Impact of ethanol and butanol as oxygenates on SIDI engine efficiency and emissions using steady-state and transient test procedures

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  - Thomas Wallner
  - Neeraj Shidore

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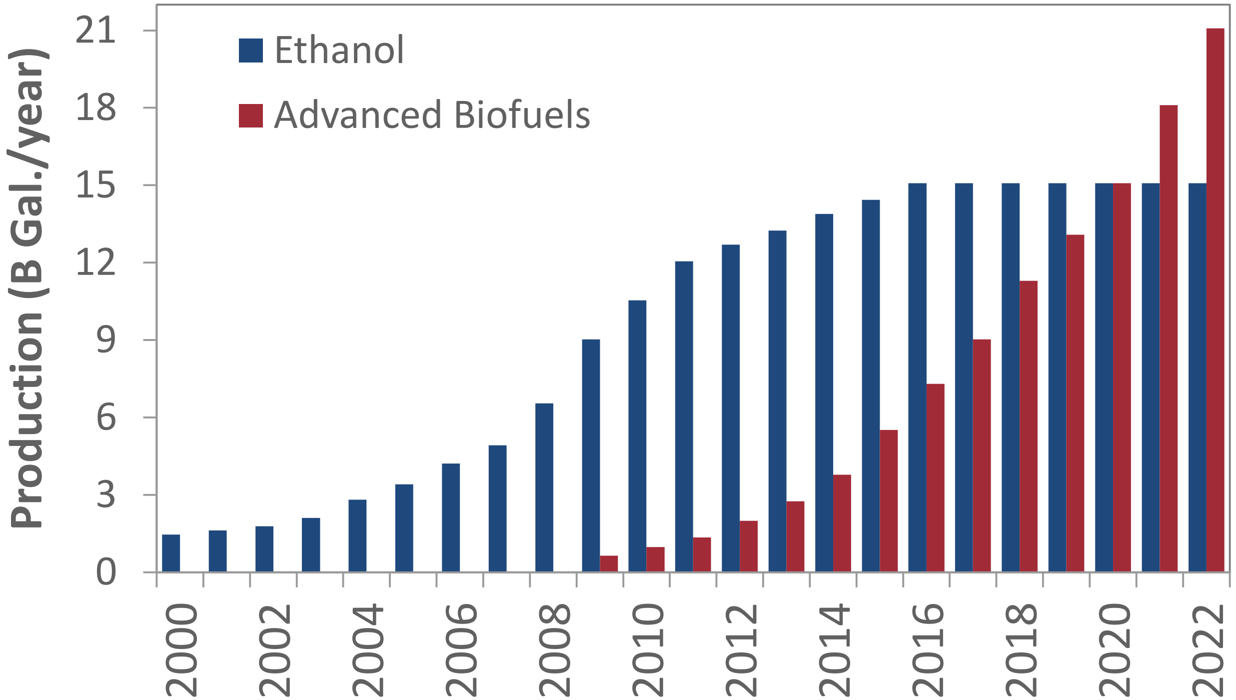
  - Lee Slezak
  - Kevin Stork
  - Gupreet Singh

Background & Motivation



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

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?

Objectives

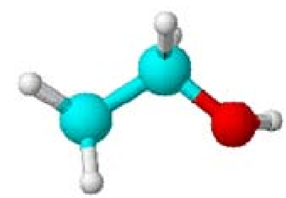
- Assess the potential of blending gasoline with several alcohol fuels for use in a gasoline direct injection (DI) spark ignition (SI) engine.

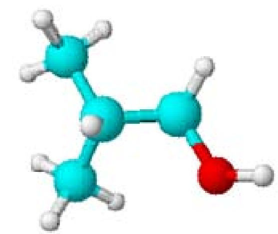
- Evaluate the effect of ethanol and butanol addition on regulated and non-regulated emissions compared to gasoline baseline.

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

Fuel Specifications

		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





Ethanol Blends	Fuel Oxygen (%-mass)	Butanol Blends
E10	**3.7**	**iso-But16**
E50	**18**	**iso-But83**

