Development of Dual-Fuel Engine for Class 8 Applications

(Dept of Energy Supertruck Program)

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Technical Session: High-Efficiency Engine Technologies Part 2

DOE DEER CONFERENCE

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Outline

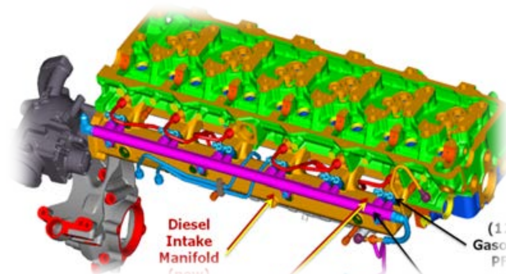
Background
- **High Efficiency Combustion Modes**
- **Base Engine and Efficiency Target**

Development Strategy
- **Fuel Reactivity Options**
- **Fueling Strategy**
- **Efficiency Roadmap**

Results
- **Gasoline + Diesel**
- **Alcohol/Gasoline + Diesel**

Summary





High Efficiency Combustion Modes

	HCCI	Fuel Reactivity	Diesel Combustion
Charge Preparation	Homogeneous	PFI + DI	DI
Fuels	Flexible, Single	Dual-Fuel	Diesel
Combustion Modes	Premixed	High Reactivity →Low Reactivity	Diffusion
Reactivity Stratification	Low →	→	High
Controllability	Poor →	→	Good
Challenges	Controllability Load Limitation	Controllability Load Limitation	High PM & NOx

Fuel Reactivity

- ✓ Provides flexibility in tailoring combustion process by manipulating PFI/DI ratio
- ✓ Widens load range by introducing reactivity stratification

Base Engine and Efficiency Target

Project Target:

✓ Demonstrate a technical path towards ***55%*** BTE with ***fuel reactivity***

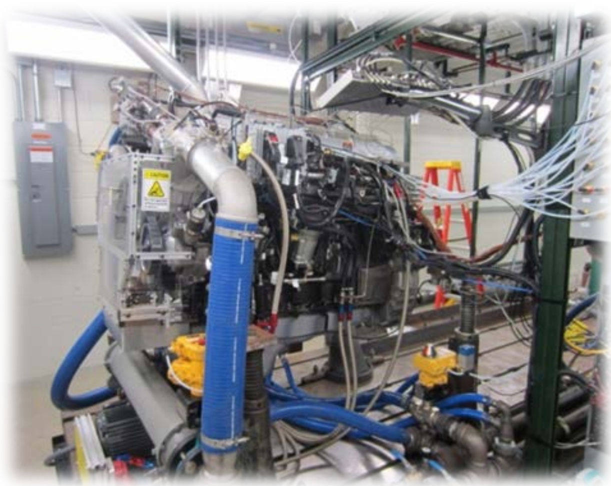
MY 2010 MAXXFORCE 13

- common rail fuel injection system
- regulated 2-stage turbocharger with intercooler
- 2-stage HP loop EGR cooling

