A Comparison of Combustion and Emissions of Diesel Fuels and Oxygenated Fuels in a Modern DI Diesel Engine

Eric Kurtz, Douglas Kuhel, James E. Anderson,
Sherry A. Mueller

This work was supported by the U.S. Department of Energy, under special project number DE-FC26-07NT43278.

Acknowledgement: Dennis Miller, Lars Peereboom, and Carl Lira at Michigan State University for supplying the fuels used in this study.

Outline

- Background
- Experimental Method
- Experimental Results
- Summary & Conclusions

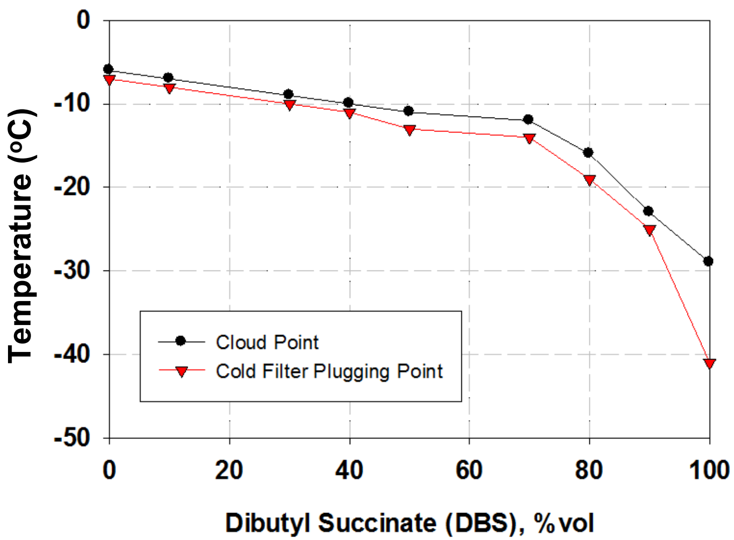
This work has been published in SAE 2012-01-1695

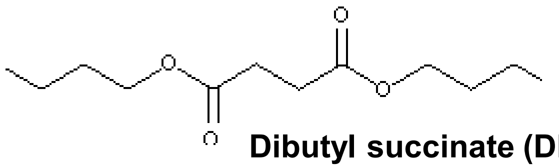
Outline

- Background
- Experimental Method
- Experimental Results
- Summary & Conclusions

MSU Fuels Investigations

- Canola-based FAMEs (CME) has relatively good cold flow properties & oxidative stability.





Dibutyl succinate (DBS)

- DBS further improves the cold flow properties of CME.
- To stay within the 40 CN U.S requirement, DBS content in CME must be limited to 40%.

Single-Cylinder Study Objectives

Study the influence of selected oxygenated fuels on combustion and emissions in a modern diesel engine

- Conventional Combustion
- Low Temperature Combustion (LTC)

Outline

- Background
- Experimental Method
- Experimental Results
- Summary & Conclusions

