Cold-Start Performance and Emissions Behavior of Alcohol Fuels in an SIDI Engine Using Transient Hardware-In-Loop Test Methods

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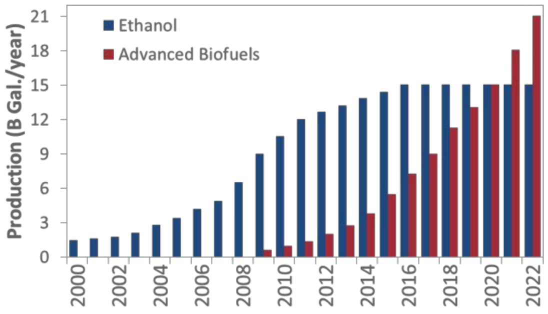
Motivation & Objectives

U.S. Renewable Fuel Standard requires an increase of ethanol and advanced biofuels to 36 billion gallons by 2022.

***iso*-Butanol** as possible advanced biofuel?



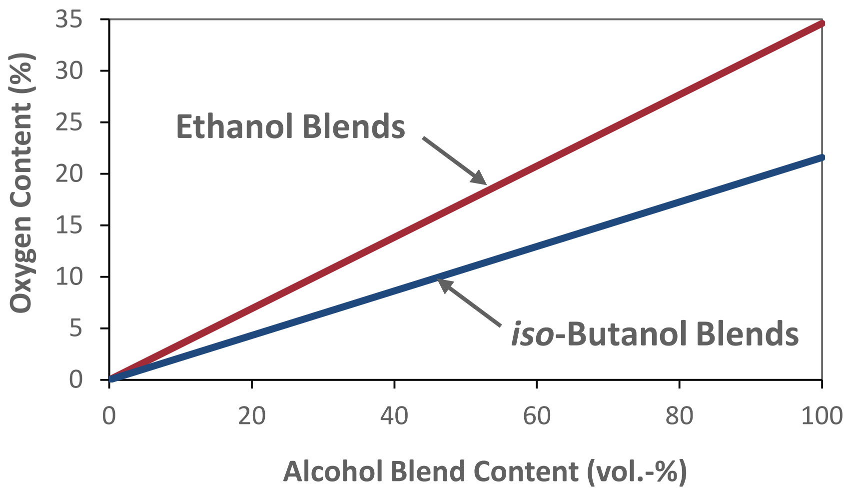
Adapted from: **Renewable Fuels Standard** *(Federal Register,* **75**(58))

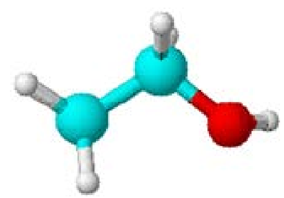
- Assess the potential of gasoline-alcohol fuel blends for use in a direct-injection (DI) spark-ignition (SI) engine.

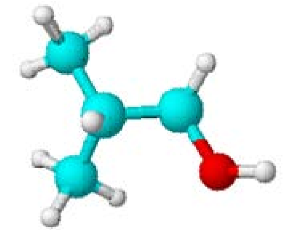
- Utilize Engine Hardware-In-Loop capability to characterize emissions trends over a simulated test cycle.

Comparison of Fuel Properties

		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	741	790	802
Octane number ((R+M)/2)[1]	-	93	100	103
Stoichiometric air/fuel ratio	-	14.7	9.0	11.2
Latent heat of vaporization[2]	kJ/kg	380 – 500	919	686
Boiling Point[1]	°C	29 (IBP)	78	108