Rated Power 475hp

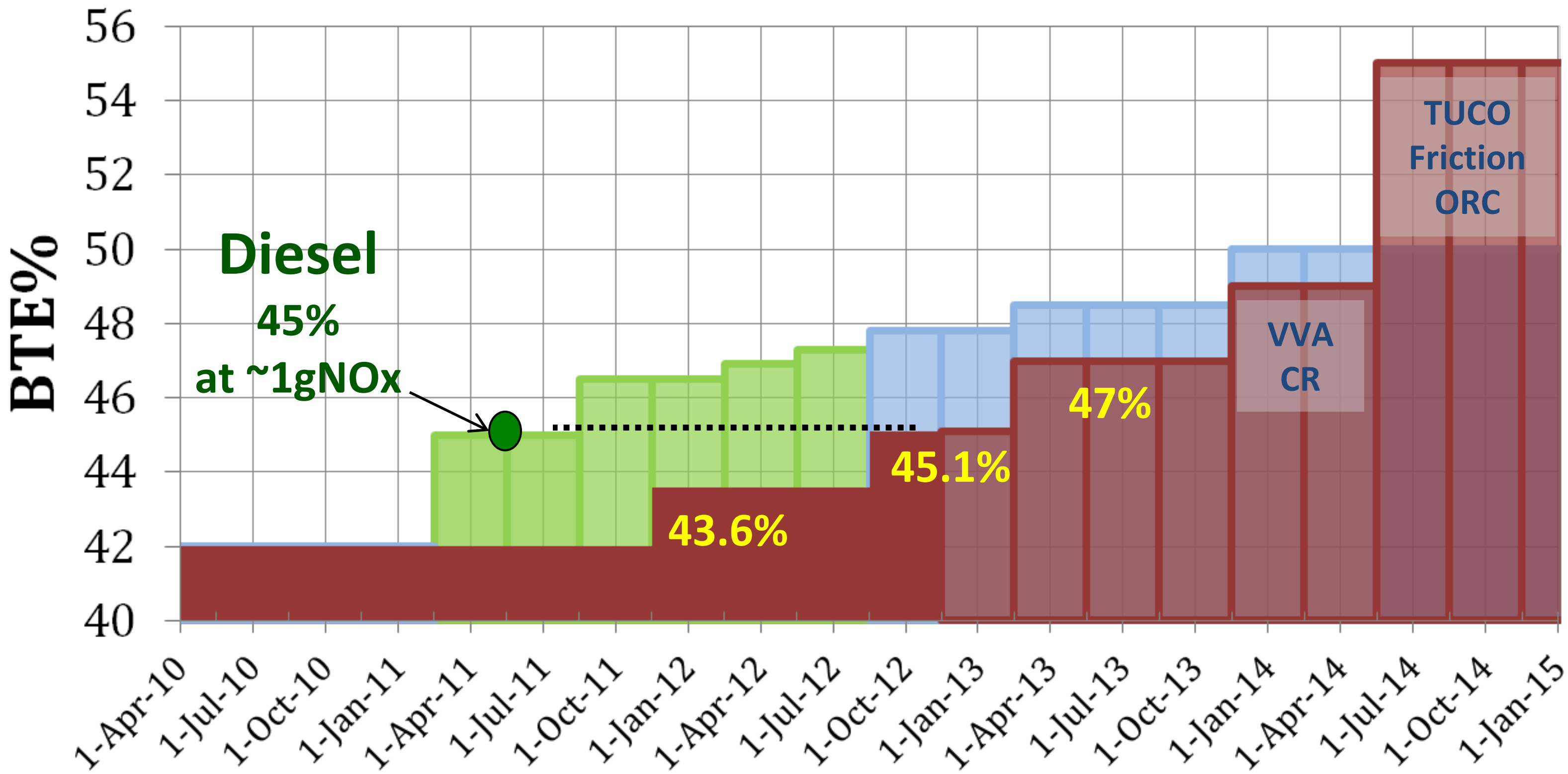
MAXXFORCE 13 Dual-Fuel

- ✓ multi-point port fuel injection
- ✓ dual-fuel control system
- ✓ variable geometry turbocharger
- ✓ variable valve actuation
- ✓ optimized piston geometry
- ✓ high pressure common rail



Fuel Reactivity
Efficiency Roadmap

- ✓ *Significant improvement on BTE with fuel reactivity*
- ✓ *At better controlled engine out emissions*



Progress to Date

Gasoline + Diesel
43.6%
NOx ~ 0.1gNOx

Alcohol/Gasoline + Diesel
45.1%
NOx ~ 0.1gNOx

Current Target

Reactivity + CR
BTE > 47%
at NOx < 0.15gNOx

Technologies

from the Diesel platform

Fuel Reactivity Options

Port Fuel Injection

Gasoline → Alcohol/Gasoline Blends → High Octane Alt.

AKI:93 → *Increased octane number*

✓ *lower reactivity suppresses charge autoignition*
✓ *oxygenates provide additional benefit in soot*

Direct Injection

FACE #1 ← Diesel → Synthetic Diesel

CN:30 | CN:45 | CN >70

✓ *longer ignition delay*
- *improved mixing*
- *less soot*

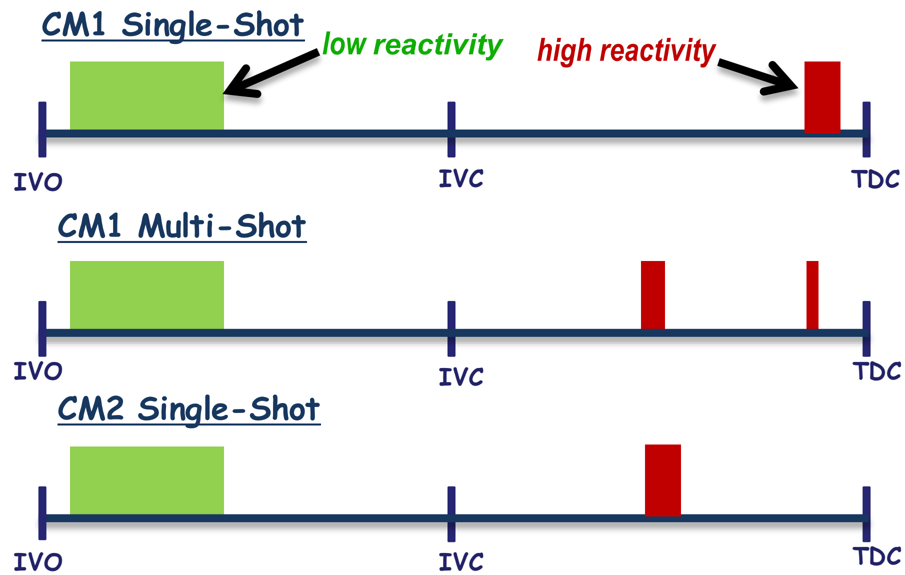
✓ *robust ignition source*
- *enhance combustion stability at late SOIs*
- *mitigate PRR*