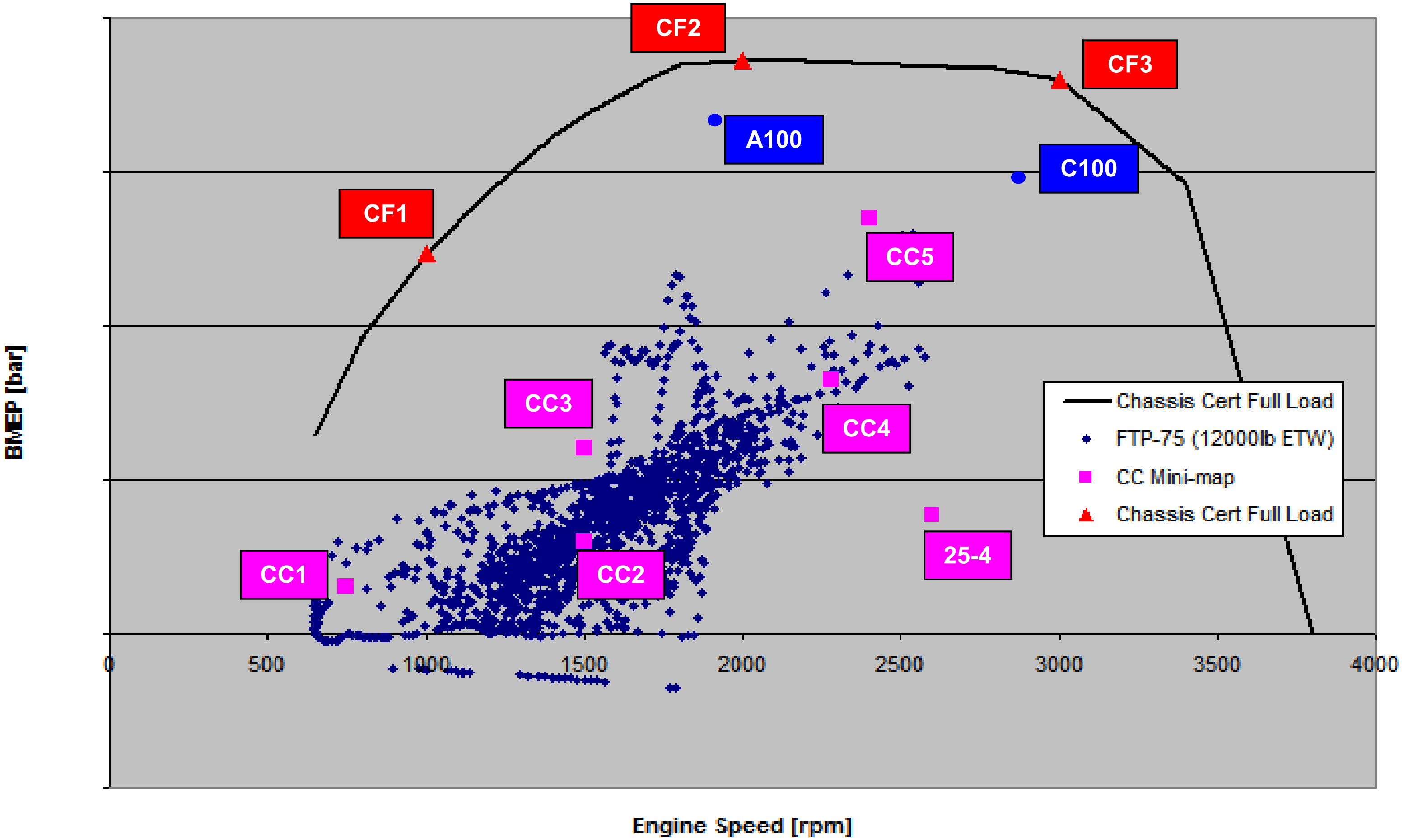
Fuels Tested

	Mineral Diesel Fuels (Control group)			Oxygenated Fuels	
	720	727	668*	CME	60-40
Cetane No.	45.6	41.8	56.5	50.8	40.8
NHV (MJ/kg)	42.9	42.4	43.2	37.4	33.2
H:C ratio	1.81	1.775	1.952	1.88	1.86
O:C ratio	0	0	0	0.11	0.19
Aromatics	28.6%	32.4%	<5%	0%	0%

*A low aromatic diesel fuel included in the study (97.7% saturates)

Test Conditions

- A single-cylinder version of the production 6.7L V8 PowerStroke®.
- Evaluated over the entire engine map.



Test Procedure

Testing attempted to mimic diesel engine controls

- Calibration settings are based on engine speed and fuel quantity
  - Fuel pressure
  - Pilot fuel quantity
  - Main SOI
  - Pilot SOI
  - EGR rate
  - Boost pressure

<u>Test Procedure</u>

- Established base calibration settings using 720 fuel (46 CN)
- Identical settings for all fuels:

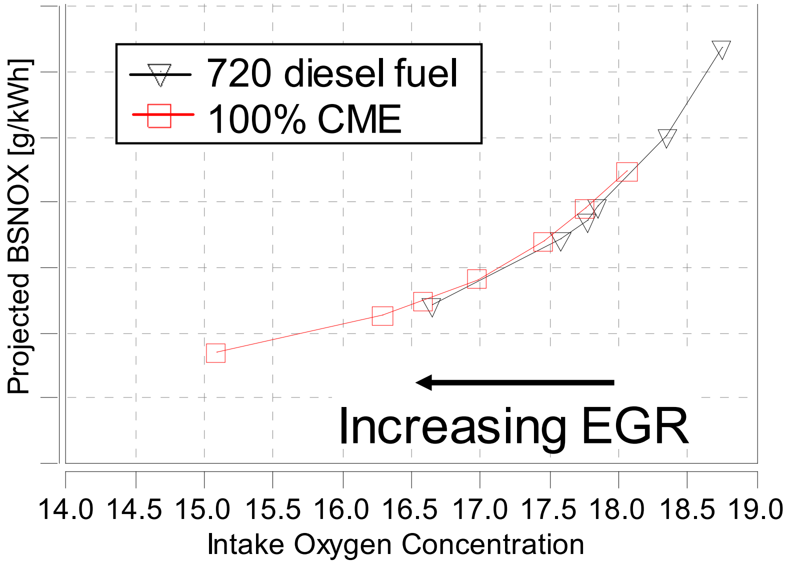
	Rail pressure	Main quantity	Pilot quantity	Pilot SOI	Main timing	EGR rate
Conventional	720 calibration setting				720 SOI	Sweep
LTC	720 cal. settings		No pilot		720 SOC	Sweep

