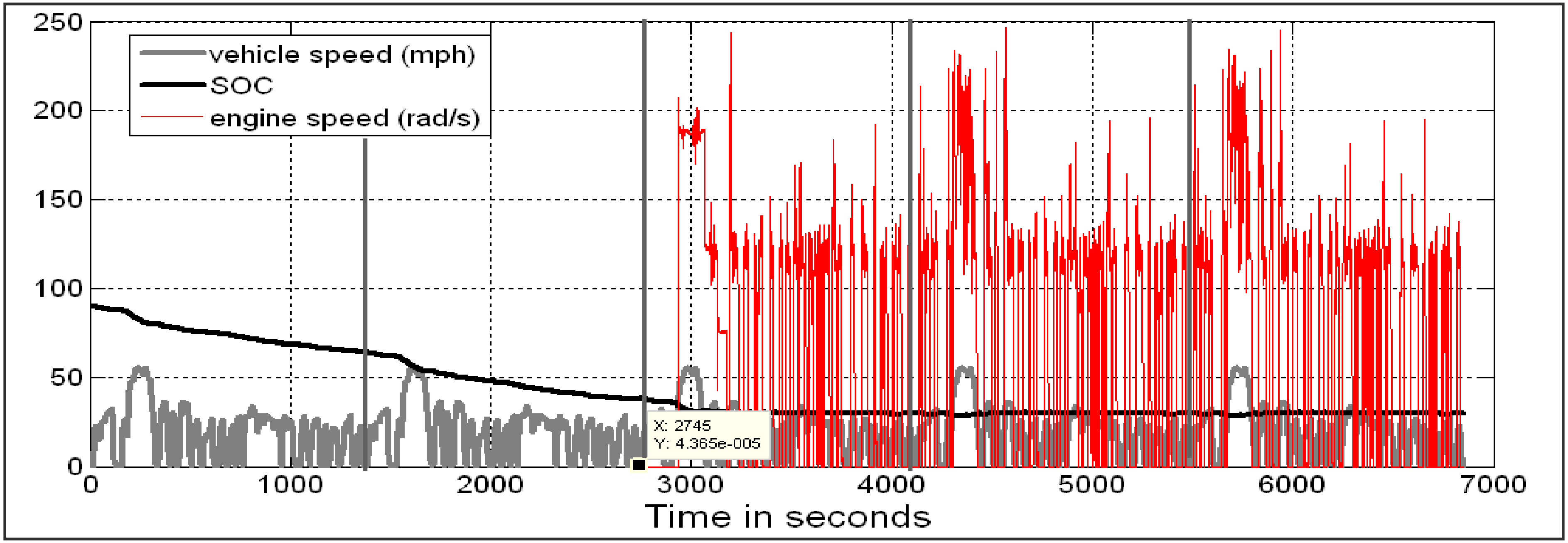
Fuel Consumption Increase	E50	E85
Hot	18.6%	37.2%
Cold	18.4%	35.9%

	Engine cold start penalty over an entire UDDS
Gasoline	5.1%
E50	5.0%
E85	4.5%

Observations:

- Increase in fuel consumption is similar for both hot and cold starts
- Cold start penalty is similar for all fuels