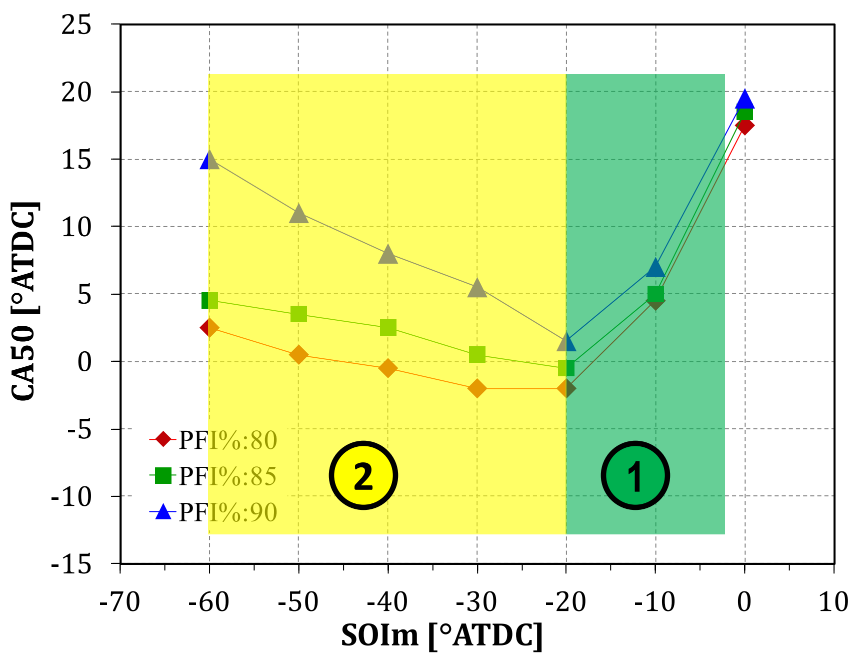
Fuel Reactivity

Fueling Strategy

Fueling Strategy Development

- ✓ PFI%
- ✓ Diesel Injection Strategy
- ✓ Load Range:
  - *low-to-medium: CM1-SS, CM1-MS, CM2-SS*
  - *medium-to-high: CM1-SS*





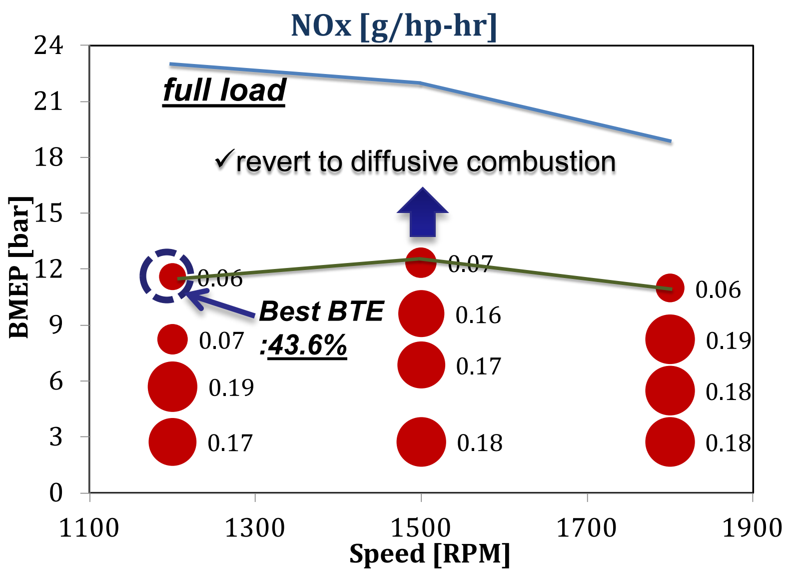
1. Combustion phasing is robustly coupled to diesel SOI (CM1):
2. Combustion phasing is largely controlled by charge reactivity (CM2):