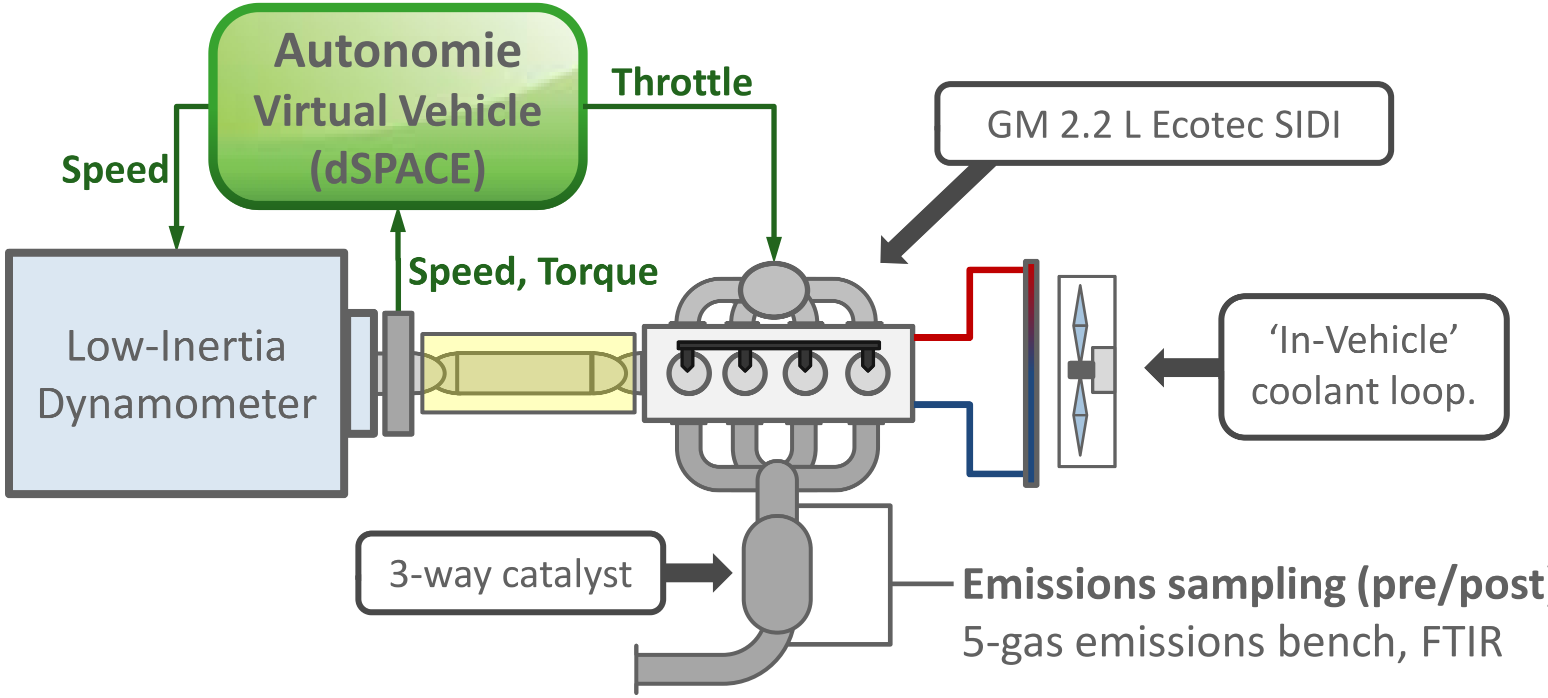






[1]Measured for gasoline, typical reference values for alcohols
[2]Typical reference values

Engine Hardware-In-Loop Concept



Vehicle Model → **Driving Cycle** → **Engine Response** → **Emissions & Fuel Economy**

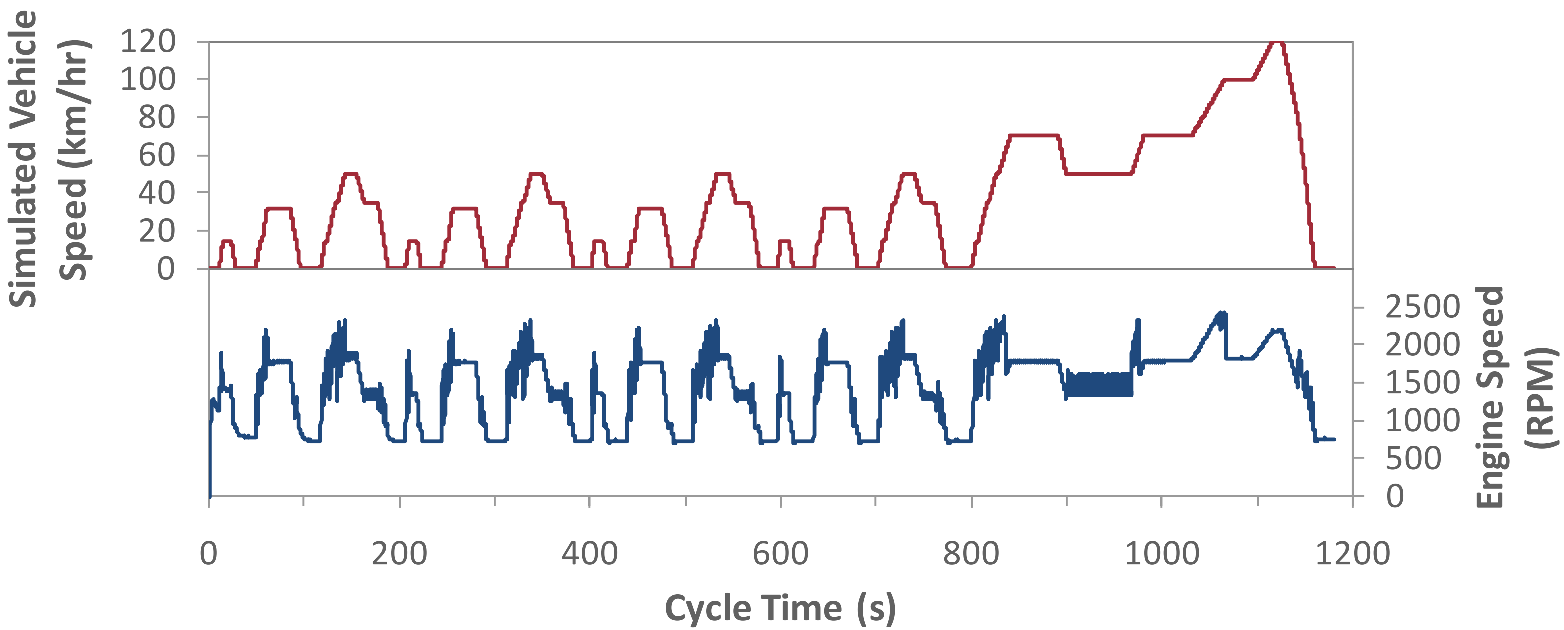
2005 Opel Vectra
2.2 L Ecotec DI
Automatic (5-sp.)

NEDC
Cold/hot start

System Validation

Cycle Fuel Consumption, Emissions Mass

Experimental Methods: Cycle and Validation



Gasoline Validation

Fuel Consumption

	Vehicle	Engine HIL
ECE-15	11.3	**12.4**
EUDC	6.1	**6.5**
NEDC	8.0	**8.7**
	l/100km	l/100km

Emissions

	Euro 4	Engine HIL
NOx	< 0.1	**0.02** ± 0.01
CO	< 1	**0.7** ± 0.2
HC	< 0.068	**0.03** ± 0.01
	g/km	g/km

Experimental Methods for Fuels Testing

Test Fuels

Gasoline

E50

E85

isoBut83

Constant oxygen content (18%-mass)

Comparable alcohol content

Engine Modifications

GM 2.2L Ecotec SIDI (European spec. engine, not ‘flex-fuel’)

ECU calibration change made for alcohol fuels

+18% fueling for E50/isoBut83

+30% fueling for E85

Conditions and Sampling Locations

Fuel variation:

Gasoline *v.* Ethanol Blends *v.* *iso*-Butanol Blend

Hot-Start

TWC at operational temperatures

Cold-Start

TWC initially non-operational

Engine not at operating temperature

Problematic for alcohol blends?

