High Cetane Number Paraffinic Diesel Fuels and Emission Reduction

Martti Larmi, Aki Tilli, Ossi Kaario, Yesun Gong, Eero Antila, Teemu Sarjovaara, Harri Hillamo, Kari Häkkinen, Kalle Lehto, Helsinki University of Technology TKK, Anders Brink ÅAU University, Päivi Aakko-Saksa VTT, Finland

TKK

The synthetic and renewable fuels to be studied

1. High CN paraffinic diesel fuels like HVO and FT-diesel Fuel
2. High CN paraffinic diesel fuels with high concentration of oxygenates

3. Biogas/NPG and Dual Fuel Combustion in Future projects
4. Neat oxygenates like DME in Future projects

Fatty acid methyl ester (FAME) biodiesel and diesel fuel (like EN 590 in Europe) are used as a reference fuels

Project Objectives

Combustion Optimization.

Significant reduction of CO_2, NO_x and Particulate Matter (PM) Emissions (70 %) without Drawbacks in Efficiency or Power Output

How to do it?

- High CN => good ignition behavior => lower ignition temperature or high dilution possible => high Miller or EGR => lower peak combustion temperatures => remarkable NOx reduction
- No Aromatics or Sulphur =>less soot and PM
- High injection pressure: good combustion control and smaller SMD and enhanced air entrainment in fuel spray => lower local equivalence ratios => less soot and PM
- Oxygenate blend => lower local equivalence ratios => less soot and PM, higher heat capacity => lower peak combustion temperatures => additional NOx reduction

How to affect combustion?

- Extreme Miller timing
- Extreme EGR rate
- Fuel injection design, timing and high pressures
- In-cylinder flow and swirl
- Combustion chamber design

Implementation

- Fuel spray studies in spray bombs
- Combustion research in optical engines
- Combustion studies in research engines
- Computational combustion and emission formation studies
- Combustion optimization by CFD
- Implementing the optimum combustion in research engines
- Extensive emission measurements

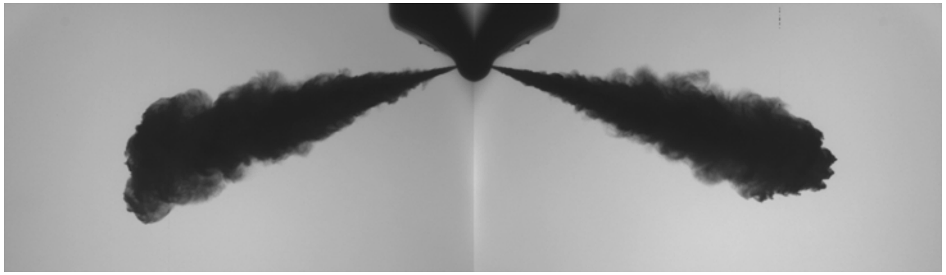
Milestones at TKK

2009 Literature review and first engine measurements with extreme Miller cycle, combustion chemistry

2010 Spray measurements, CFD analysis, new engine tests

2011 Optical combustion measurements, optimum combustion for high CN dieselfuels

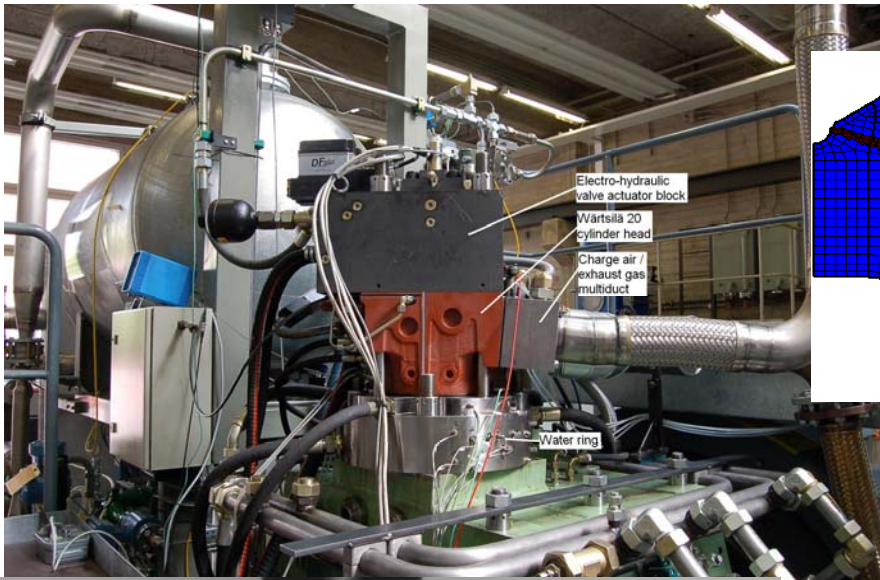
2012 Optimum combustion for highly oxygenated diesel fuels