Fuel Reactivity

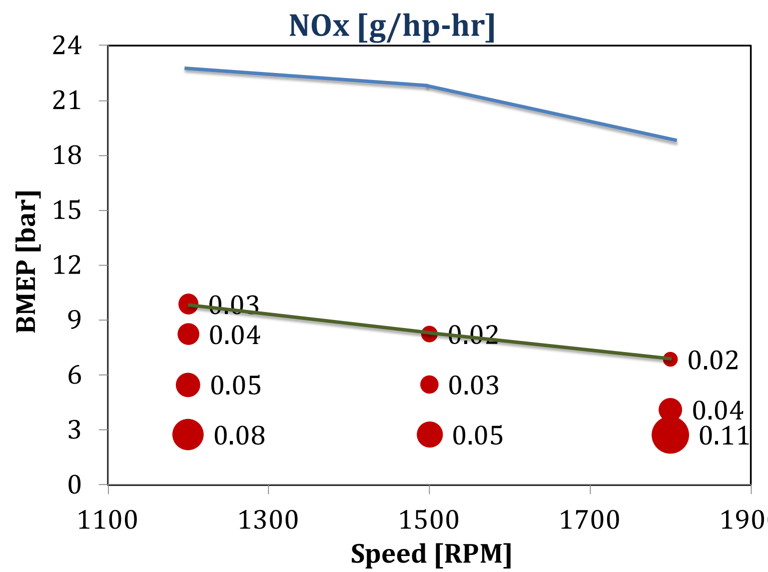
Gasoline + Diesel – Overview

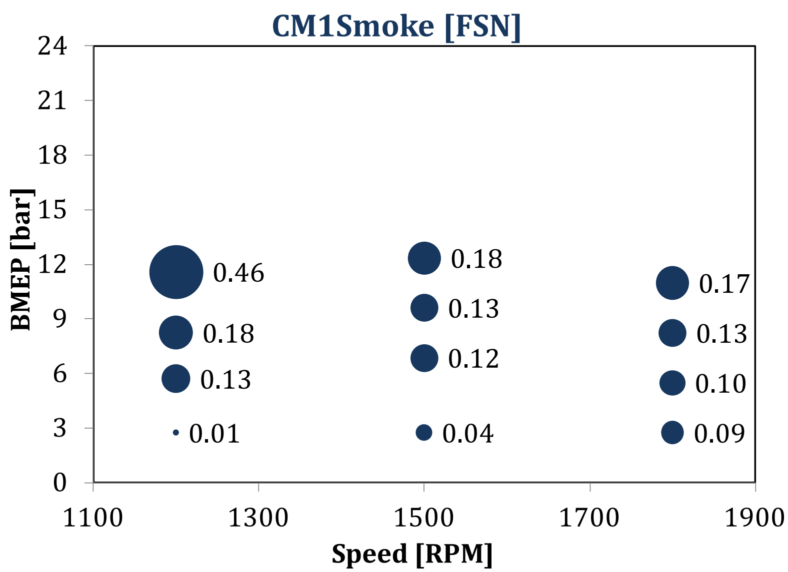
- *CM1 led to wider low temperature combustion range than CM2*
- *CM2 yielded lower NOx and soot than CM1*