Pre-TWC Emissions

- Emissions trends comparable to those of steady state data

Post-TWC Emissions

- Full conversion in TWC yields near-zero emissions

Pre-TWC Emissions

- Useful for diagnosing engine behavior

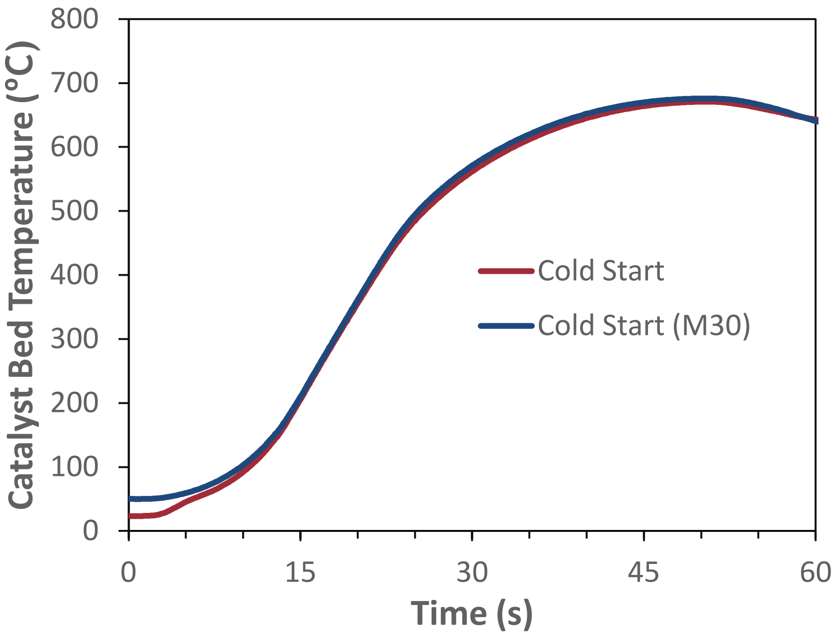
Post-TWC Emissions

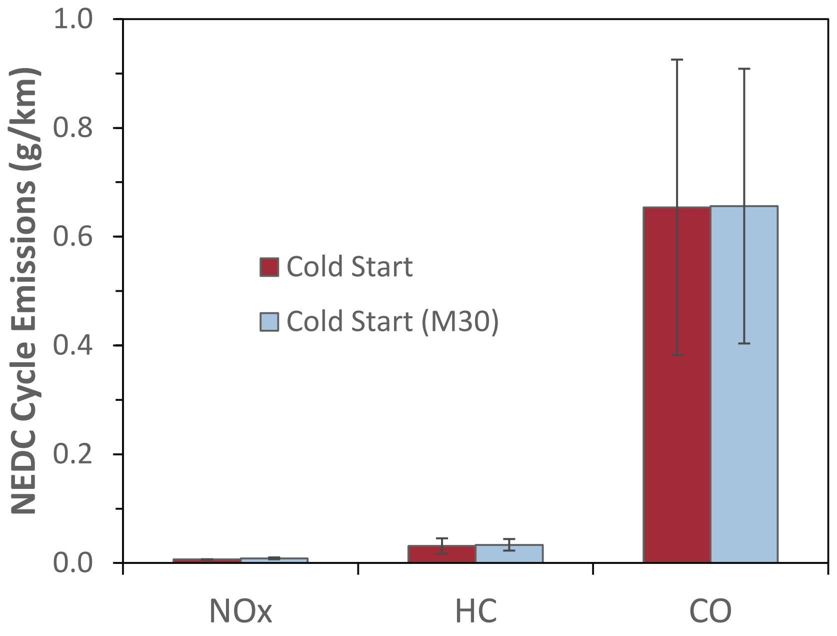
- Levels are subject to regulation

Modified ‘Cold Start’ for High Alcohol Fuels

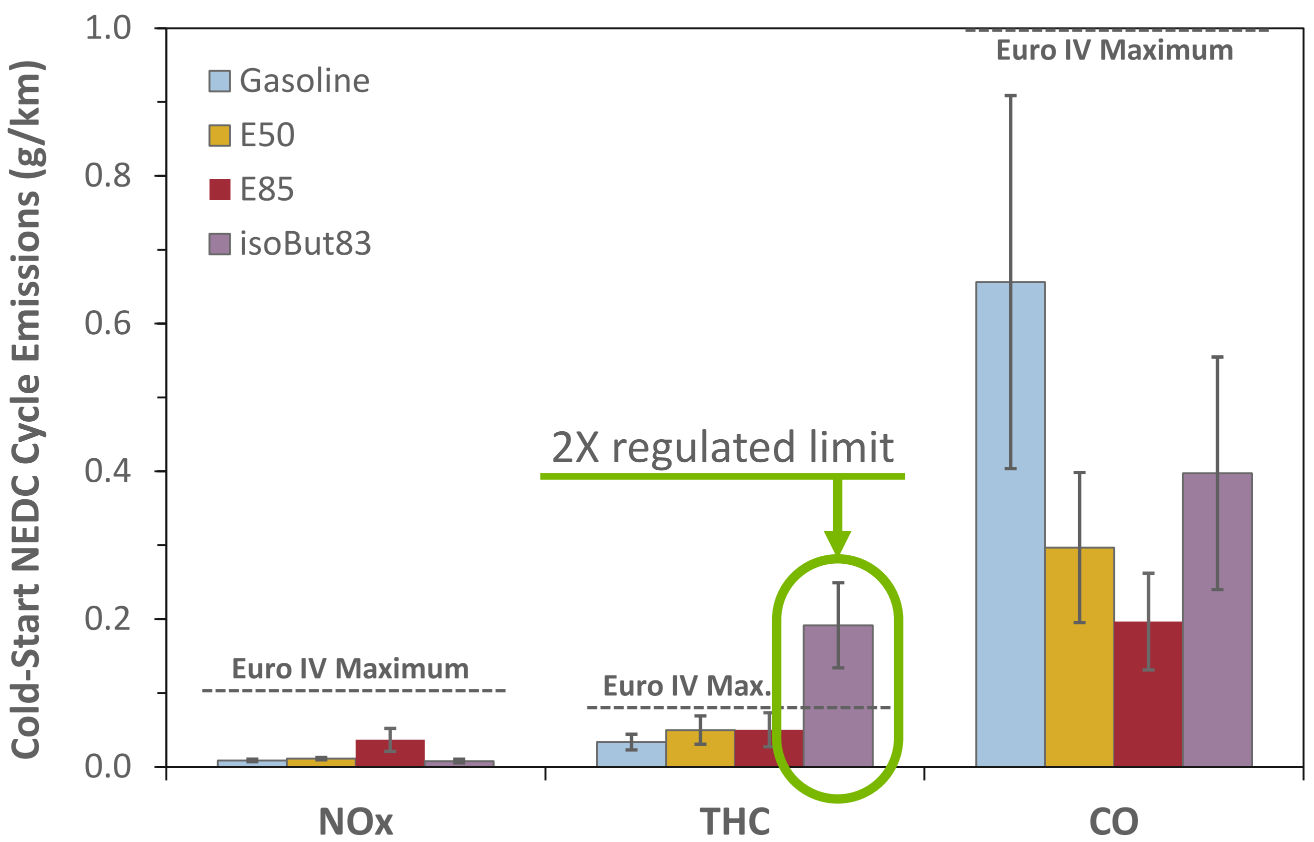
Initial Problem: Engine would not start (reliably) with high alcohol blends