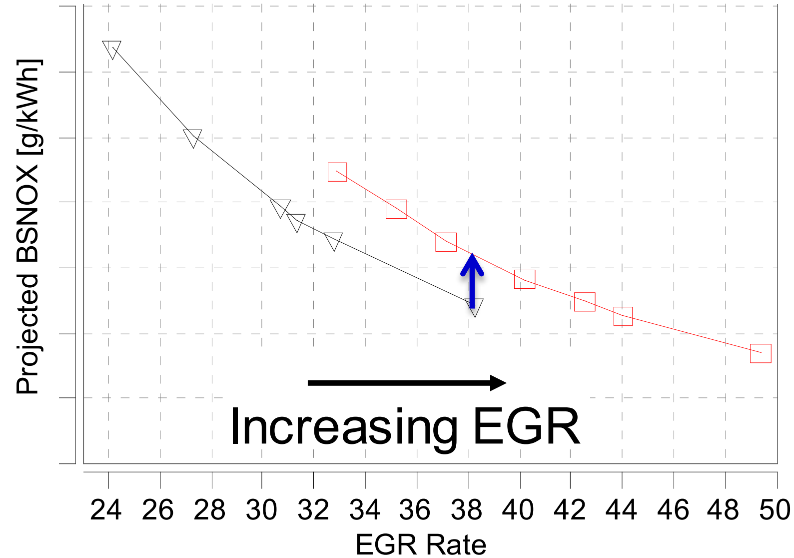
- Select conditions also tested with constant injected fuel energy by adjusting the quantity of <u>each</u> fuel pulse (adjusted for fuel NHV).

Outline

- Background
- Experimental Method
- Experimental Results
  - Emissions
  - Combustion noise (not presented)
  - BSFC & Efficiency (not presented)
- Summary & Conclusions

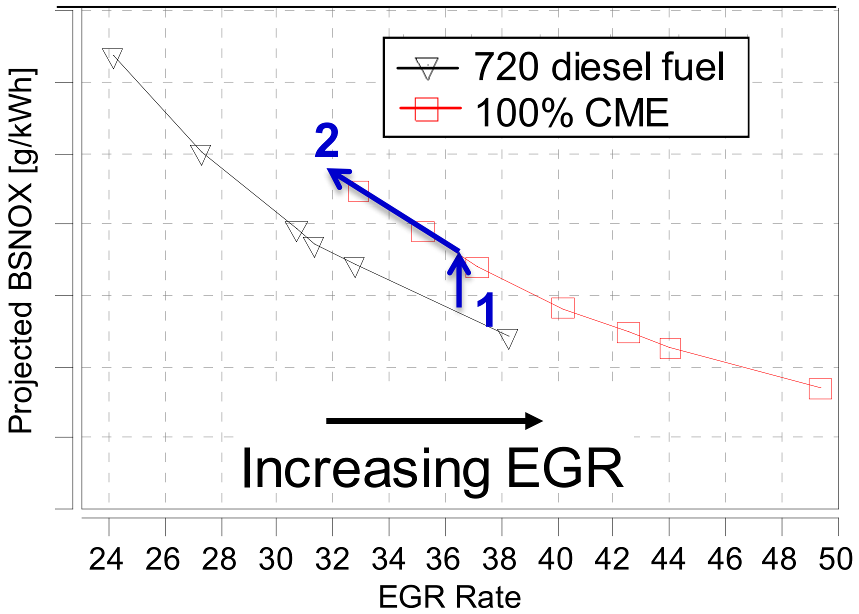
NOx and Oxygenated Fuels





- NOx emissions appear to be primarily a function of intake oxygen concentration for both fuels (independent of fuel oxygen content)
- At the same intake O_2, no statistical difference in NOx was observed with oxygenated fuels
- EGR is typically controlled based on a EGR rate or air mass flow
- Fuel O increases the total intake O_2 for a given EGR rate – NOx increases