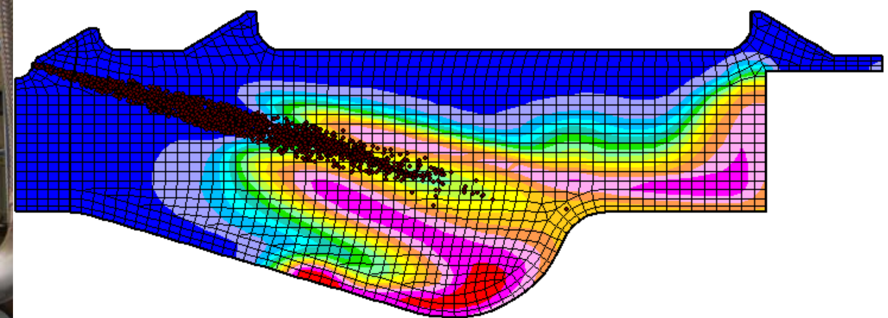


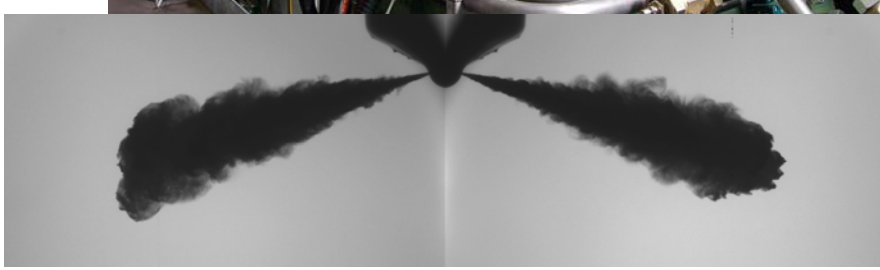
Resources at TKK

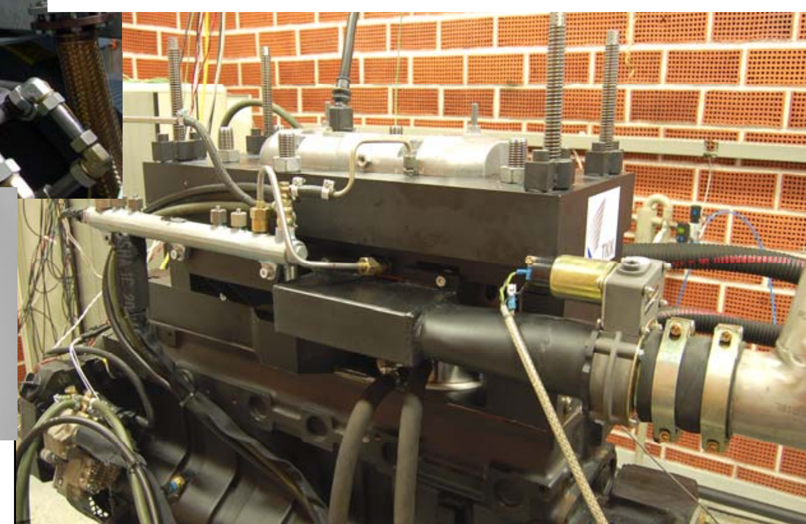
- Low Emission Optical (LEO) engine
- Extreme Value Engine (EVE)
- Optical diagnostics (PIV, LIF, LII and backlight imaging)
- Spray chambers (40–100 bar ambient pressure)
- Modern Heavy duty diesel engines
- CFD–tools

Resources at TKK



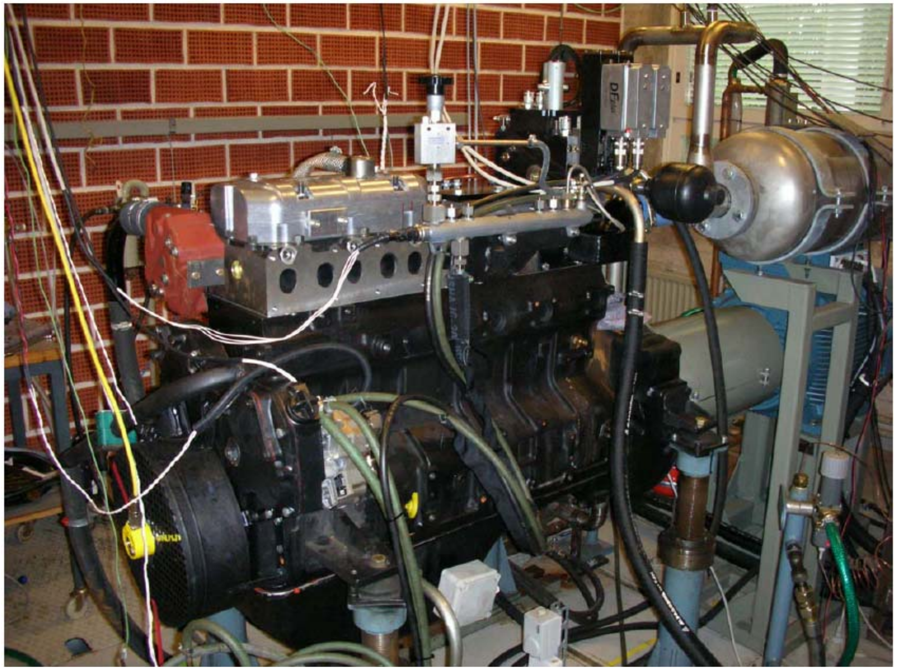






Main research engine: LEO with EHVA

- LEO (Low Emission Optical engine) is single-cylinder research engine based on a 6-cylinder SISU 84 CTA off-road engine by AGCO SISU POWER.
- EHVA is the Electro Hydraulic Valve Actuator