Constant oxygen mass content

Blend lower heating values

Gasoline: 42 MJ/kg

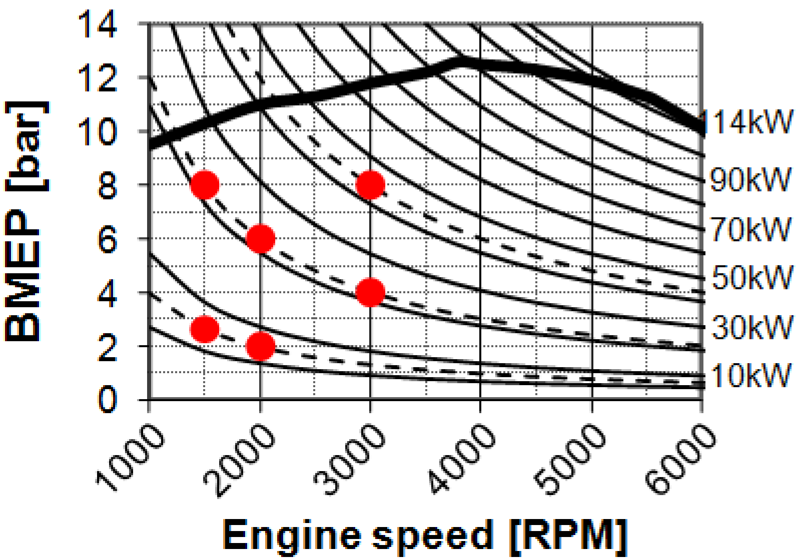
E10/B16: 41 MJ/kg

E50/B83: 35 MJ/kg

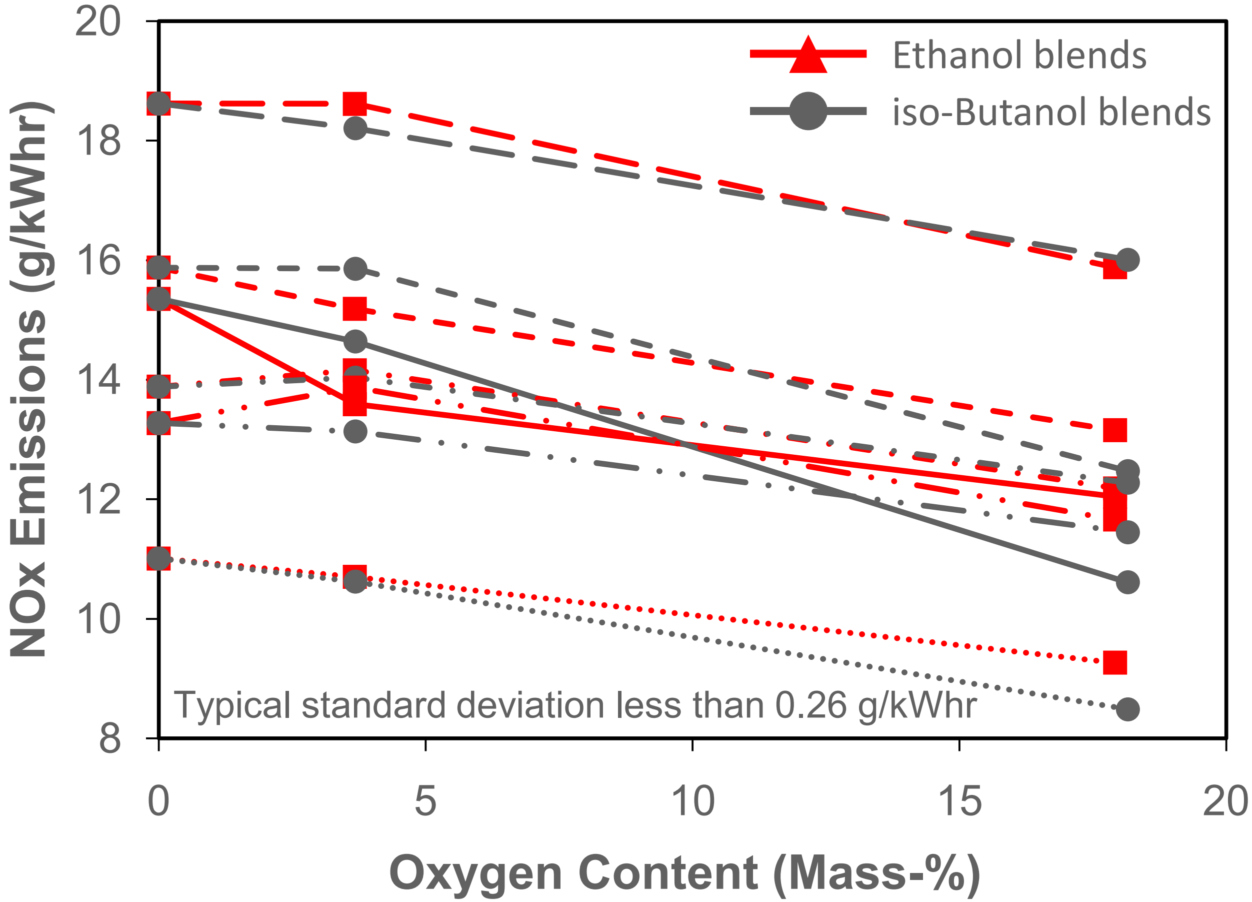
Experimental Methods - Steady State Testing

- **Opel 2.2 l Ecotec Direct (GM L850)**
  - SIDI 4-Cylinder Engine, no VVA
  - ECU calibrated for gasoline
- **Emissions measurement**
  - Horiba MEXA Model 7100D-EGR
  - AVL Sesam FTIR

- **Typical vehicle operating points**
  - Constant speed
  - Constant load
  - Constant power
- **Engine-out (no TWC) emissions**



Regulated Emissions

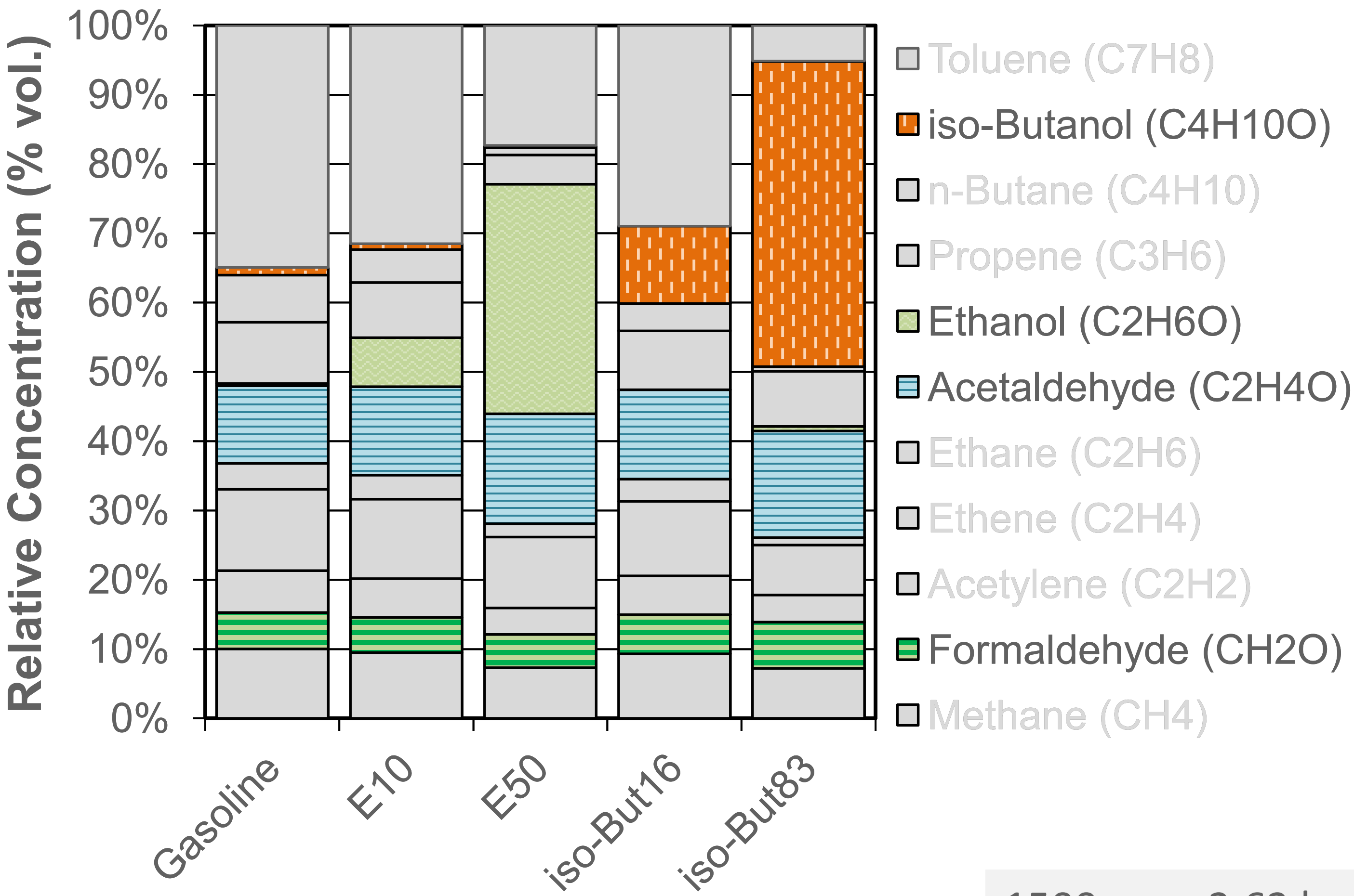


Operating Points

3000 rpm, 4 bar
2000 rpm, 2 bar
1500 rpm, 2.62 bar
2000 rpm, 6 bar
3000 rpm, 8 bar
1500 rpm, 8 bar