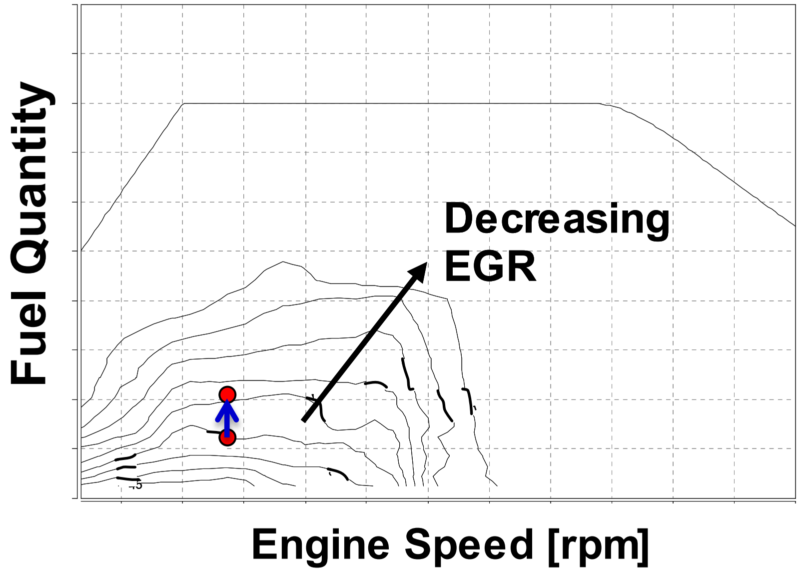
Example Control Scenario



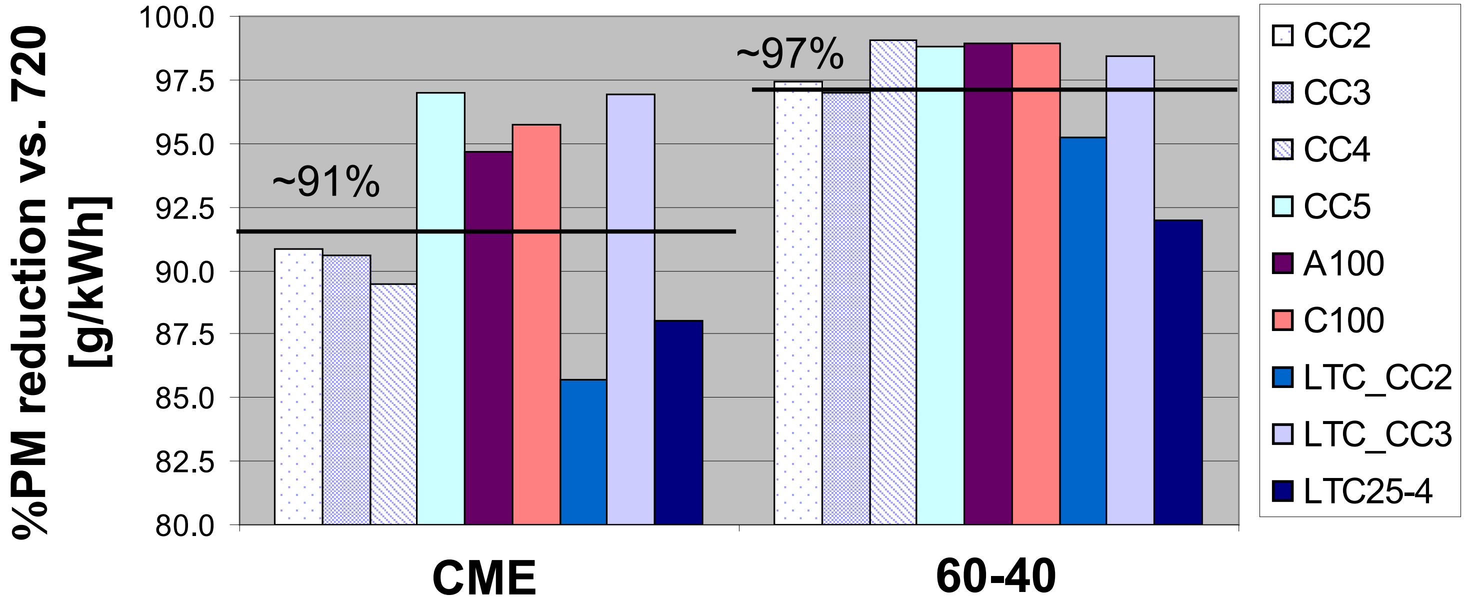
- Commanded fuel quantity will increase to adjust for lower fuel energy.
- As commanded fuel quantity increases, typically EGR rate decreases, boost and injection pressure increase.
- Leads to a further increase in NOx emissions.