Solution: modified ‘cold-start’ procedure
- Motor engine at 1000 rpm until coolant temperature reaches 30°C
- Execute ‘cold-start’ (M30)



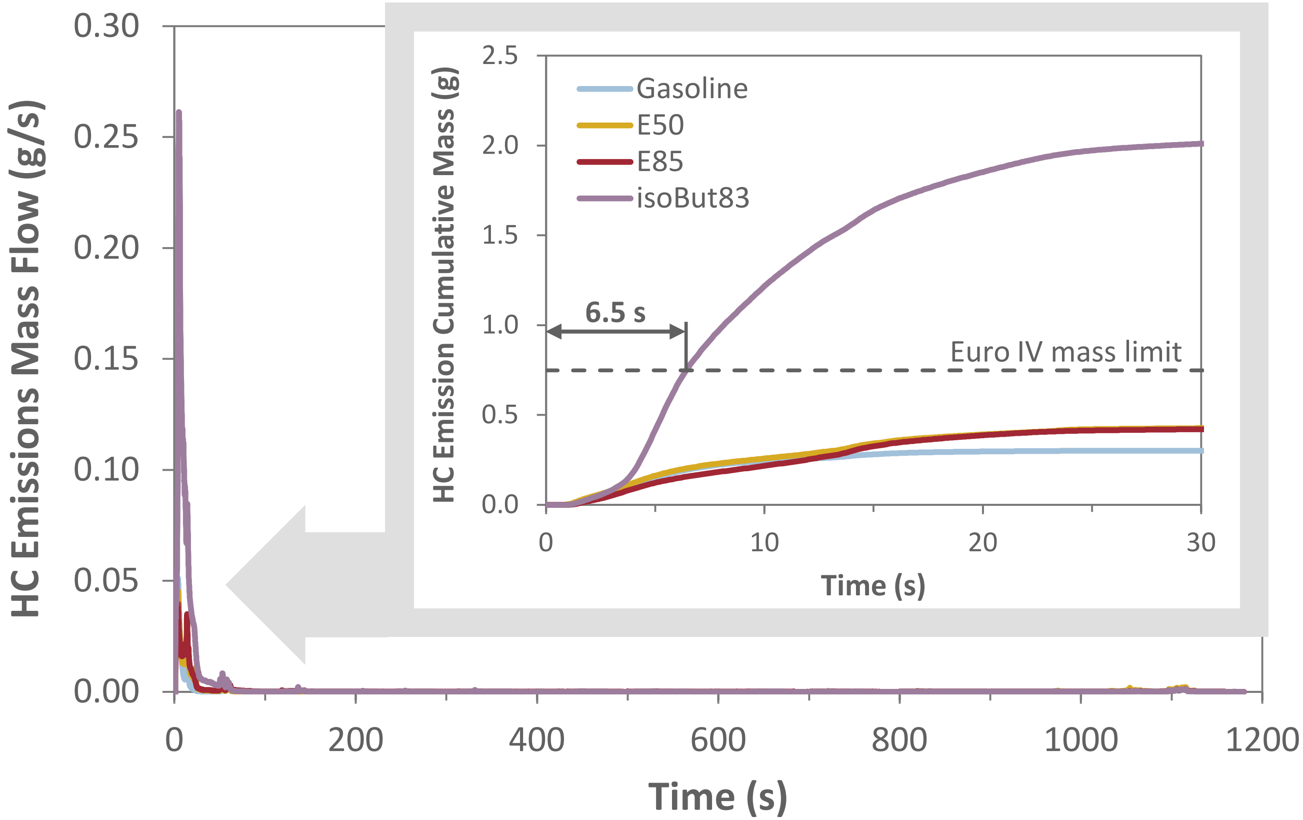


Cycle Emissions Results