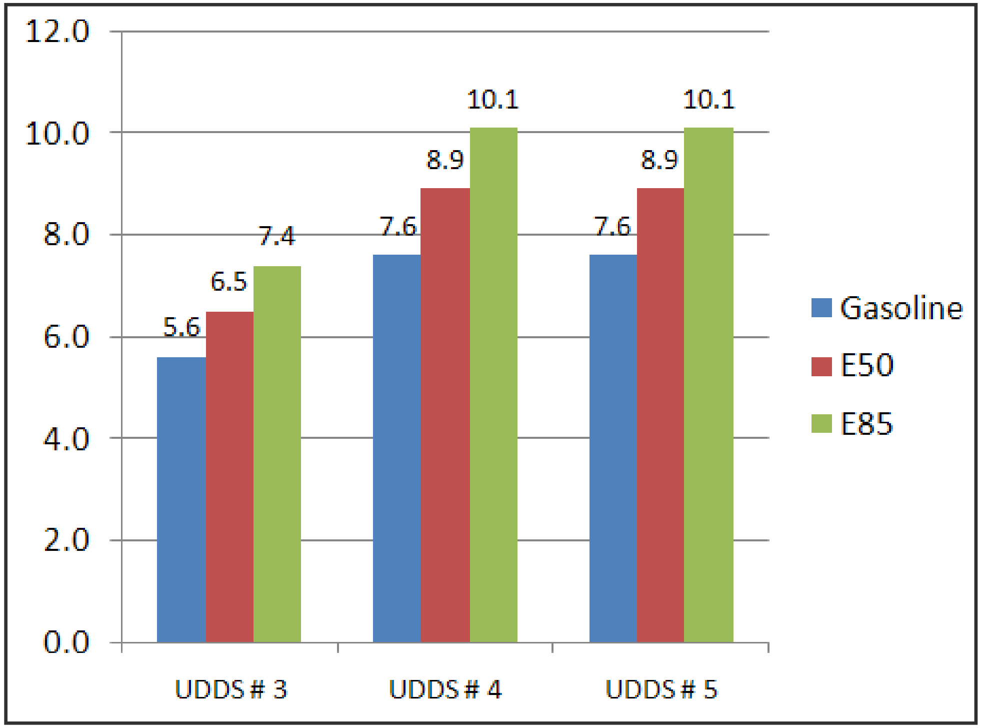
Vehicles Have Identical Behavior for All Fuels



Electrical consumption (Wh/mi)	UDDS # 1 EV	UDDS # 2 EV	UDDS # 3 transition	UDDS # 4 CS	UDDS # 5 CS
Gasoline	369.1	357.2	108	-6.5	-6.5
E50	369.1	357.2	107.3	-6.6	-6.6
E85	369.1	357.2	105.7	-6	-6.5

PHEV Series Test Cycle and Electrical Consumption

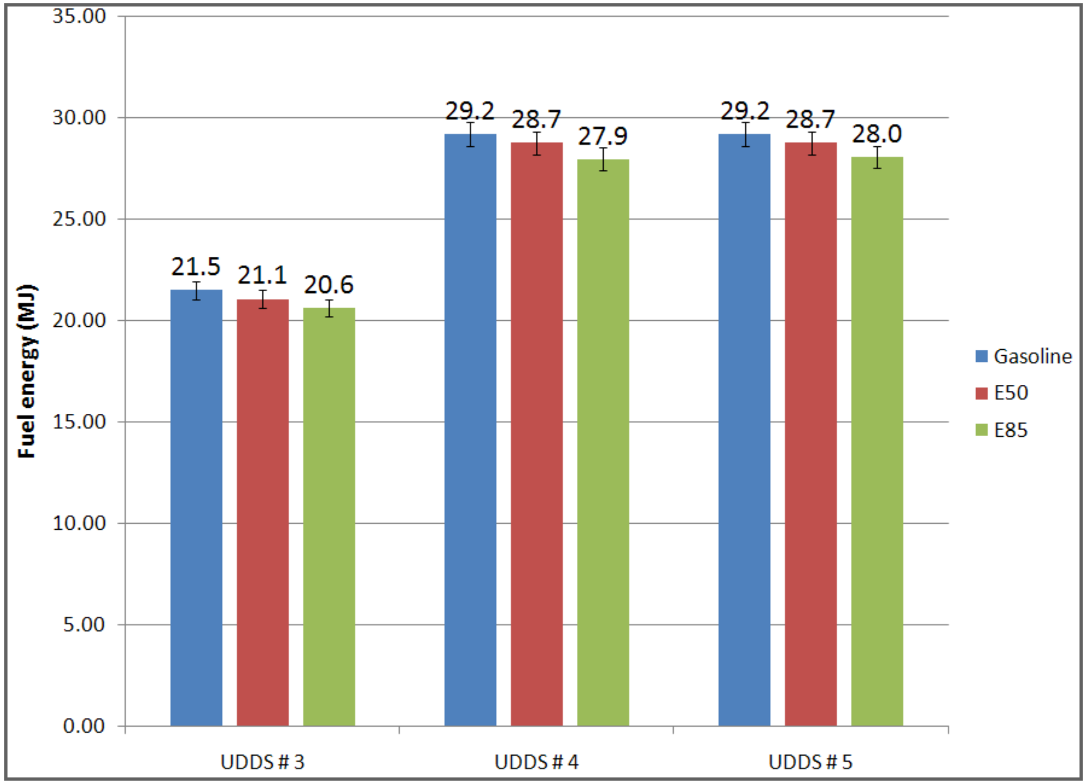
PHEV Fuel Consumption Increases with Higher Ethanol Content