1 – higher intake O2

2 – lower EGR rate, higher boost pressure, higher injection pressure

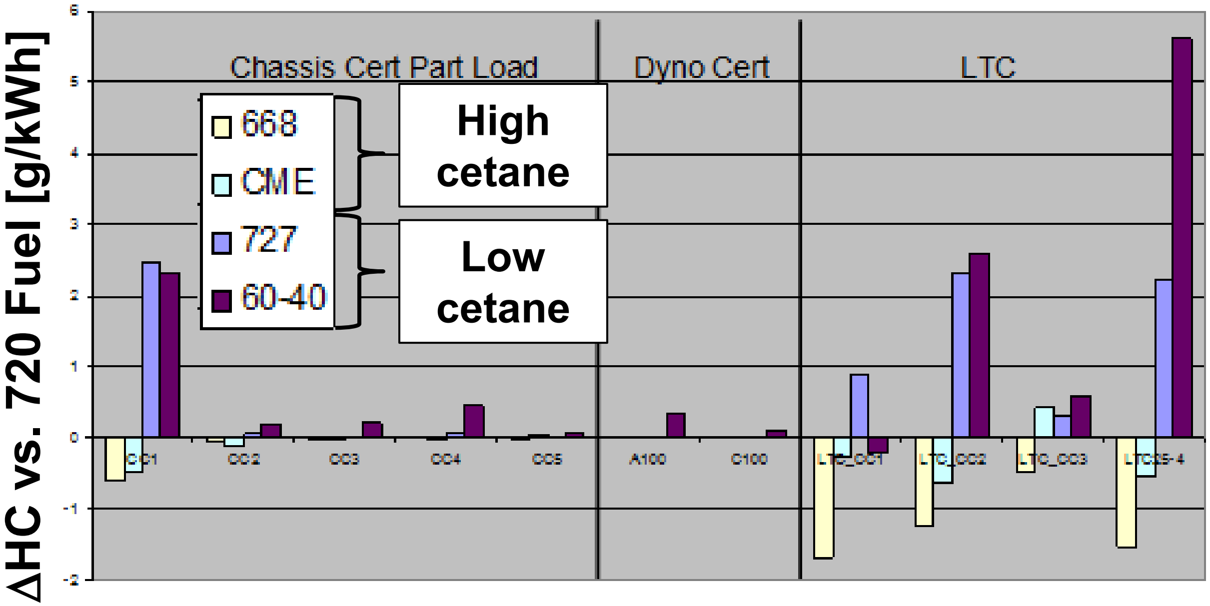


Particulate Emissions



- Large PM reductions with both oxygenated fuels
- Mechanism #1: PM reduction is due to displacement of aromatic
  - A relatively small PM reduction with low aromatic fuel (668)
  - PM reduction with 668 was not statistically significant
- Mechanism #2: PM reduction is the result of fuel oxygen
  - PM reduction is consistent with fuel oxygenation
  - Consistent with estimated oxygen equivalence ratio at the lift-off length