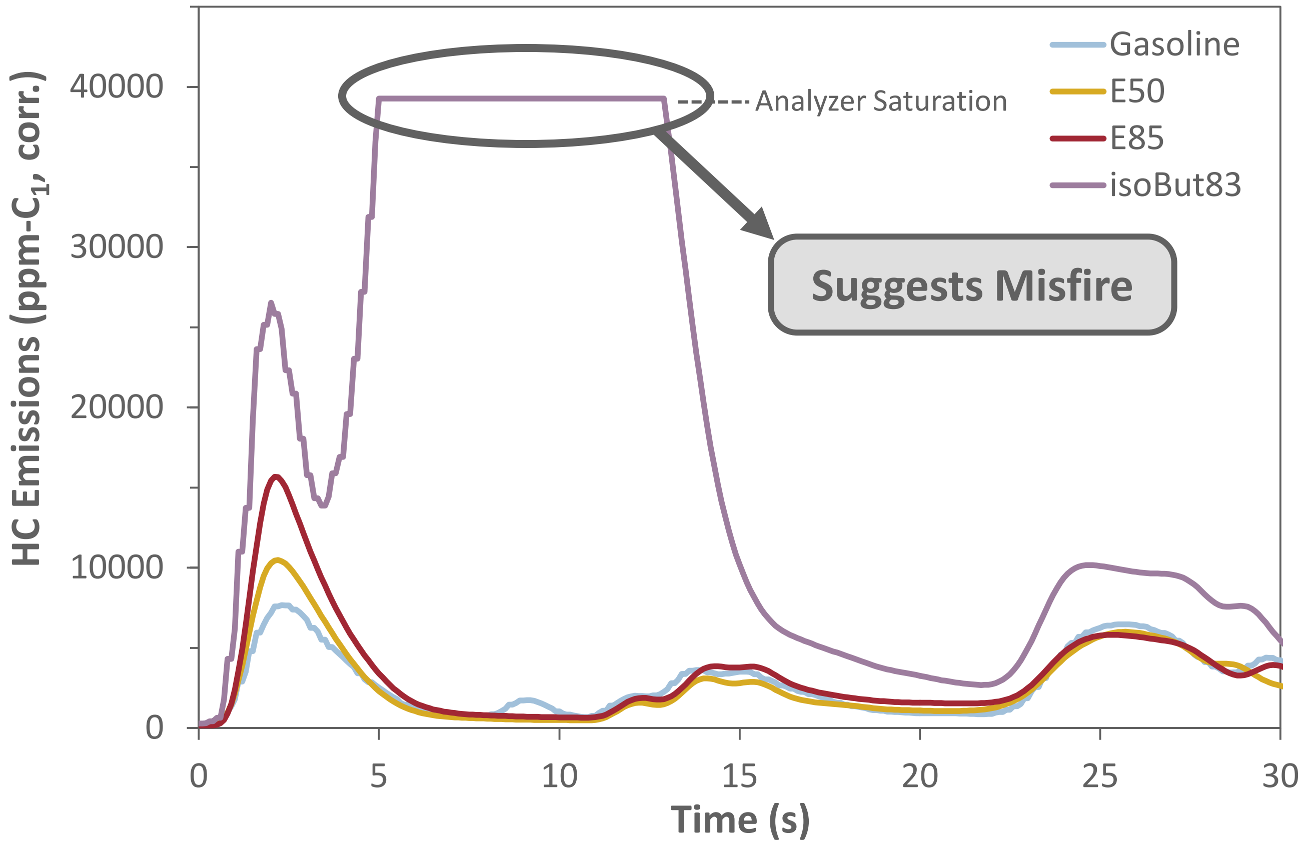
NEDC, cold-start, post-TWC emissions

Hydrocarbon Mass Emissions with Time



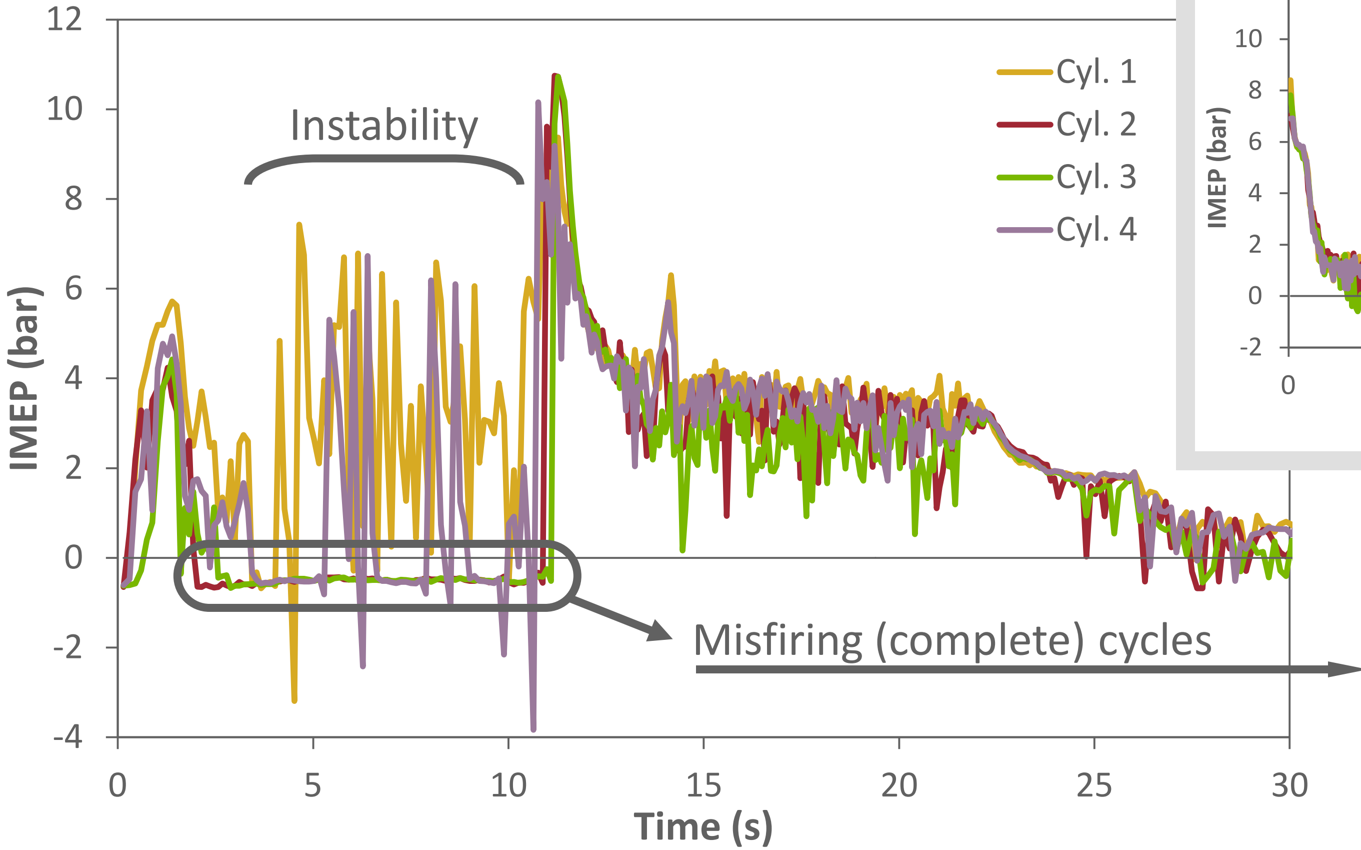
NEDC, Cold-Start (M30), post-TWC hydrocarbon emissions