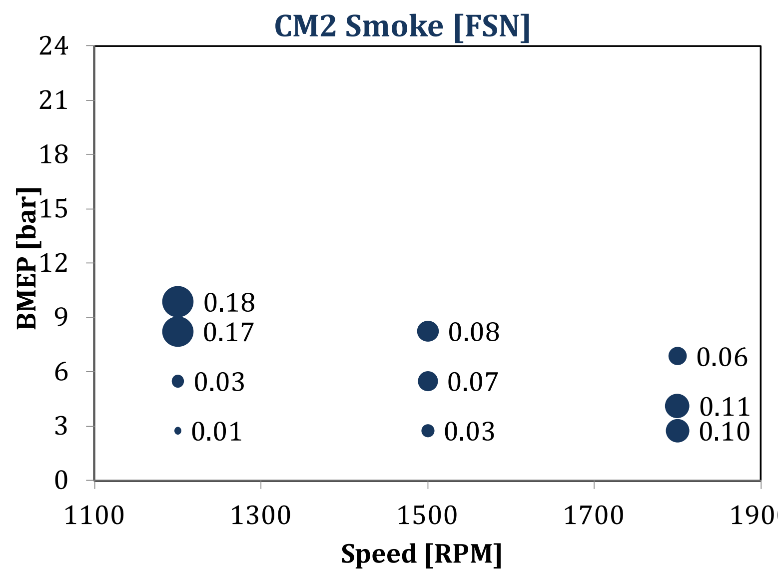
CM1-SS



CM2-SS



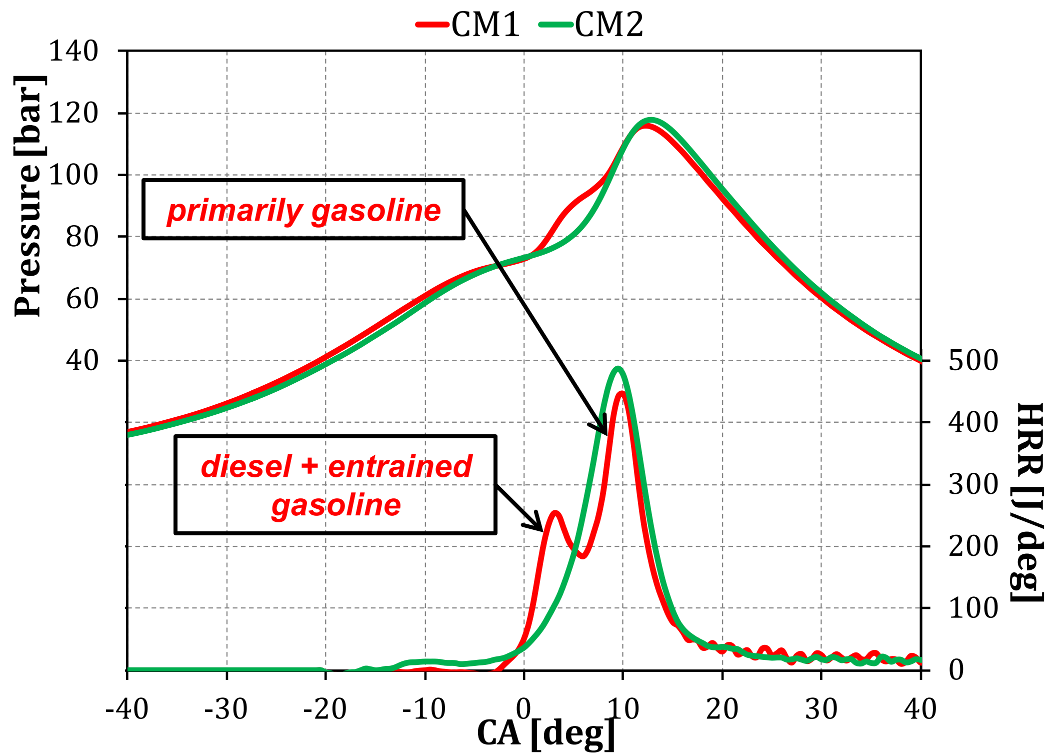




Fuel Reactivity
Gasoline + Diesel – CM1 vs.CM2

1200 rpm; 10 bar BMEP

	CM1	CM2
BTE (%)	42	42
Gasoline (%)	84	93
NOx (g/hp-hr)	0.05	0.03
Smoke (FSN)	0.32	0.18
SOI (aTDC)	-12	-58
EGR (%)	increase →	

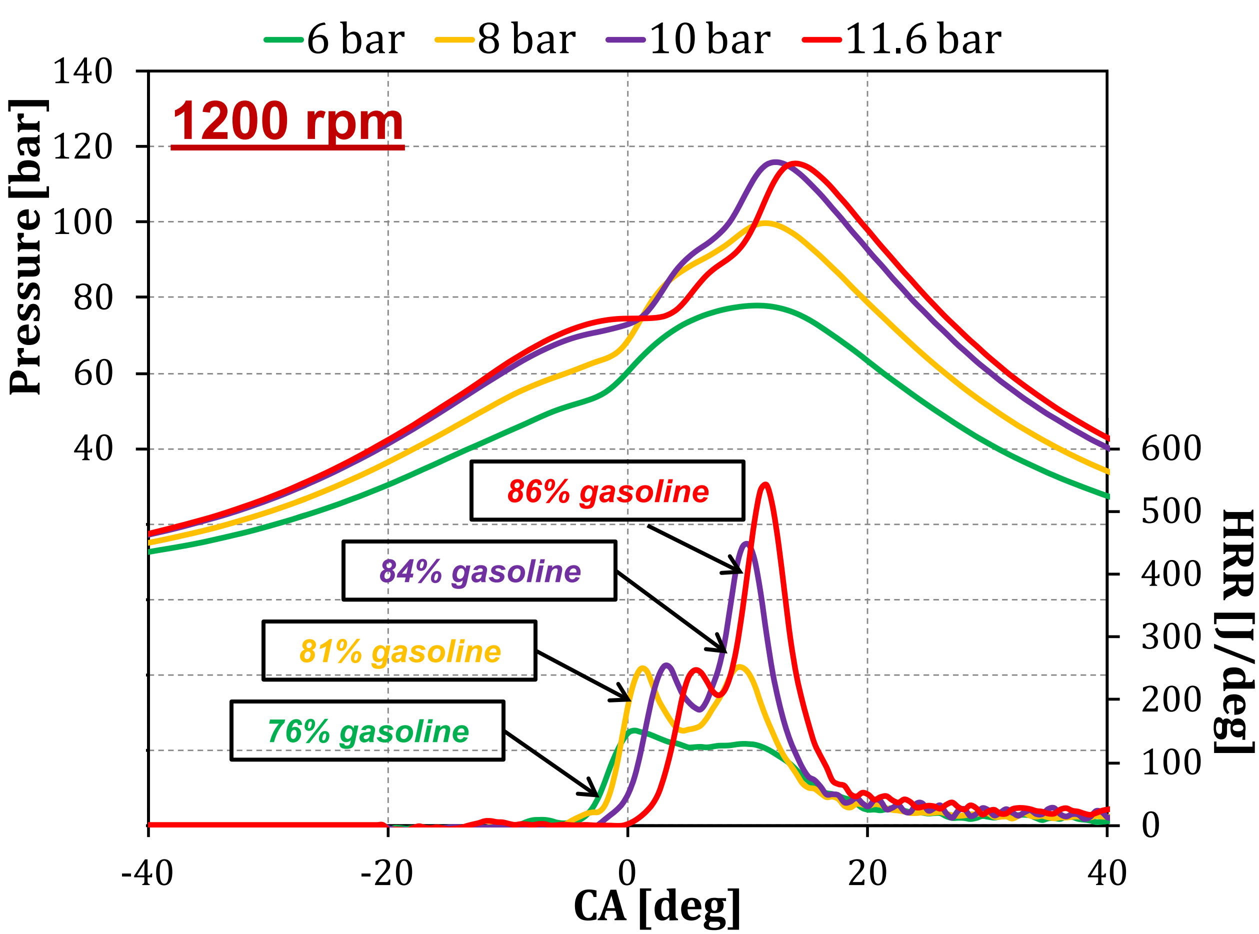


- Comparable fuel efficiency
- CM2 demands more EGR and higher gasoline%
- Combustion characteristics:
  - *CM1 combustion proceeds through two-stages*
  - *CM2 combustion goes through a single-stage heat release*