Hydrocarbon Emissions

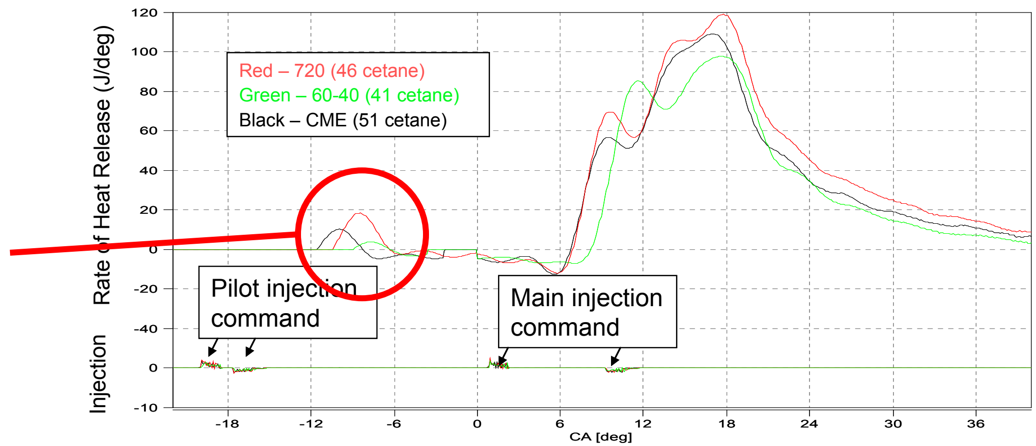


LTC

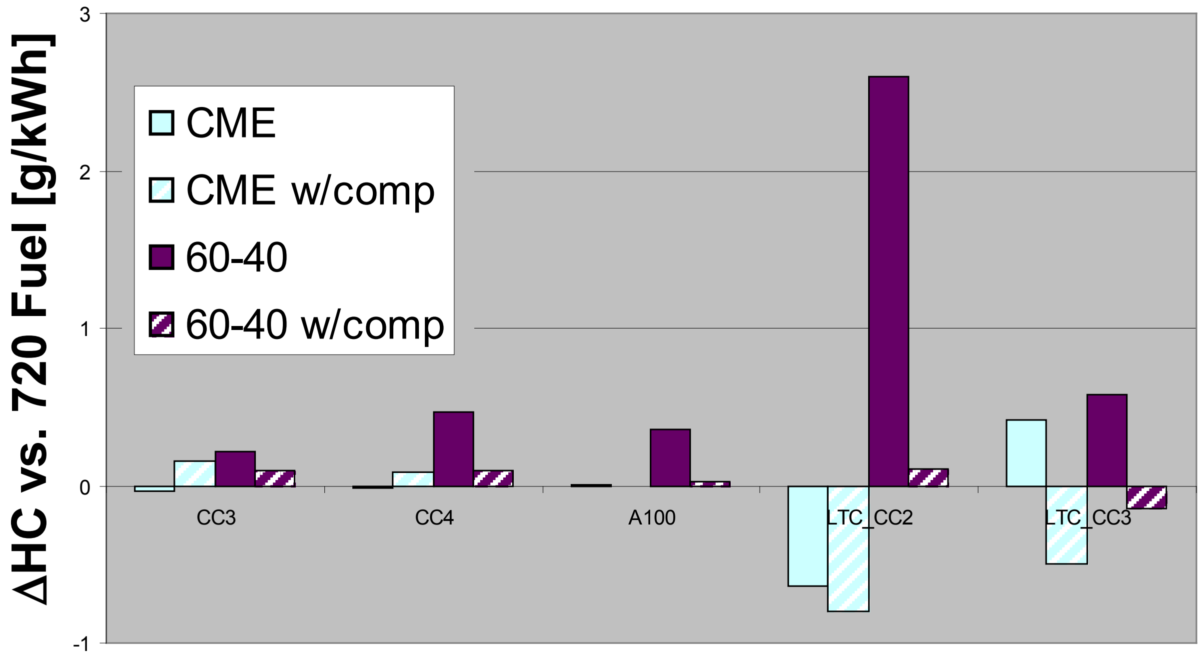
- Results track with cetane number rather than oxygenation
  - 668 & CME: low HC
  - 727 & 60-40: high HC
- True also of combustion noise (not shown)

Conventional Combustion

- Higher HC emissions observed with the 60-40 blend.
- Pilot heat release was weak with the 60-40 blend due to low energy content and low cetane number.



HC Emissions with Compensation



- Equivalent HC emissions with the 60-40 blend vs. the base fuel once injected quantity was adjusted for fuel energy content
- Adjusting quantity reduced HC in LTC for both oxygenated fuels
  - Increased load
  - Shorter ignition dwell

Outline

- Background
- Experimental Method
- Experimental Results
- Summary & Conclusions

Effect of Oxygenation - Summary

	Conventional Combustion	Low Temperature Combustion
NOx	Oxygenation had no effect[1]	
PM	Decreased significantly w/ fuel oxygen	
HC	Same as diesel[2]	Function of cetane[3]
Noise	Same as diesel[2]	Function of cetane
Thermal Efficiency	Oxygenation had no effect[2]	
Fuel Consumption	Degraded due to lower NHV[4]	

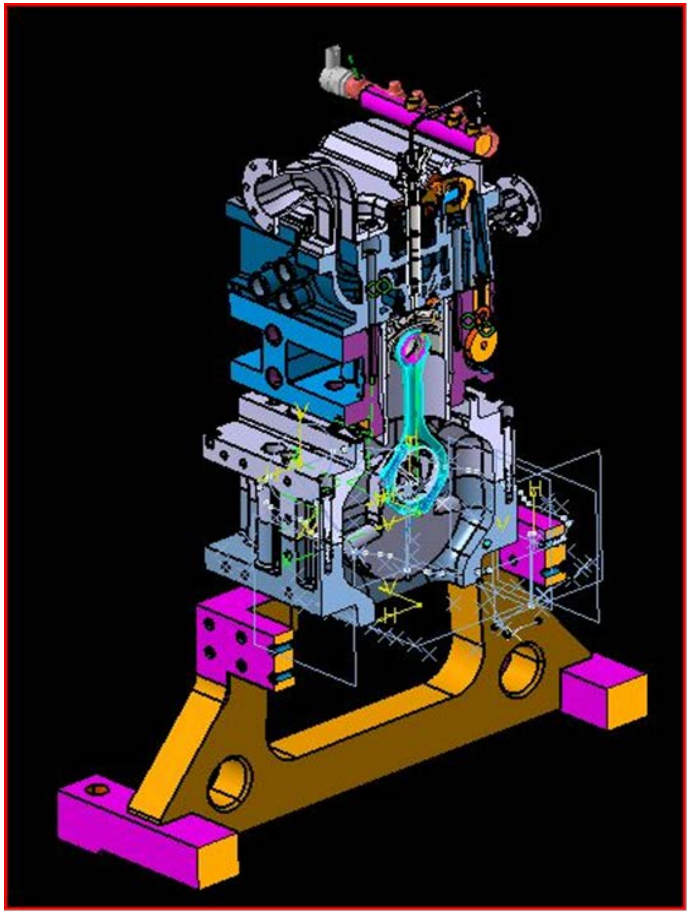
[1] Maintaining calibration settings, including intake O_2.
[2] Adjusting injected fuel quantity for fuel energy content.
[3] Lower HC when injected fuel quantity adjusted for fuel energy content.
[4] A function of fuel energy density.