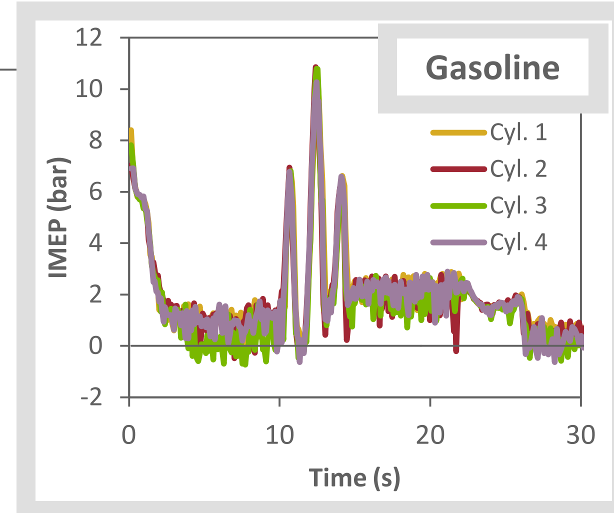
Hydrocarbon Levels Engine-Out



NEDC, cold-start (M30), pre-TWC hydrocarbon emissions

Combustion Instability with *iso*-Butanol83 During Initial Idle Period

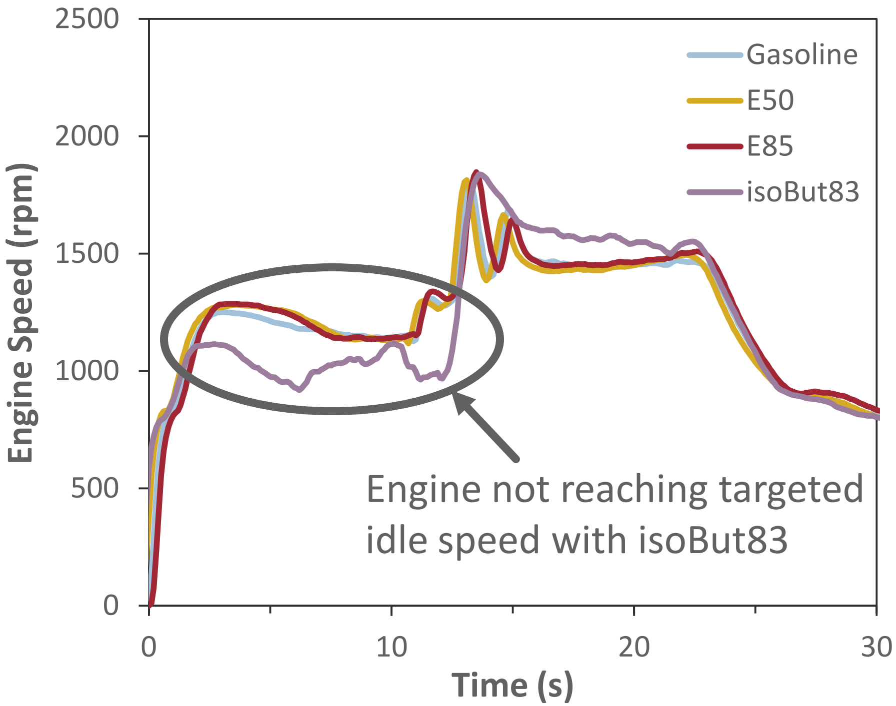


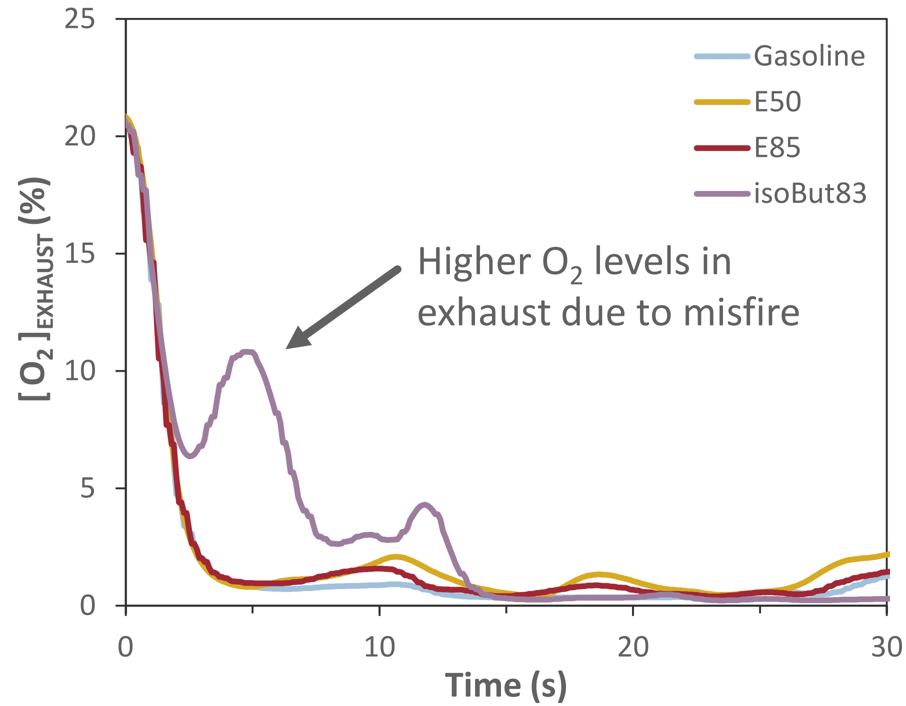


Cylinder	Cycles Misfiring
#1	9
#2	74
#3	72
#4	40

NEDC, cold-start (M30), *iso*-Butanol83 fuel

Engine Behaviors Effecting ECU Responses

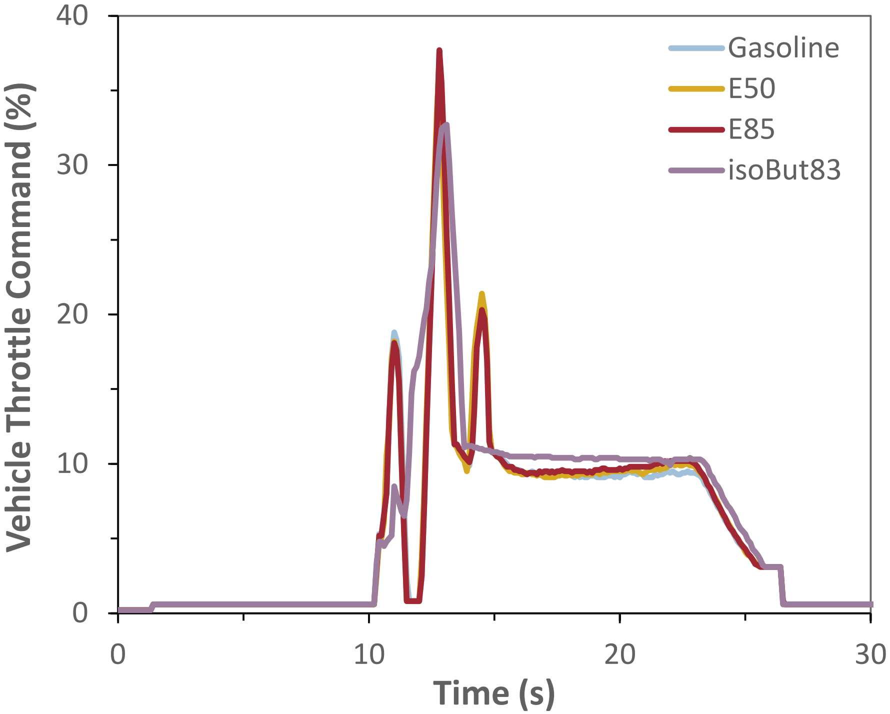


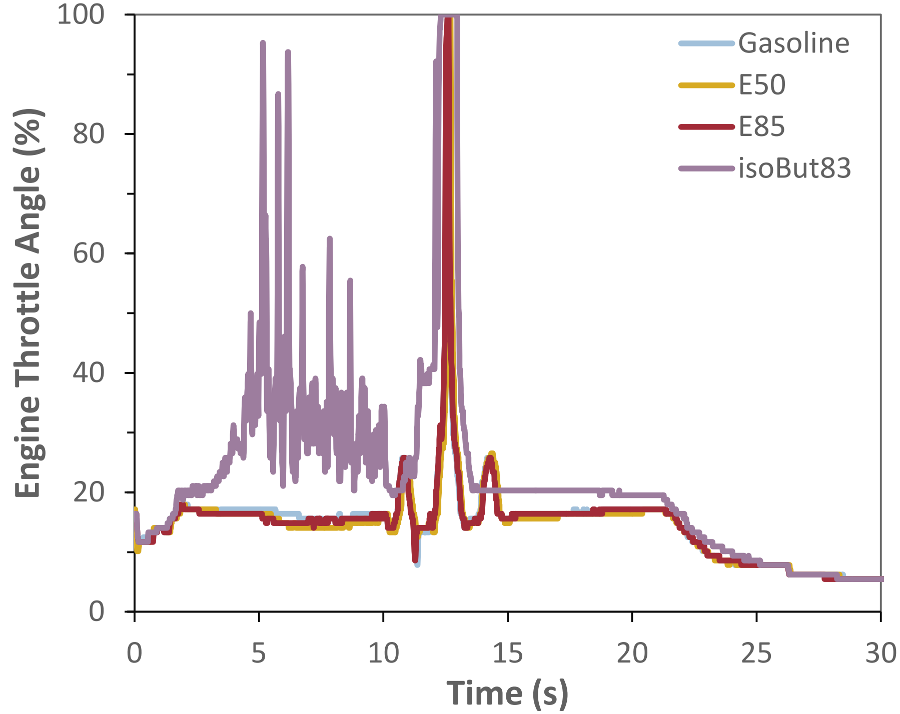


Engine Underspeed at Idle

Increased Exhaust Oxygen Concentration