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

% increase in FC compared to gasoline	UDDS # 4	UDDS # 5	Conventional hot start
E50	17.7%	17.9%	18.6%
E85	33.1%	33.6%	37.2%

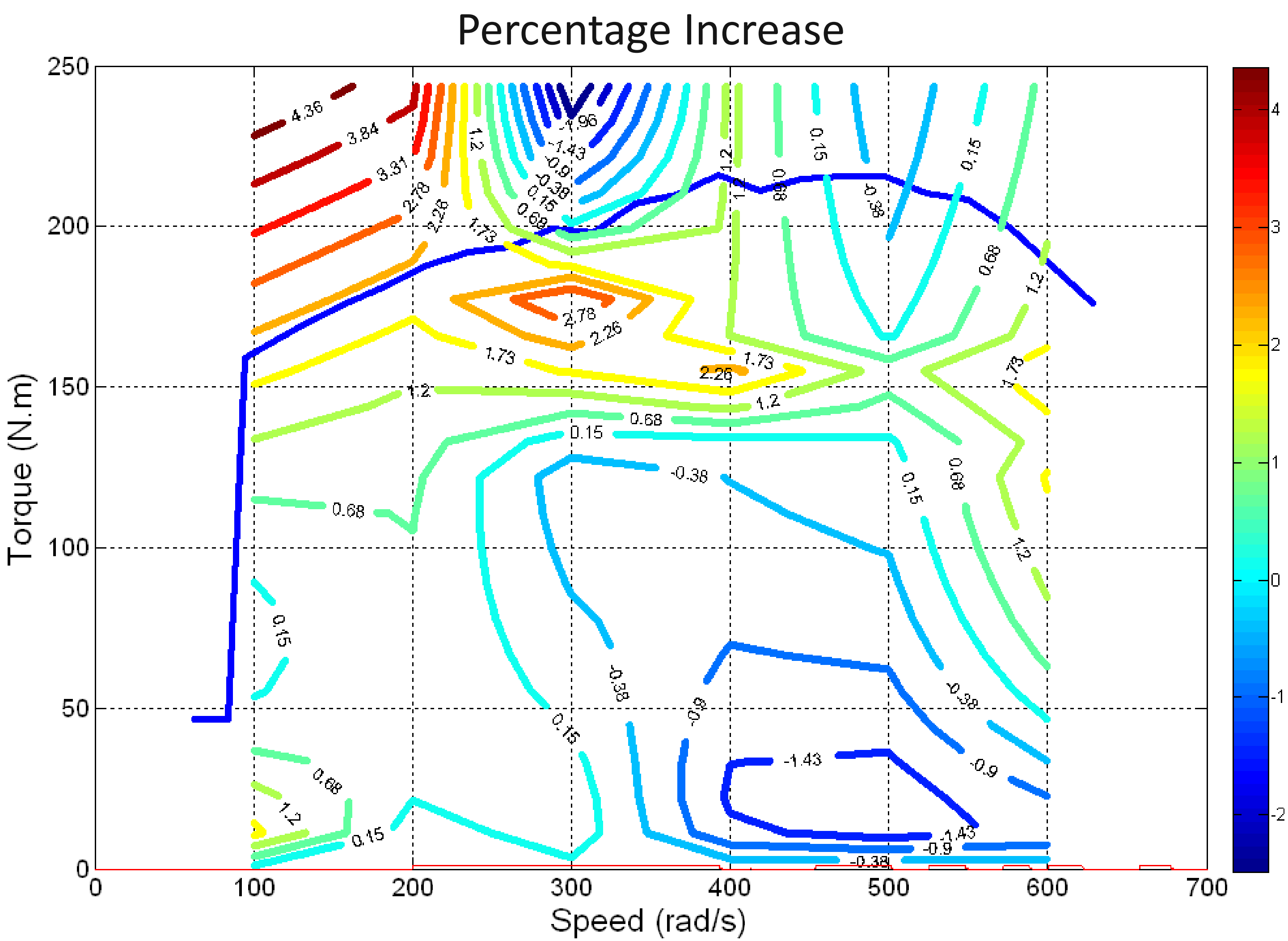
Impact of Ethanol on HEV Fuel Consumption is Lower than for Conventional