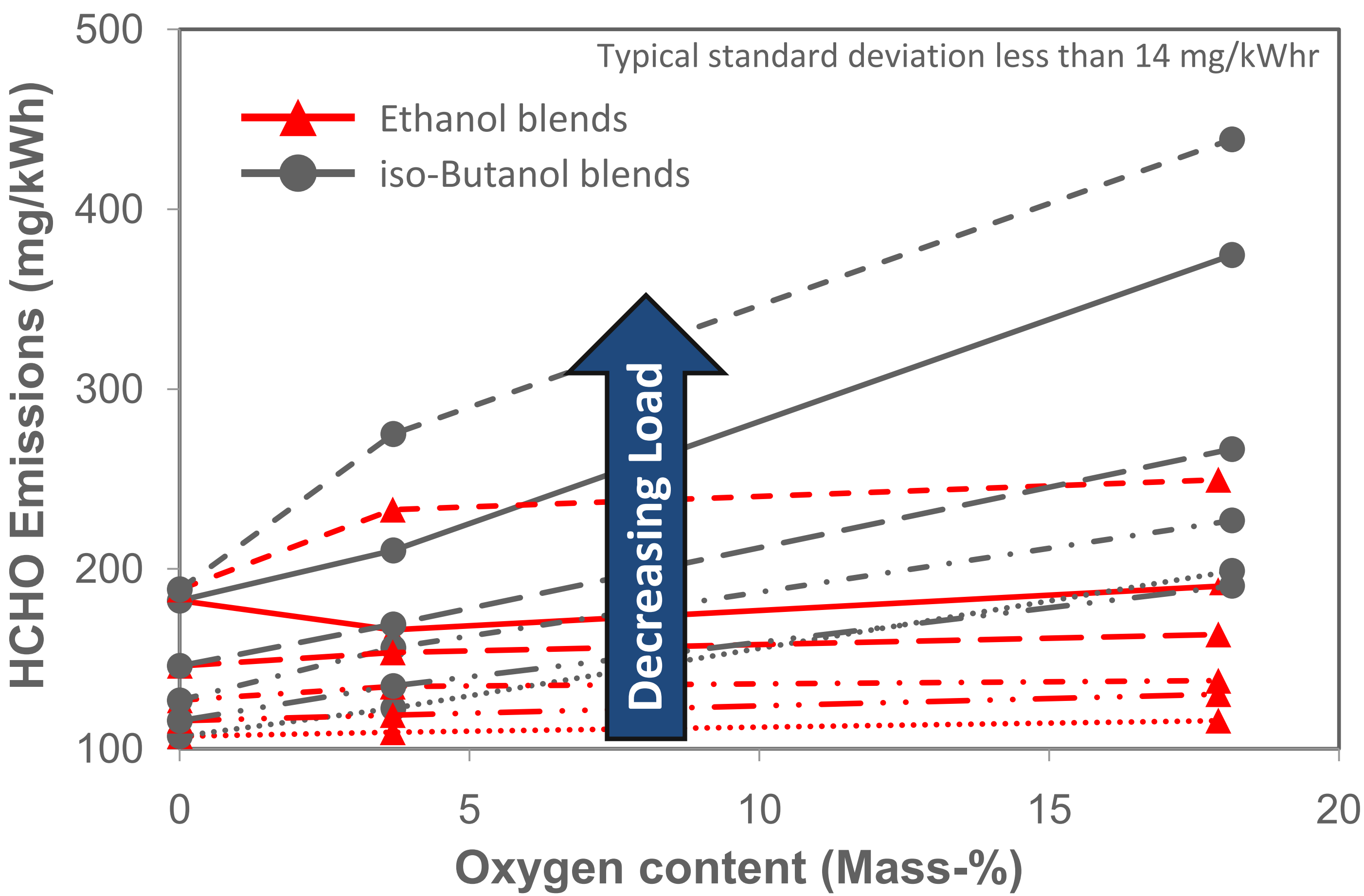
NOx decreases with increasing fuel alcohol and oxygen content

Speciated Hydrocarbons (from FTIR)