Fuel Reactivity

Gasoline + Diesel – Combustion Characteristics

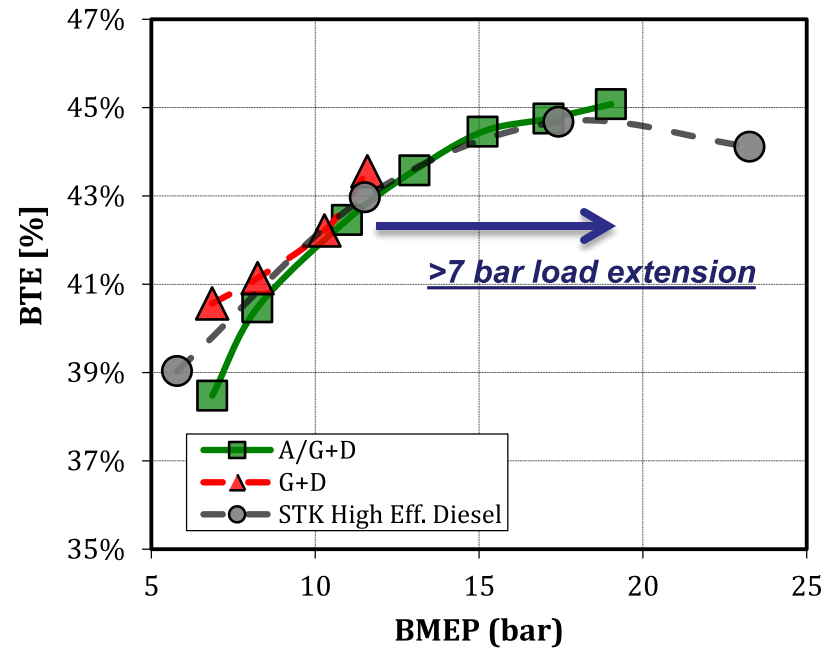
- *CM1 heat release peaks merge with load increase*
- *Towards load-limit, higher gasoline% led to more premixed combustion and higher PRR*