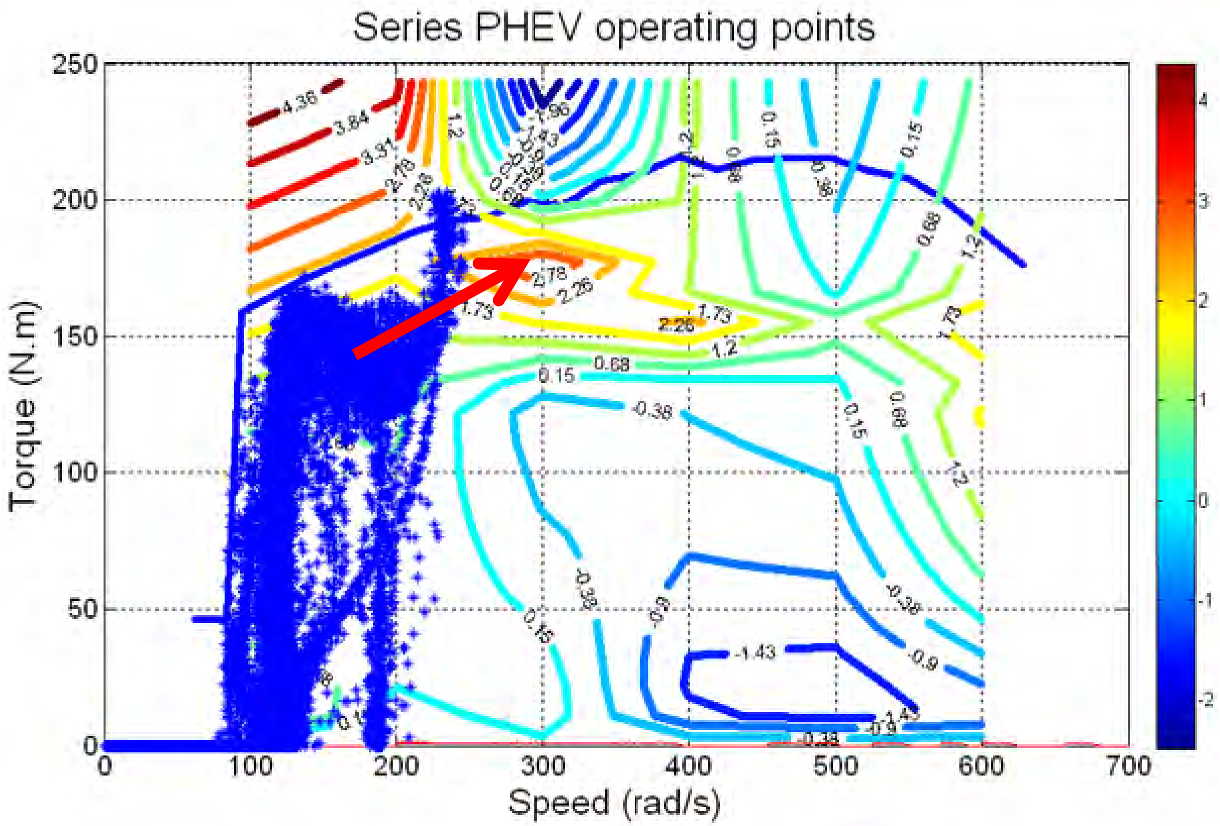
Test to test variation of +/-1% in fuel consumption for the same fuel has been observed

% decrease in fuel energy consumption compared to gasoline	UDDS # 4	UDDS # 5	Conventional hot start
E50	1.4%	1.4%	0.7%
E85	4.2%	3.8%	1.2%