1500 rpm, 2.62 bar BMEP

Formaldehyde Emissions

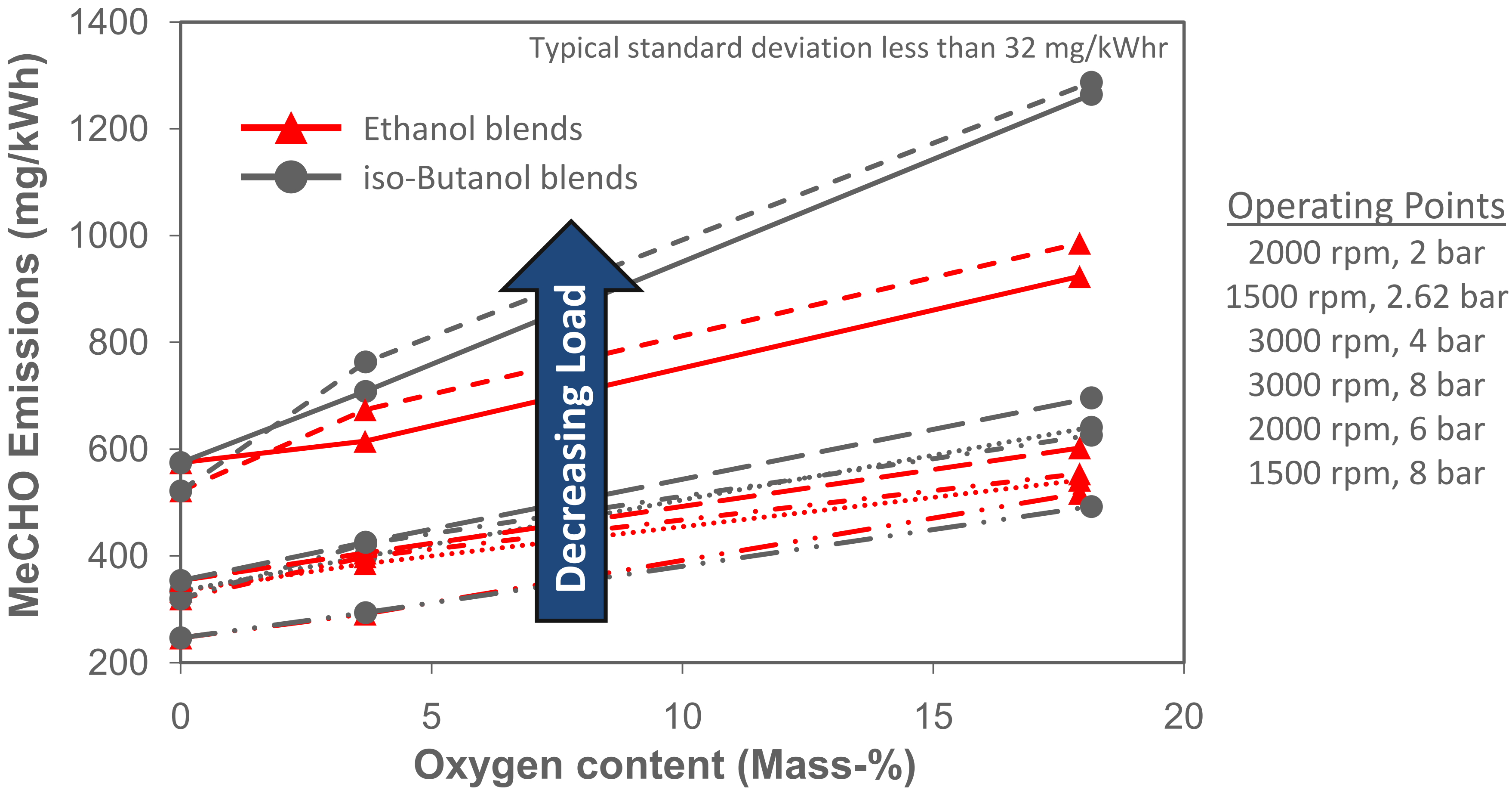


<u>Operating Points</u>

2000 rpm, 2 bar
1500 rpm, 2.62 bar
3000 rpm, 4 bar
2000 rpm, 6 bar
3000 rpm, 8 bar
1500 rpm, 8 bar

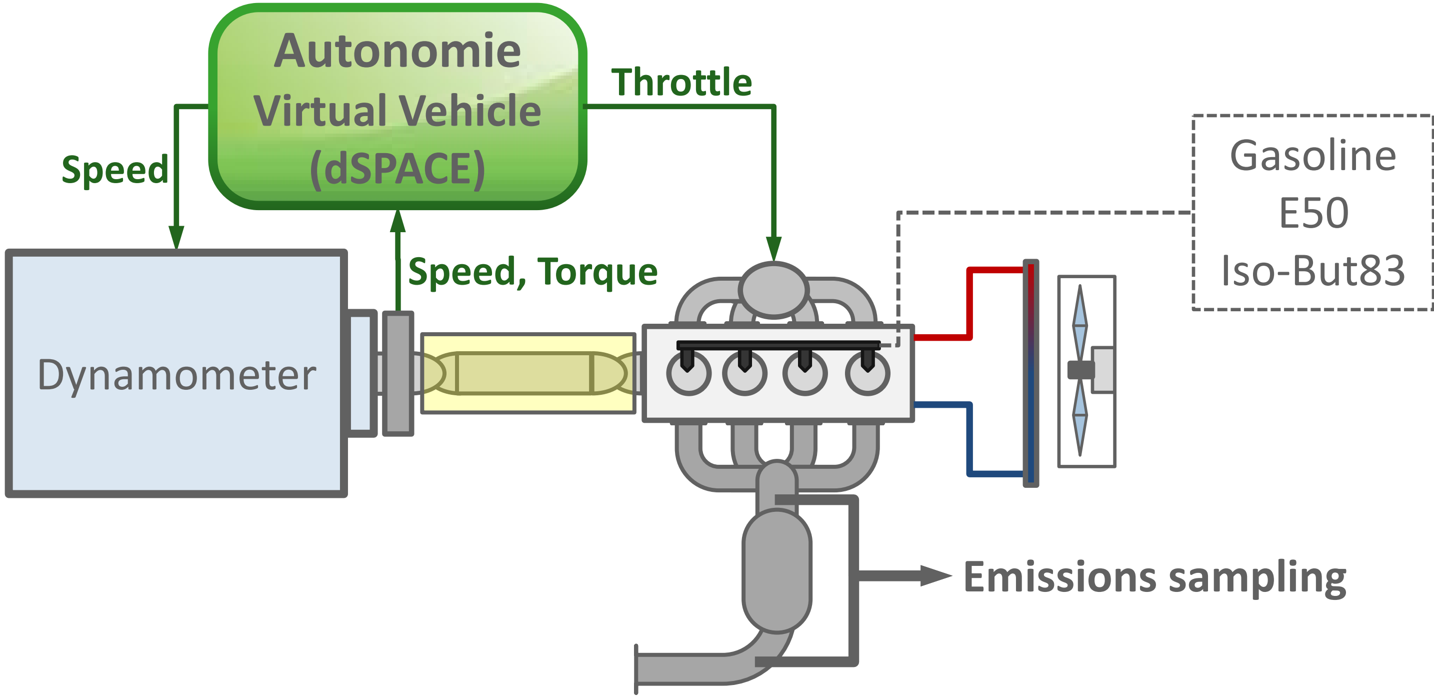
Increased formaldehye with *iso*-butanol blends, but not with ethanol blends

Acetaldehyde Emissions



Increased acetaldehye with both ethanol and *iso*-butanol blends

Engine Hardware-In-Loop Concept



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

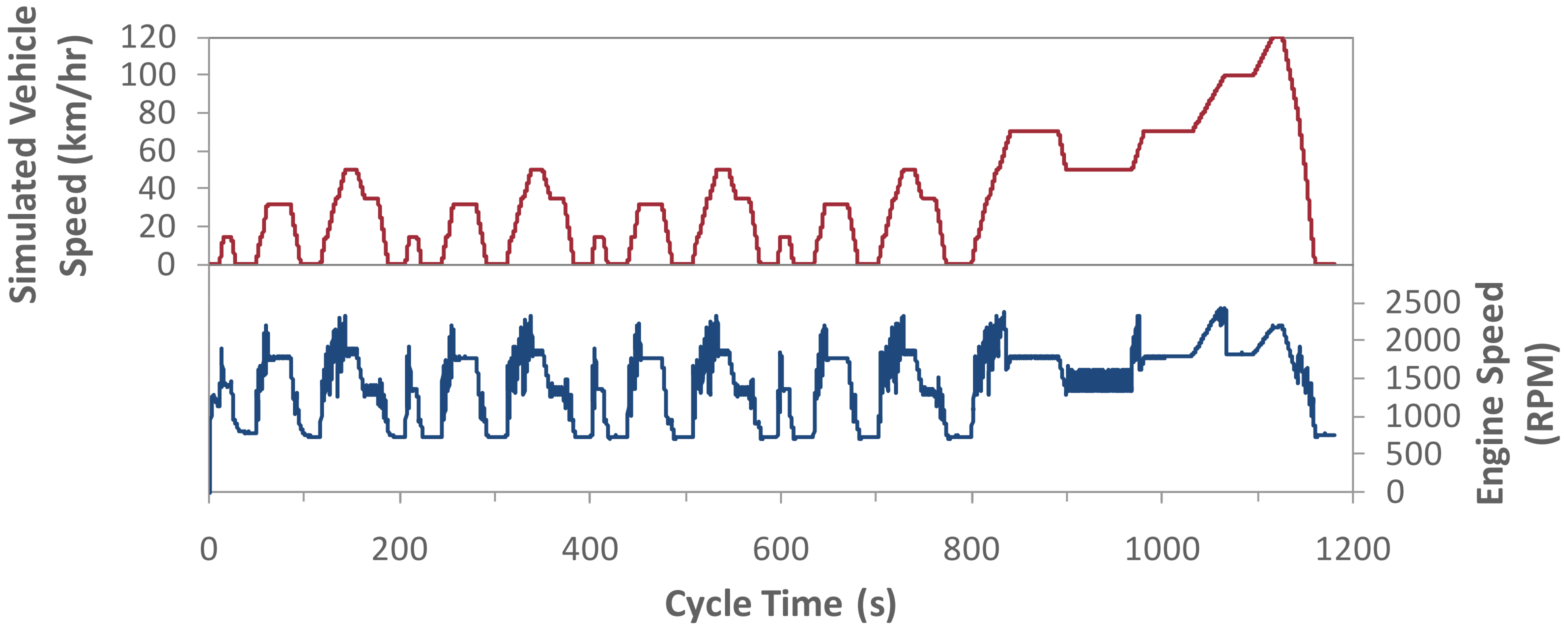
2005 Opel Vectra
2.2 L Ecotec DI
Automatic (5-sp.)