Thank you!

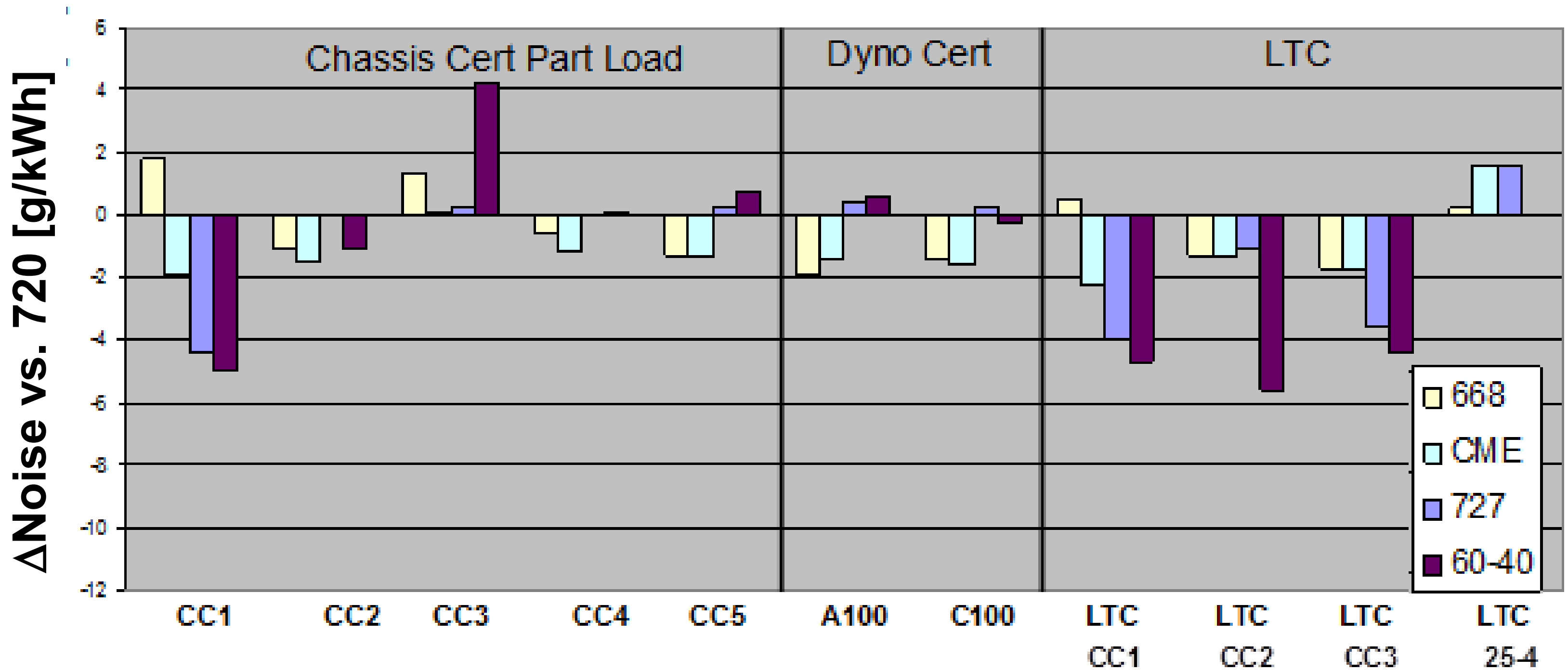
Engine Description

Type	Single-cylinder
Cycle	4-stroke
Valves per cylinder	4
Bore	99 mm
Stroke	108 mm
Displacement	0.83 L
Compression Ratio	16.2:1
Maximum Rail Pressure	2000 bar
Combustion system design	Chamfered

* Engine & combustion system specifications matched the production 6.7L PowerStroke®