E85 Engine Has Higher Efficiency than for Gasoline

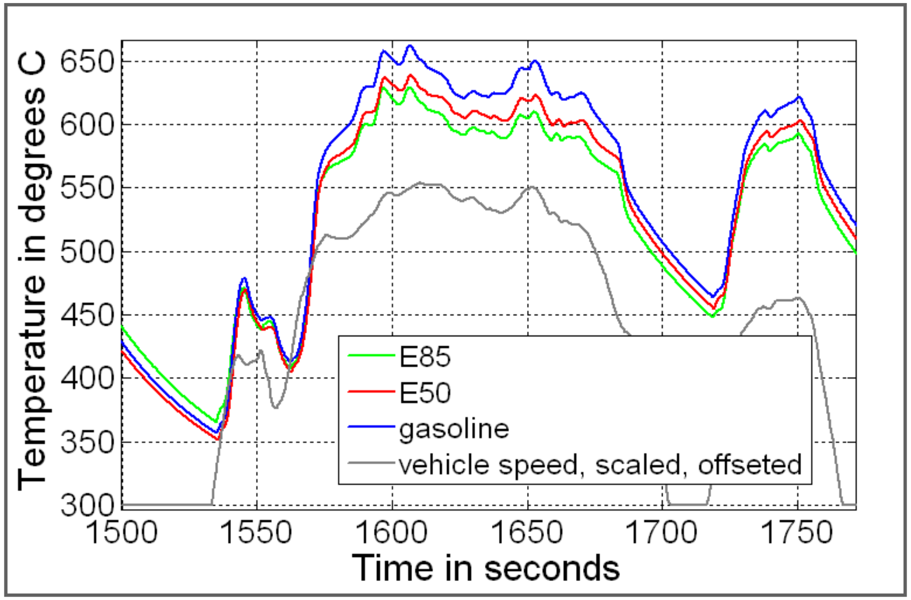


Change in Engine Operating Region for E85 Could Result in Further Fuel Consumption Improvement



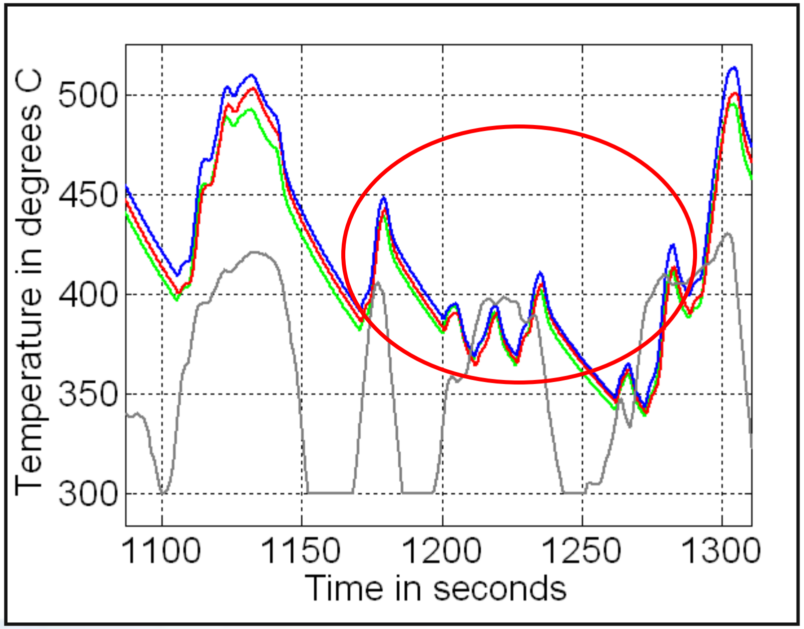
- There is potential for further improvements in fuel economy for ethanol blends by optimizing the vehicle level control strategy
- E50/ E85 engine and generator efficiency maps (for a series PHEV) will be used to determine high efficiency regions for series operation