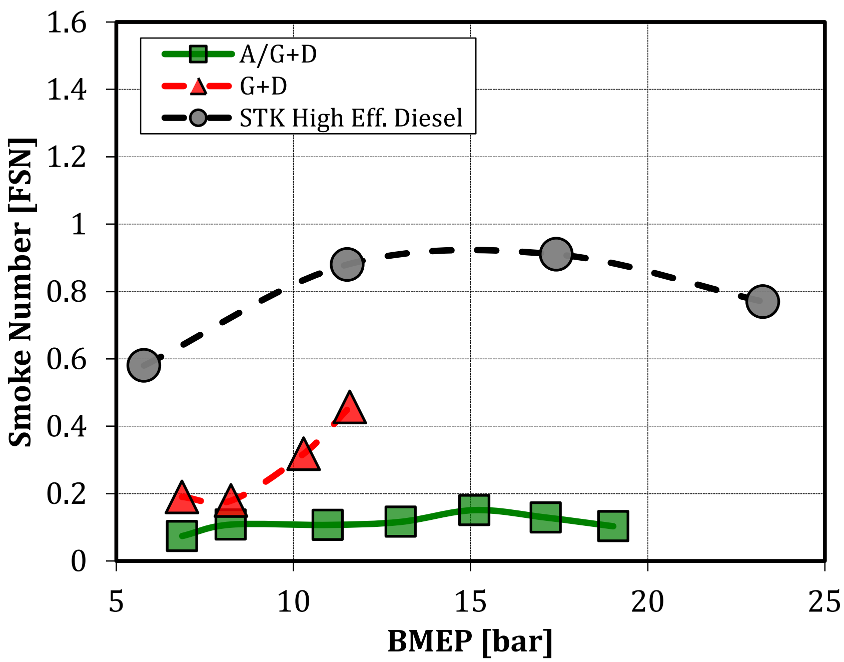


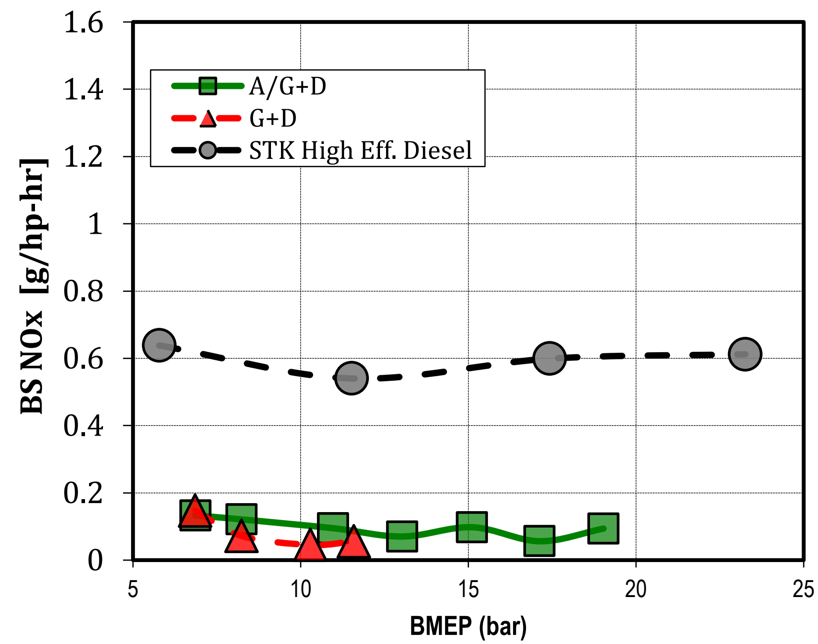
Fuel Reactivity

Alcohol/Gasoline + Diesel – Performance

- ✓ Alcohol/gasoline extended LTC load range to **19 bar** BMEP
- ✓ Fuel-bound oxygen led to soot reduction
- ✓ improved fuel efficiency
  - *best BTE:* ***45.1%***





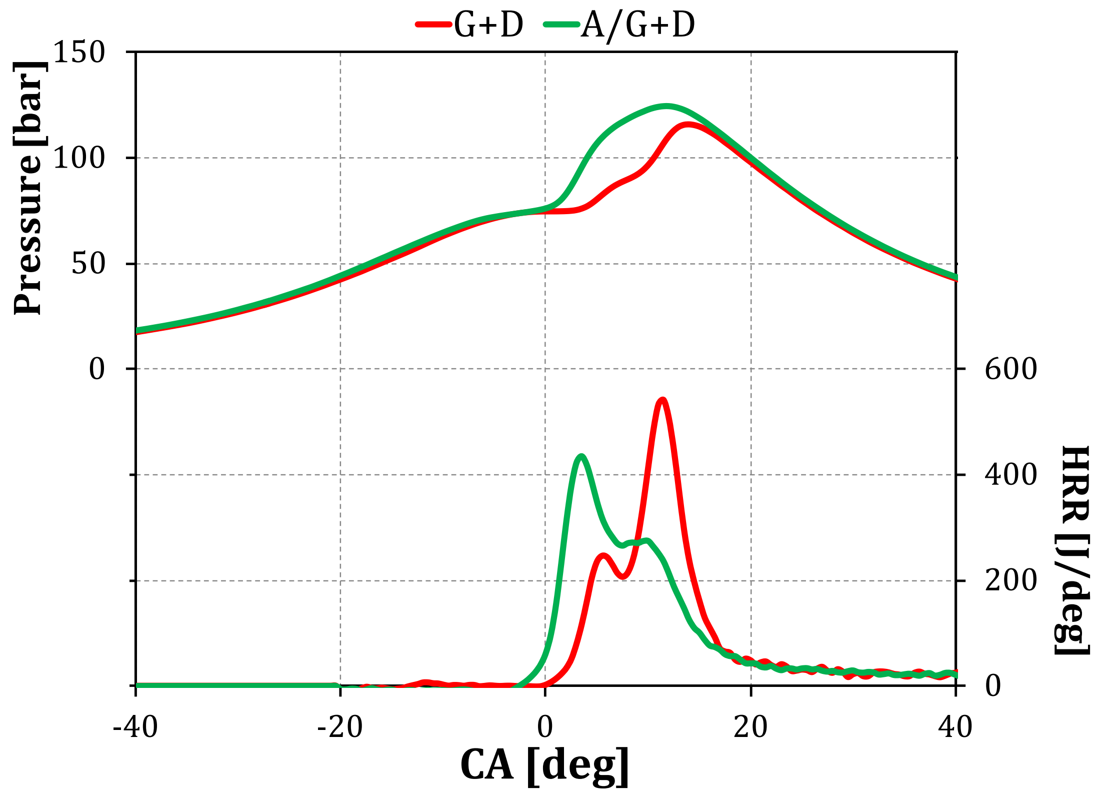


Fuel Reactivity

Alcohol/Gasoline + Diesel vs. Gasoline + Diesel

1200 rpm; 11.6 bar BMEP

	G+D	A/G+D
BTE (%)	43.6	43
PFI (%)	84	78
EGR (%)	reduce →	
SOI (aTDC)	-7	-13
NOx (g/hp-hr)	0.06	0.08
Smoke (FSN)	0.46	0.11