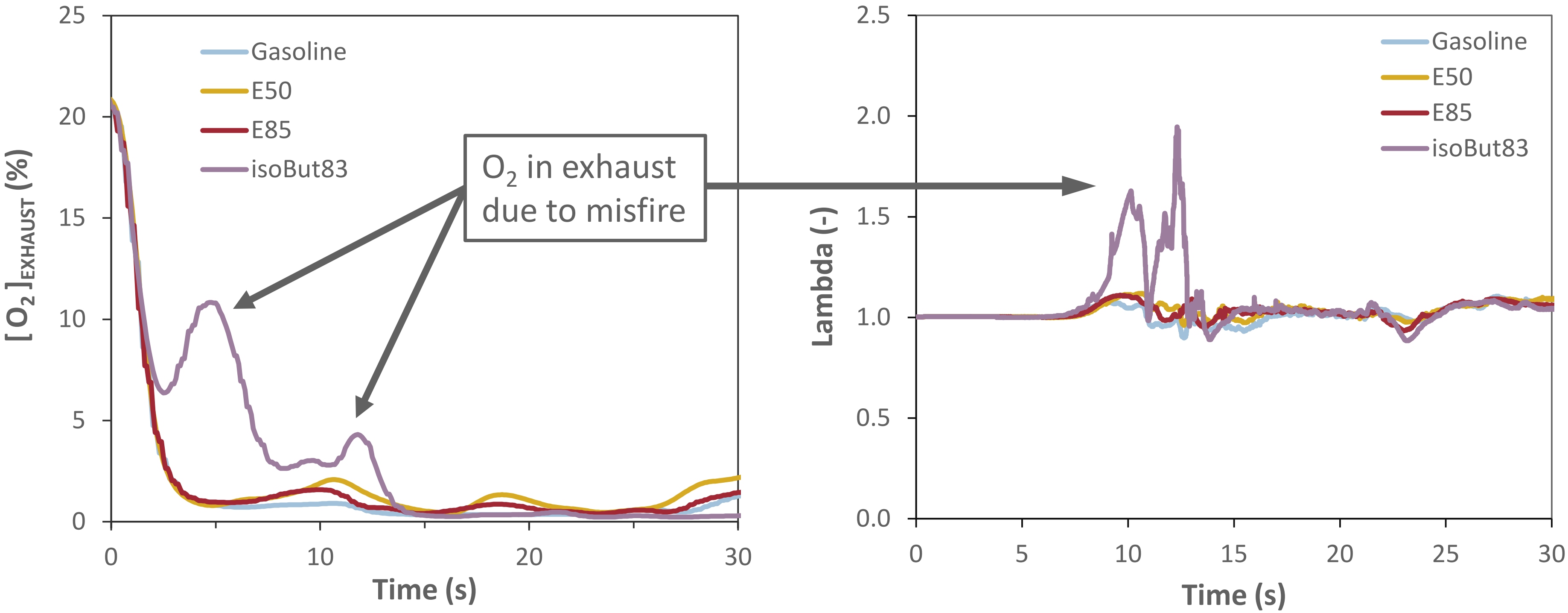
Engine Underspeed & System Reaction





Vehicle Command → ECU Command to Throttle

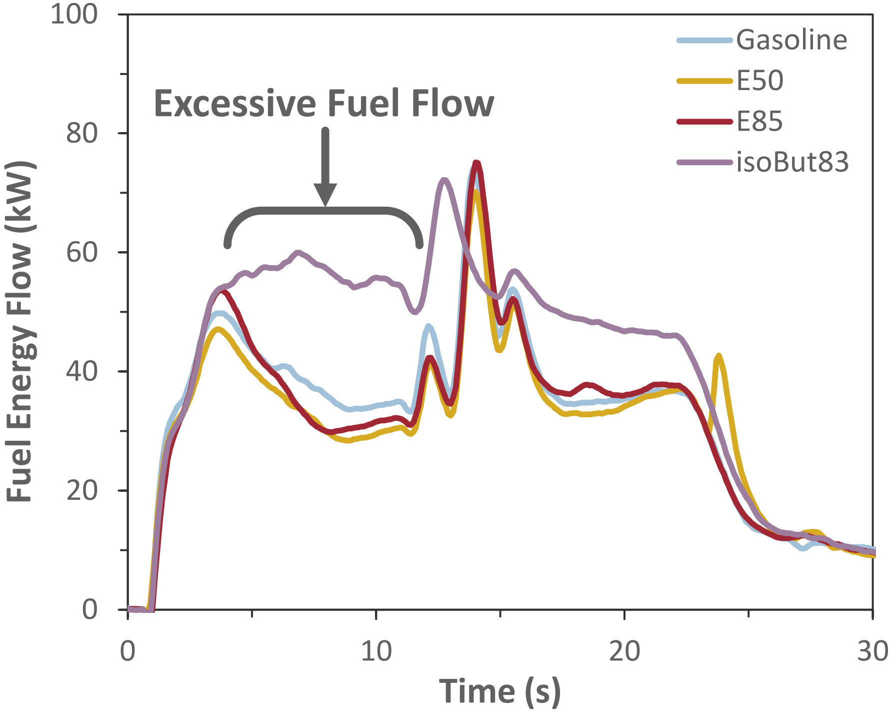
Lean Lambda Signal with *iso*-Butanol83 Misfire



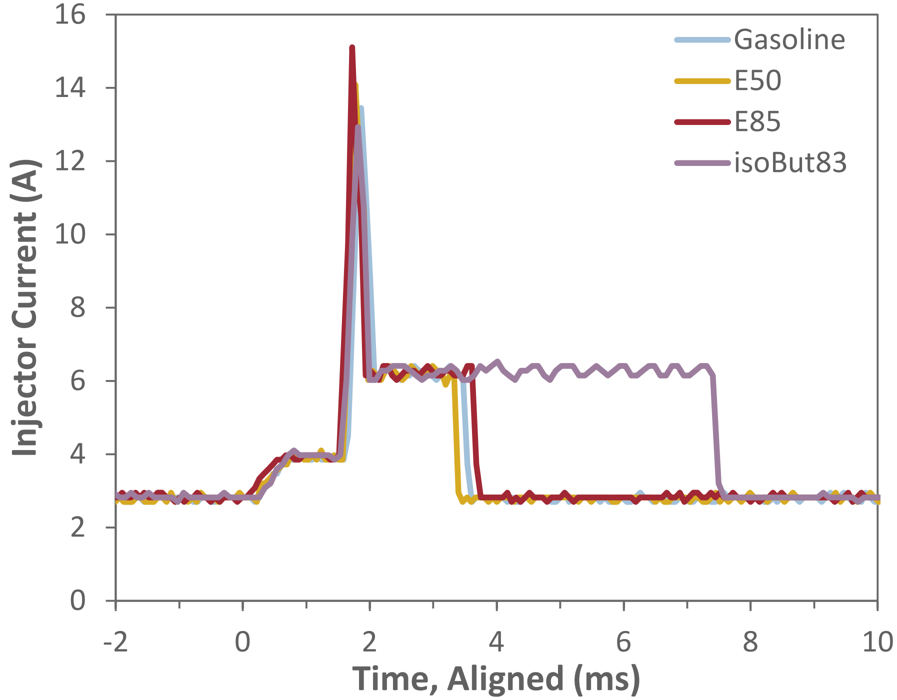
Exhaust Oxygen Content

ECU Lambda Signal

Increased Fuel Flow with *iso*-Butanol83



Measured Fuel Flow



Injection at Time = 6 s.

Conclusions & Future Opportunities

- Highlights cold-start as a significant limitation to the “drop-in” potential of high level *iso*-butanol blends as a gasoline replacement fuel.
- Persistent misfire during initial cold-start idle period responsible for high HC emissions, and failure to meet emissions targets, using blend of 83% *iso*-butanol with gasoline.
- Comparable behavior was not attained with near matched blend of ethanol and gasoline (E85).

- Opportunities lie in (1) development of cold-start control strategies for high alcohol fuels like *iso*-butanol and (2) developing a detailed understanding physical behavior of fuels under initial engine start conditions.

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