NEDC
Cold/hot start

System Validation

Cycle Fuel Consumption, Emissions Mass, Species Behavior

Experimental Methods: Engine HIL Testing



Fuel Consumption

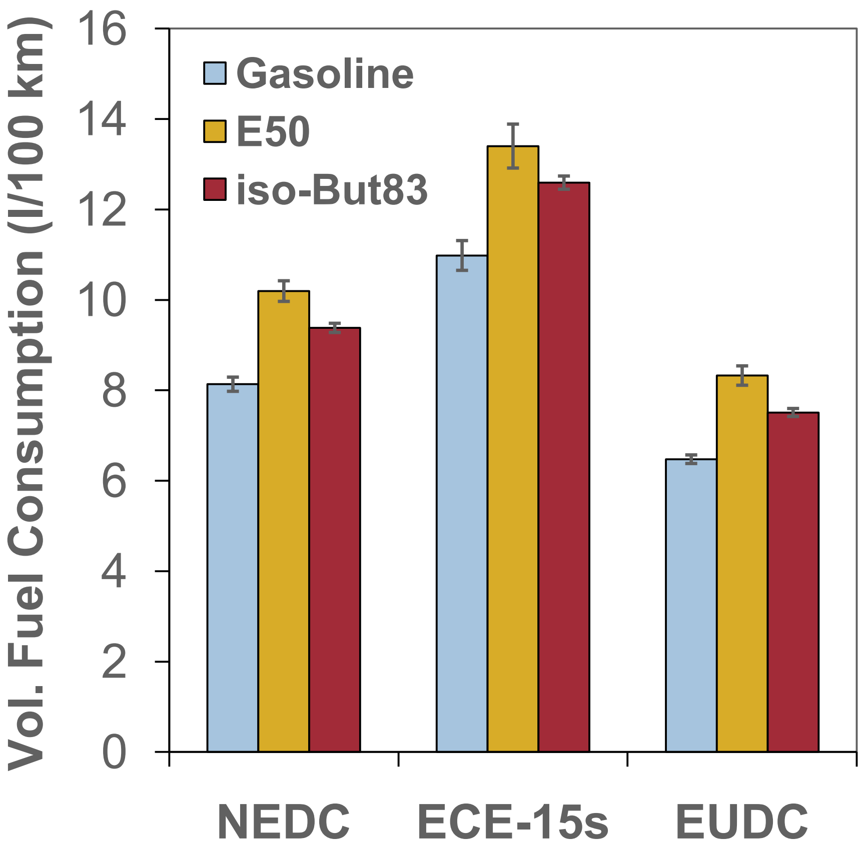
	Vehicle	Engine HIL
ECE-15	11.3	**12.4**
EUDC	6.1	**6.5**
NEDC	8.0	**8.7**
	l/100km	l/100km