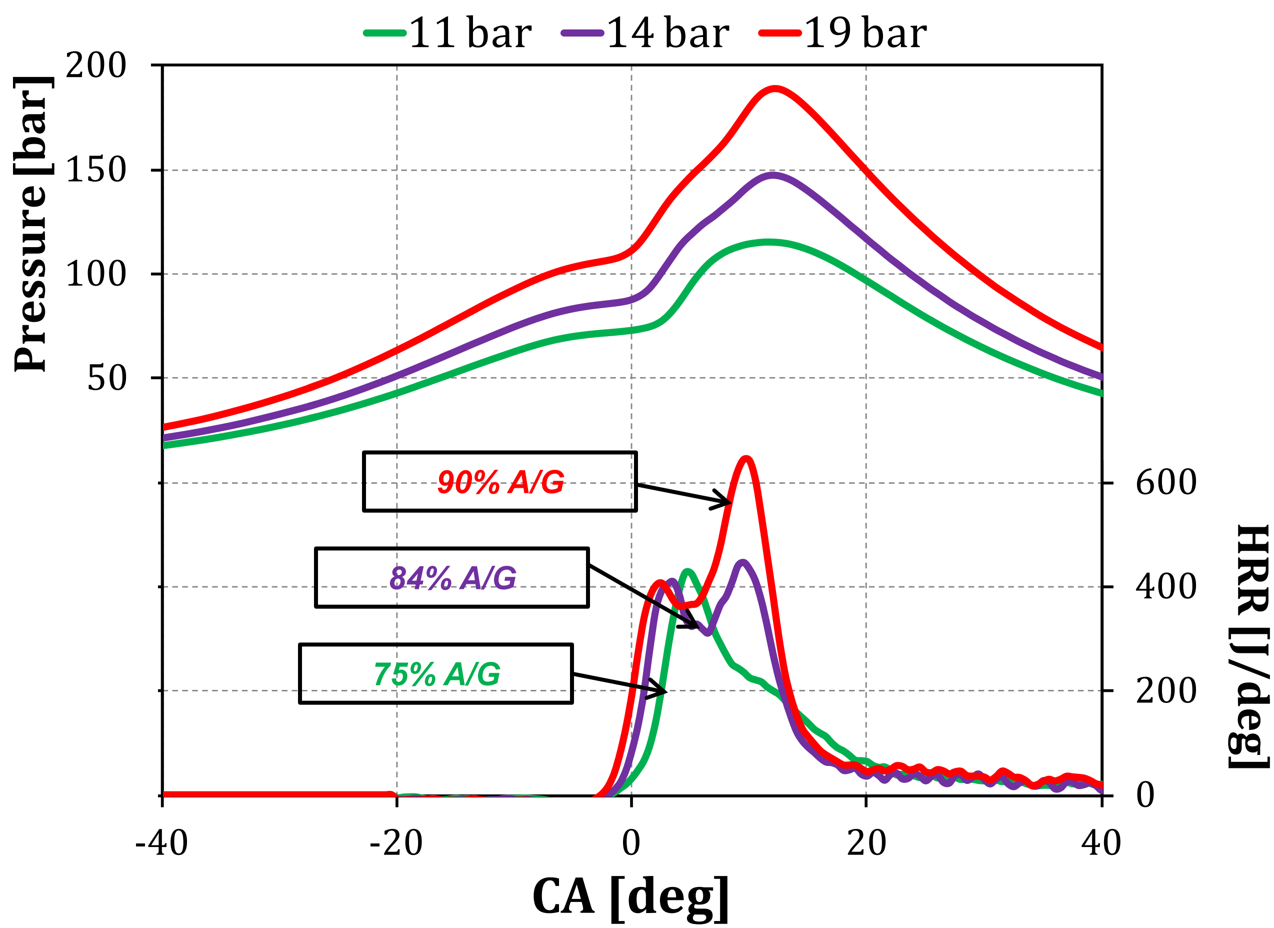


- *Alcohol/gasoline showed less rapid second-stage heat release*
- *Alcohol/gasoline allowed for more advanced SOI and earlier combustion phasing without sacrificing soot and PRR*

Fuel Reactivity

Alcohol/Gasoline + Diesel – Combustion Characteristics

✓ *Alcohol/gasoline led to wider heat release spread and better contained PRR*



Fuel Reactivity

Summary

Project Target:

✓ Demonstrate a technical path towards 55% BTE with fuel reactivity

Milestones:

✓ Phase I with **gasoline + diesel** demonstrated LTC operation up to **11.6 bar** BMEP with best BTE of **43.6%**

✓ Phase II with **alcohol/gasoline + diesel** achieved LTC operation up to **19 bar** BMEP with best BTE of **45.1%**

Further Improvements

✓ Further exploration of fuel reactivity
✓ Combustion system optimization (CR, piston geometry)
✓ Air system upgrade (VVA+turbo)

Acknowledgements

Engine Project Partners

Combustion Simulation	Fuels	Enabling Technologies	
WERC	ARGONNE NATIONAL LABORATORY	BOSCH	FEDERAL MOGUL

Thank You for Your Attention

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