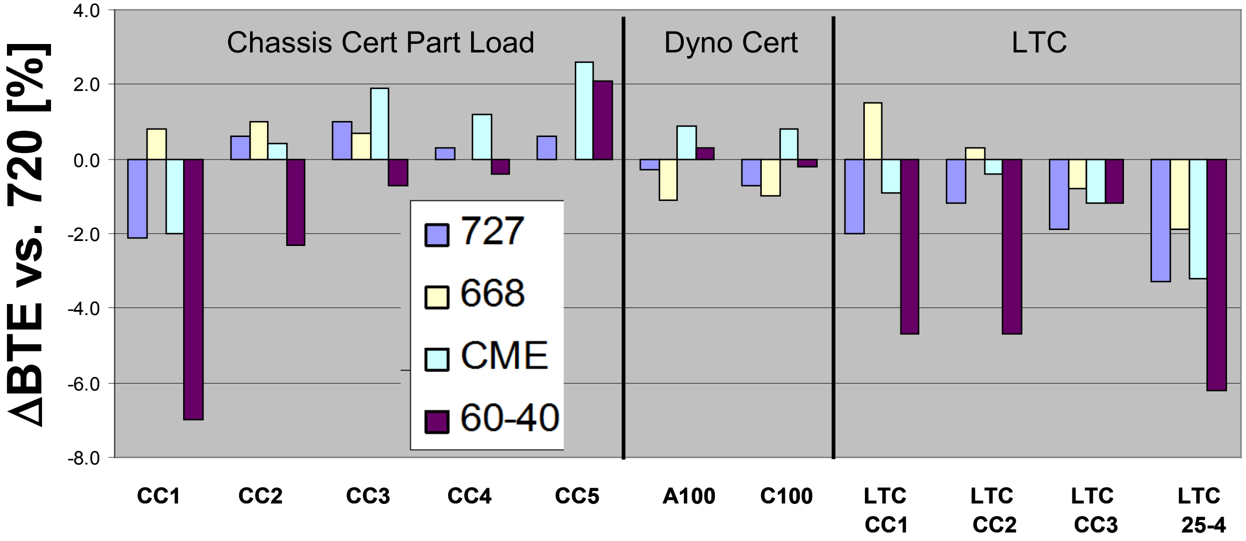
Combustion Noise



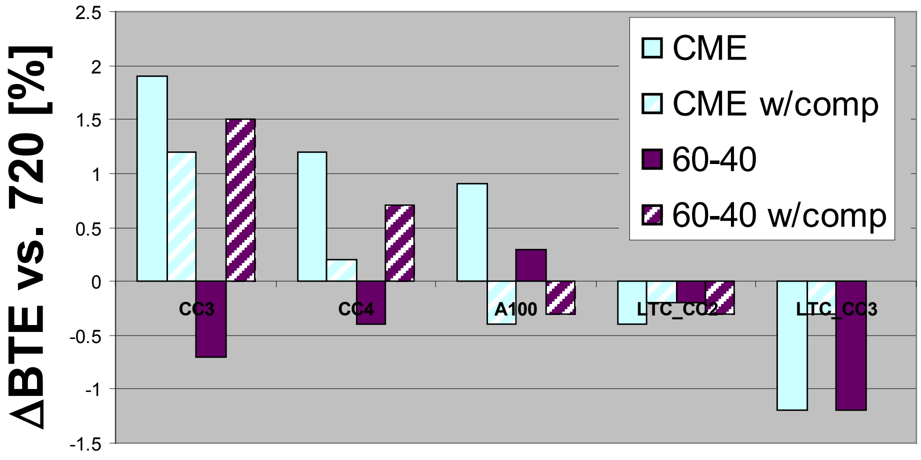
- Differences in combustion noise correlate with cetane number of the test fuel in both conventional combustion and LTC.
- Compensation for NHV reduces slightly difference from 720 fuel.

	High Cetane		Low Cetane	
	668	CME	727	60-40
CDC	Lower		Similar	
LTC	Similar		Lower	

BSFC & Thermal Efficiency



- Higher BSFC with oxygenated fuels
  - Lower NHV
  - Lower BMEP
- Thermal efficiency of CME was comparable to the diesel fuels



- Lower thermal efficiency with the 60-40 blend without fuel quantity adjustment – later combustion phasing
- Similar thermal efficiency for all fuels when injection quantity was adjusted for energy content

Additional Conclusions

It is speculated that NOx increase found in the literature may be due to

- An increase in intake O_2 with fuel oxygen content when EGR rate or air mass flow are controlled
- Reduced EGR, increased boost and increased injection pressure when the commanded fueling injection is increased to meet torque demand with oxygenated fuels (lower energy content)
- When the intake O_2 and engine calibration are the controlled to the same value, oxygenated fuels do not appear to have a negative impact on NOx emissions in a modern diesel engine