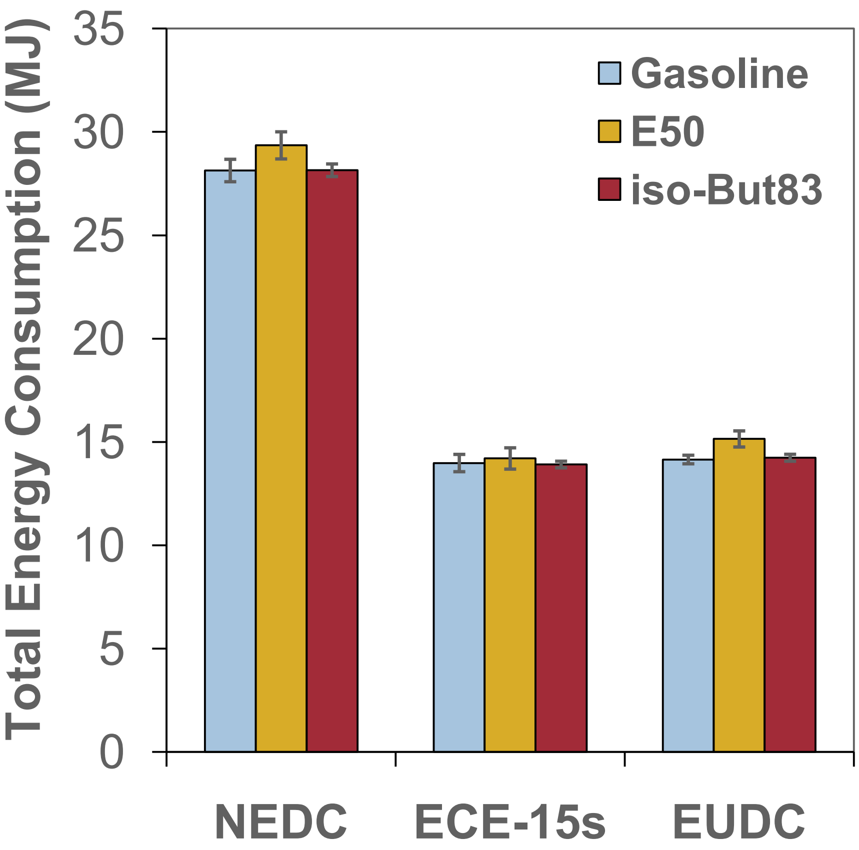
Gasoline Validation

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

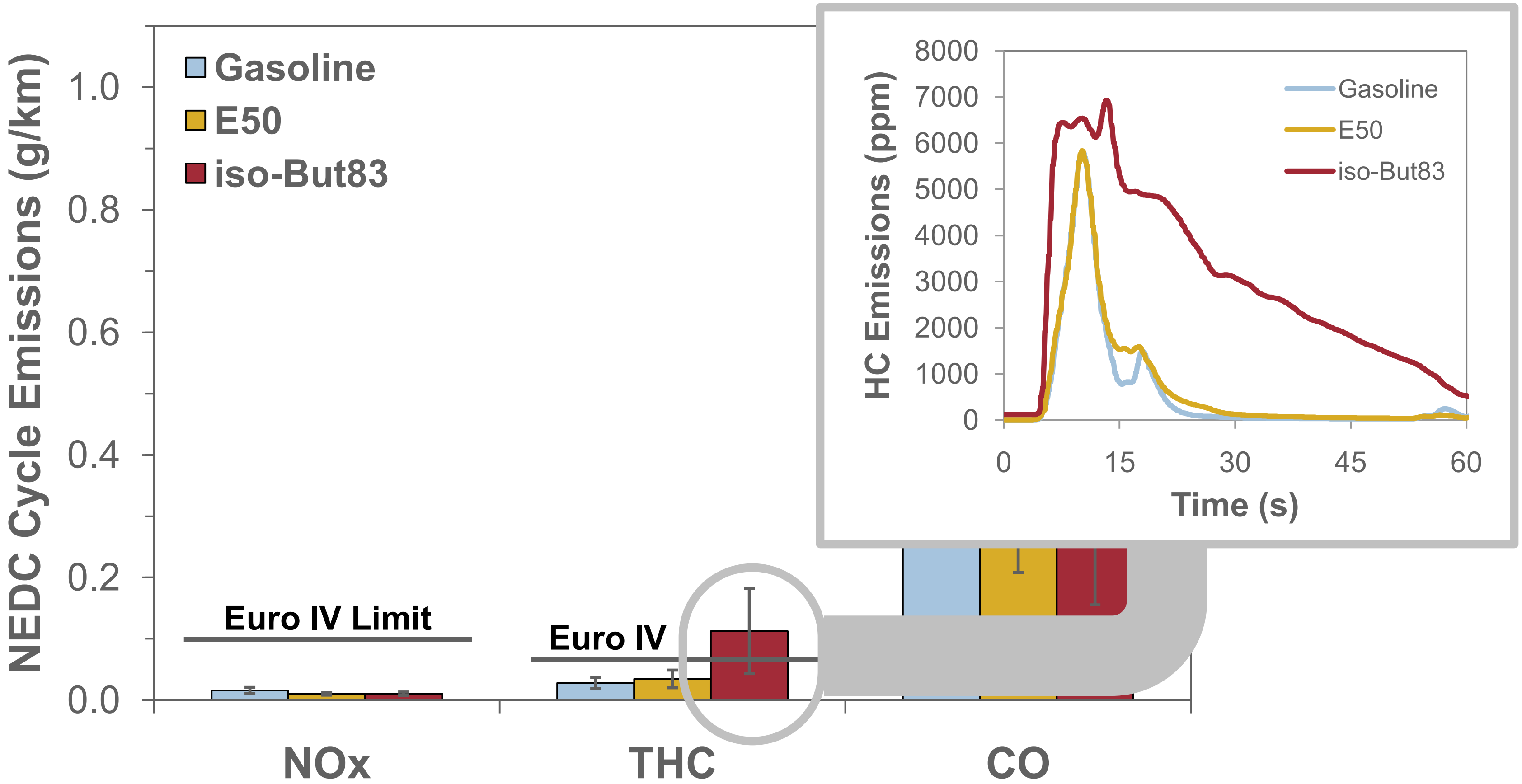
Cycle Fuel and Energy Consumption





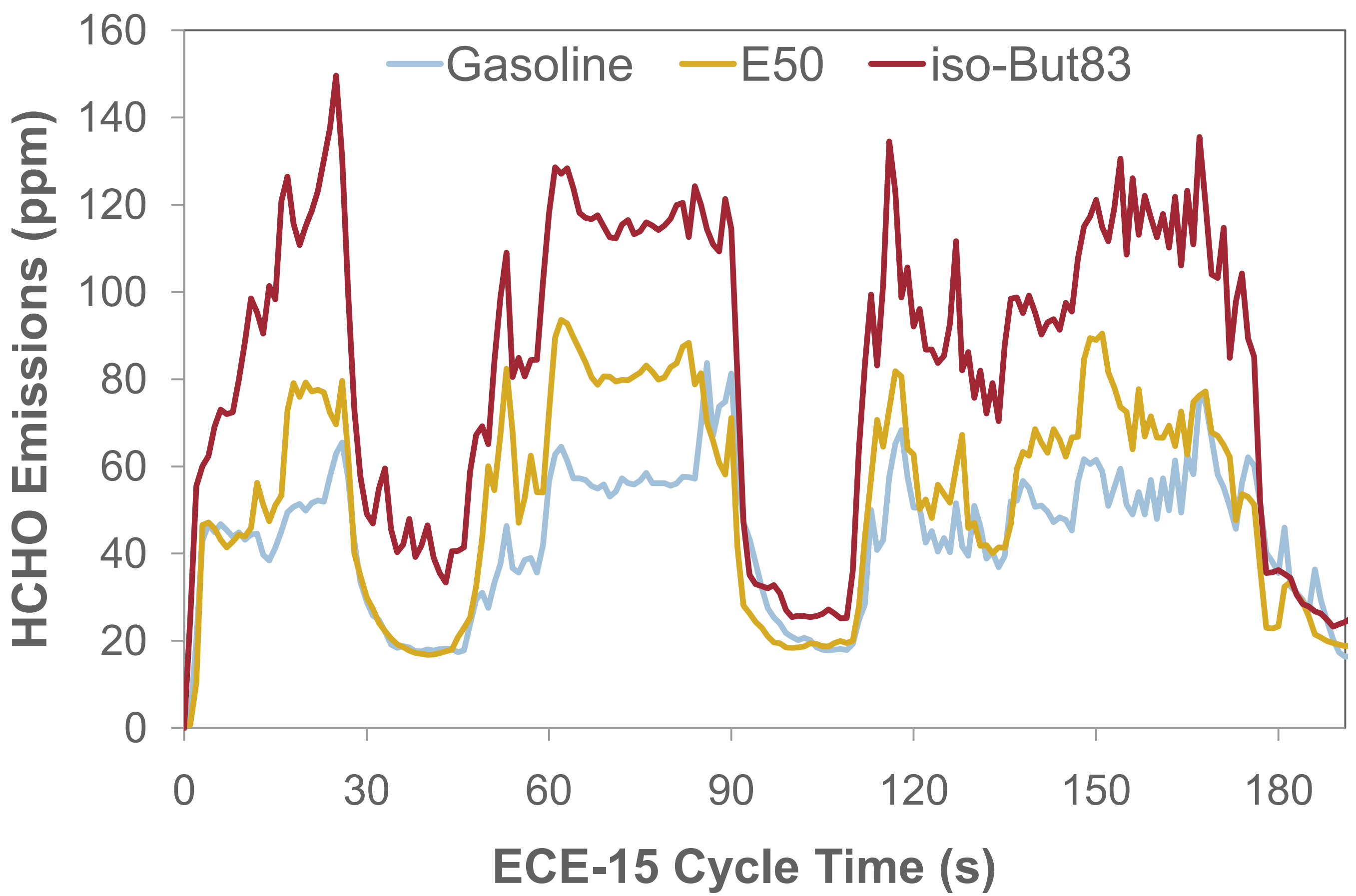
Hot-start cycles, integrated fuel flow