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

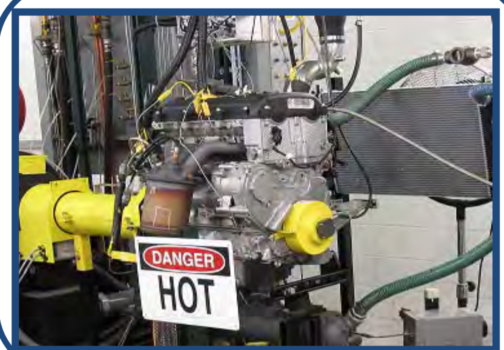
Potential follow-up

- 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

OEM support for ECU Calibration for Ethanol blends

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



DOE technology evaluation
- DOE requests
- National Lab requests

AUTONOMIE
Virtual vehicle ,
PHEV control

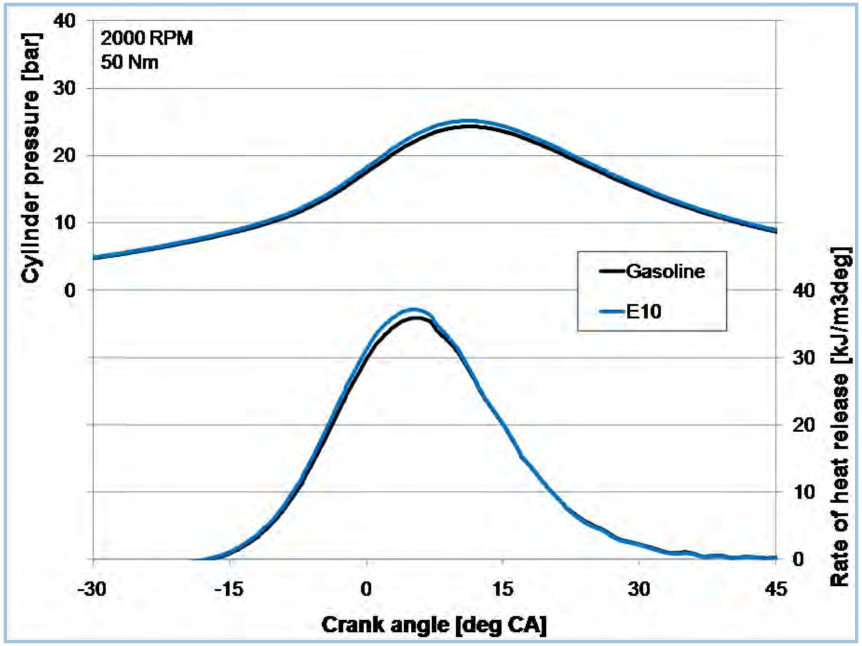
USCAR, tech teams and OEMs
Share test plans, data and analysis