Total Cycle Emissions Mass



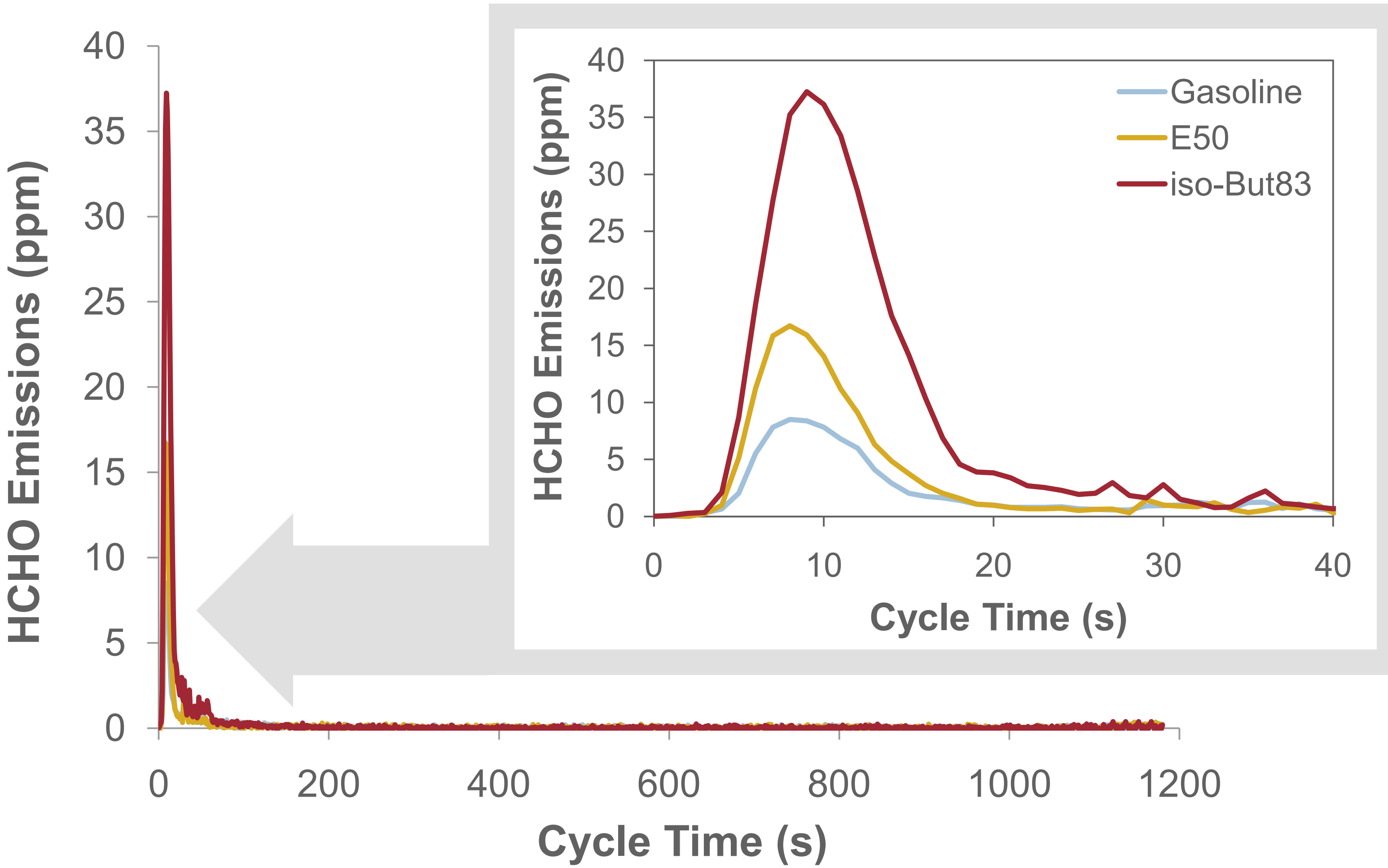
NEDC, cold-start, post-TWC emissions

Formaldehyde Emissions: Hot-Start, Pre-TWC



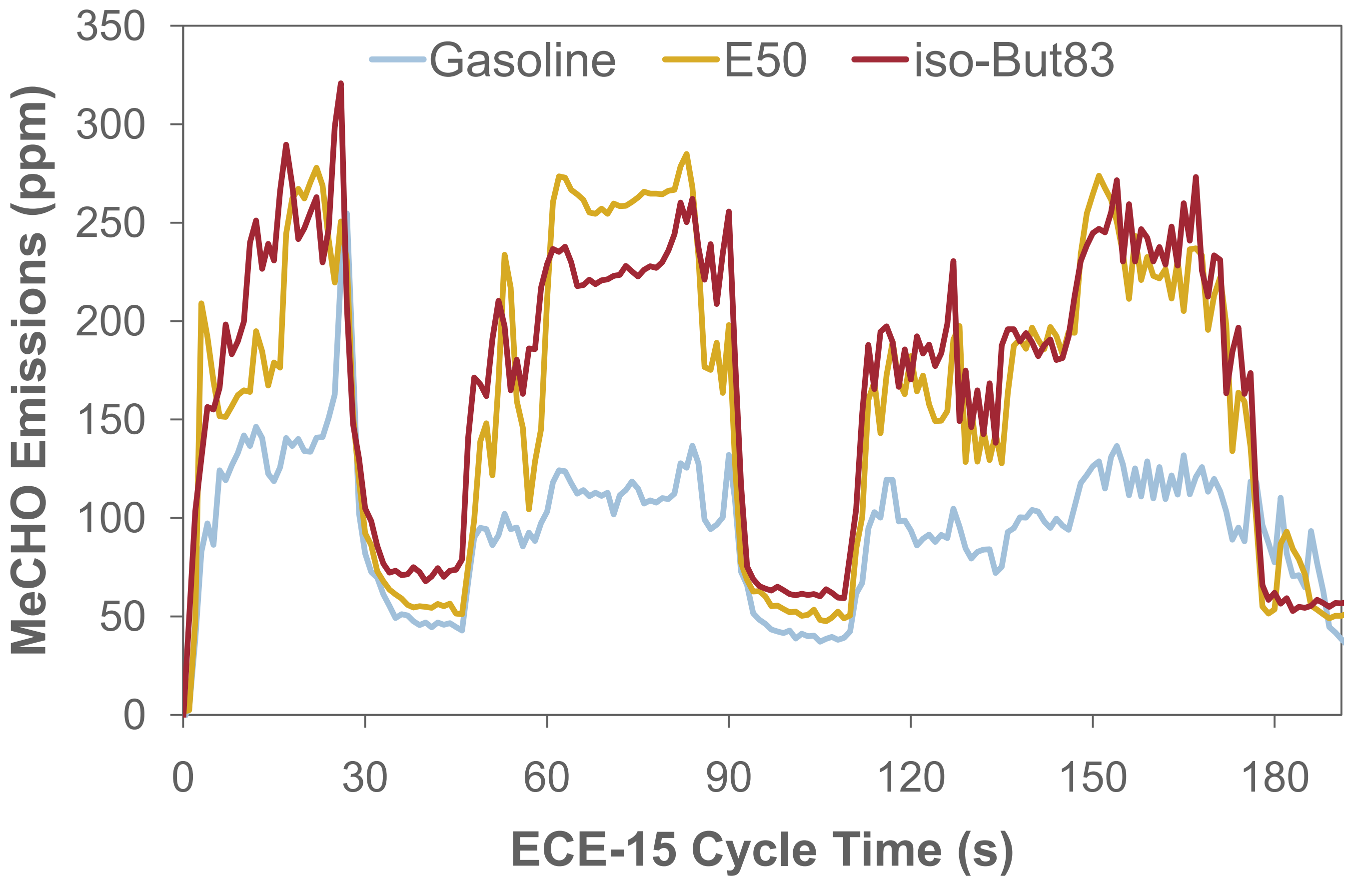
1st urban cycle of NEDC, hot-start, pre-TWC emissions

Formaldehyde Emissions: Cold-Start, Post-TWC



	Gasoline	E50	iso-But83
Cycle mass HCHO emitted (mg/km)	**1.5**	**2.0**	**7.0**

Acetaldehyde Emissions: Hot-Start, Pre-TWC



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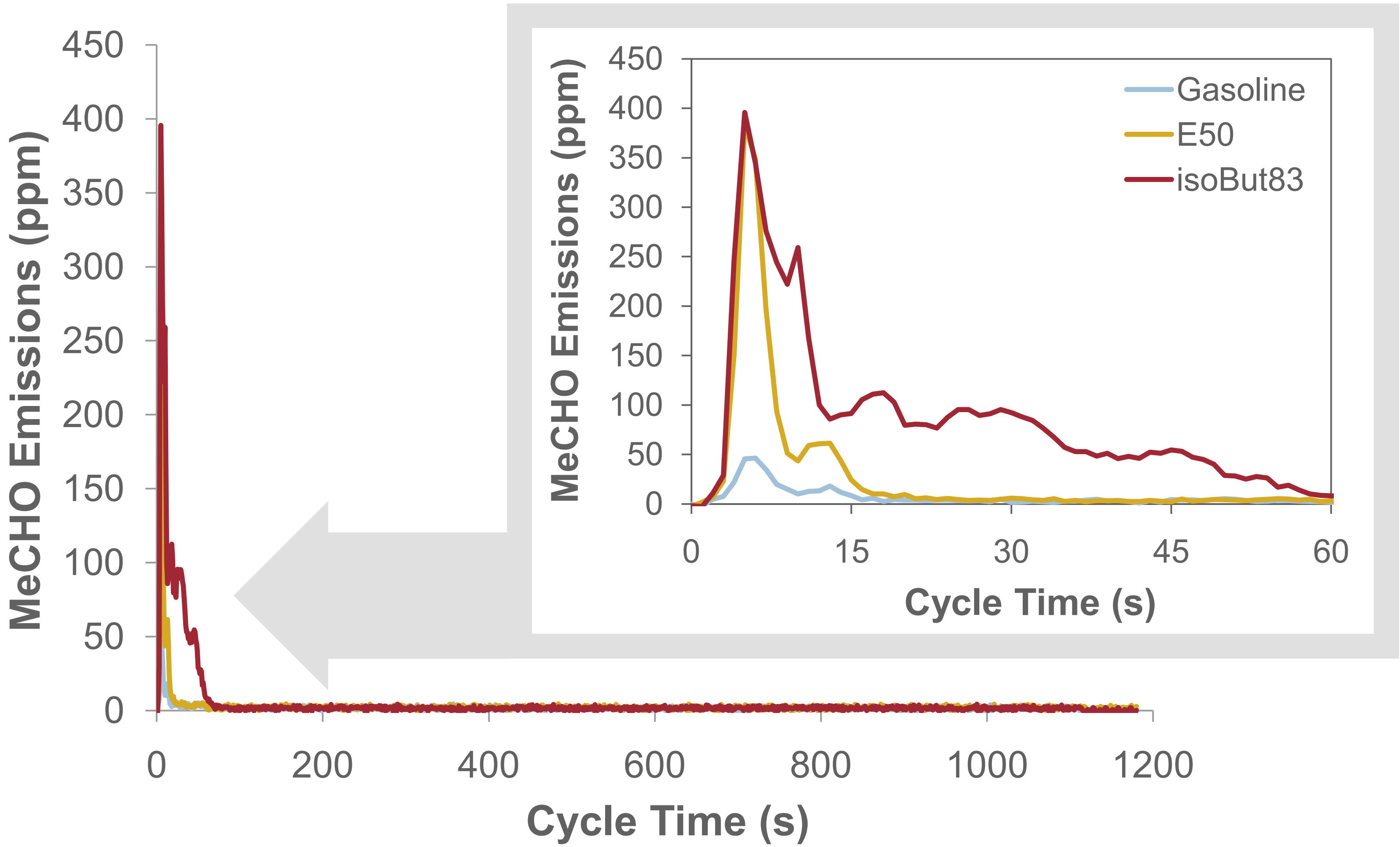
Acetaldehyde Emissions: Cold-Start, Post-TWC



	Gasoline	E50	iso-But83
Cycle mass MeCHO emitted (mg/km)	**10**	**40**	**110**

Conclusions & Future Opportunities

- Both ethanol and *iso*-butanol blends reduced cycle mass emissions of NOx and CO, and yield comparable cycle energy consumption.
- Blends of gasoline and *iso*-butanol increase both acetaldehyde and formaldehyde emissions, while ethanol-gasoline blends increase acetaldehyde emissions, but not significantly formaldehyde.
- Aldehyde emissions are eliminated in an active (warm) three-way catalyst: cycle aldehyde emissions stem from initial cold-start phase.
- Improved cold-start engine operation with high-alcohol fuels (including *iso*-butanol blends) is critical for meeting emissions targets
- Future exploration opportunities include particulate matter characterization from alcohol fuels utilizing engine HIL.

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