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

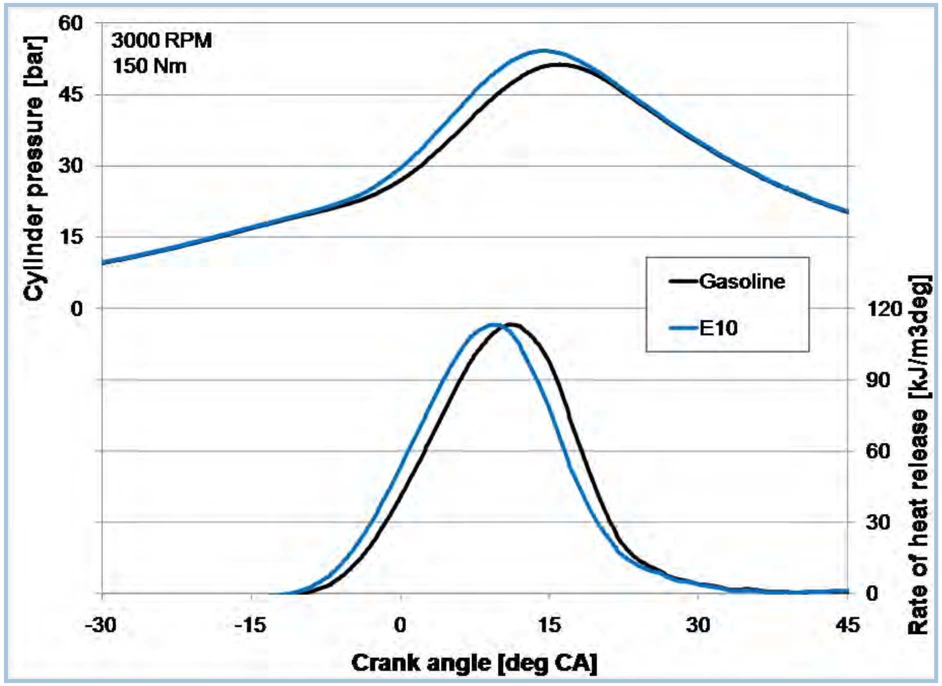
Technical Back-Up Slides

Efficient engine operation with ethanol blends possible because of spark advance



Low engine load

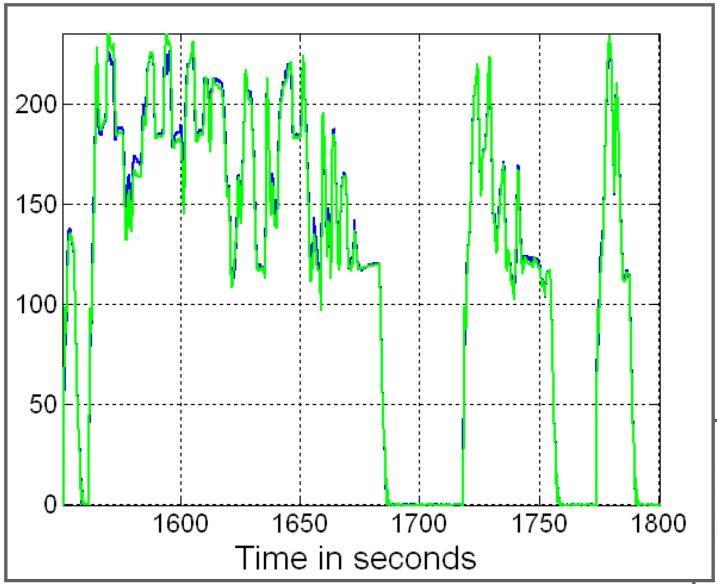
High engine load

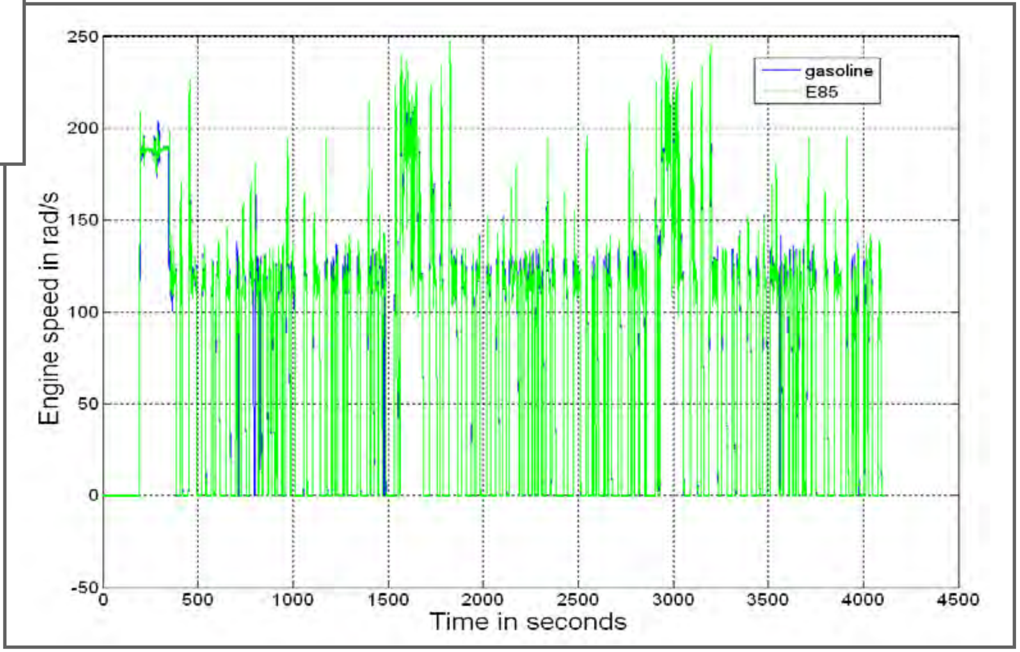


Vehicle assumptions

Parameter	Values (PHEV)	Values (conventional)
GVW	1936 kg	1783 kg
Engine	110 kW , 2.2 L SIDI engine	110 kW , 2.2 L SIDI engine
Electric Machine Power	130 kW / 13000 rpm	N.A.
Generator Power	110 kW / 6000 rpm	N.A.
Battery	41 Ah, 10 kWh Li-ion	
Cd	0.37	0.37
FA	2.54 m2	2.54 m2
Tire	P225_75_R15 (0.359)	P225_75_R15 (0.359)
Fixed ratio	1.6	1.6
Final drive ratio	4	4

PHEV Engine Operation is the Same for Gasoline and E85 – Engine Speed





PHEV Engine Operation is the Same for Gasoline and E85- Engine Torque