- bore 111 mm
- stroke 145 mm
- nominal speed 2200 r/min

LEO with EHVA

- LEO with EHVA will be operated mainly at speed 1000 – 1500 rpm
- EHVA has been tested at speed 2200 rpm succesfully
- The valves can be opened and closed at speed which corresponds to 3000 rpm

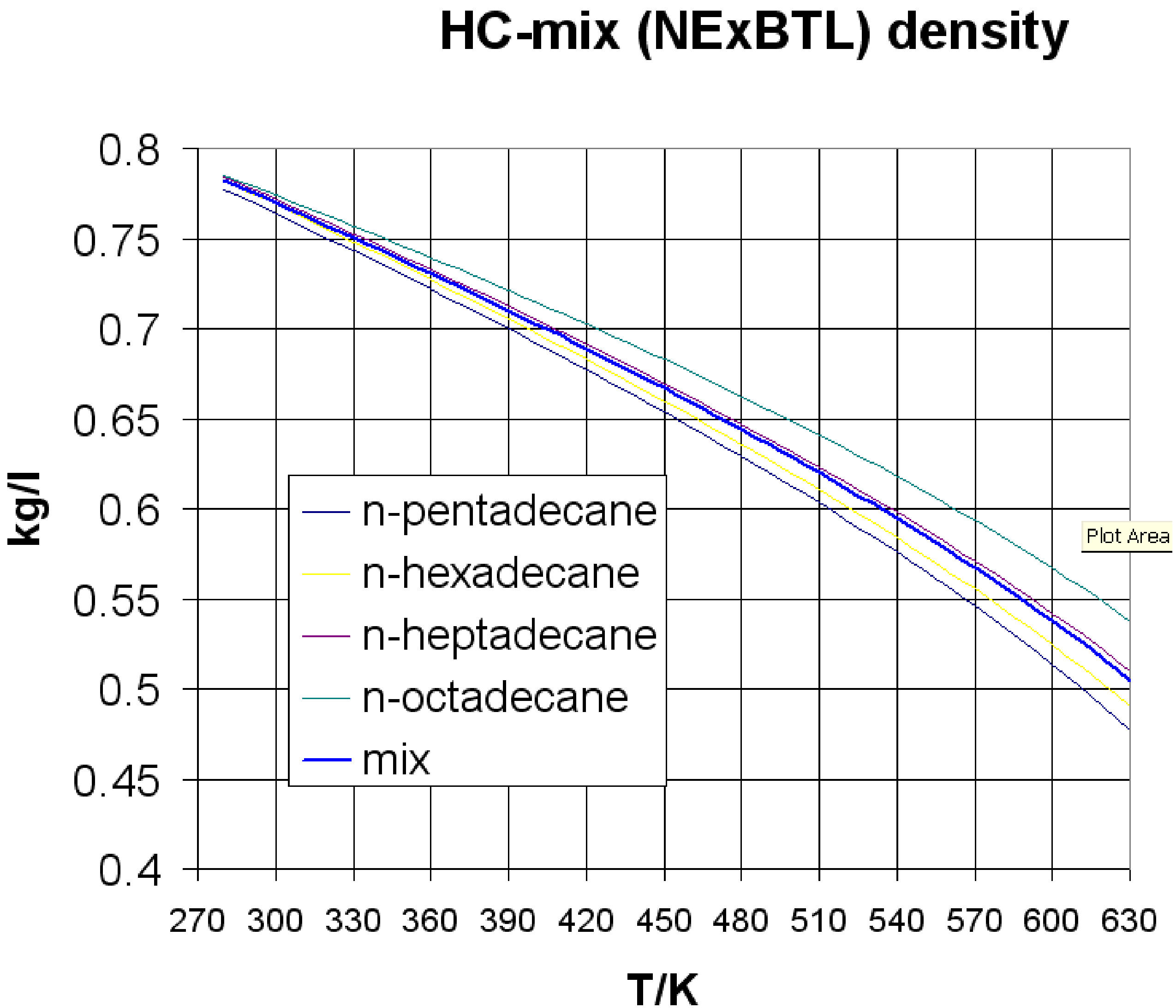
Literature study on previous research

- FT/HVO –diesel test runs, emission measurement results
- Modern combustion technologies => results
- Combustion optimization results
- Paraffinic fuel properties@high T and p?

Fuel properties

	HVO	GTL Diesel	FAME	EN590/05 Summer	PetroDiesel winter MK1
Density @ +15ºC (kg/m^3)	775 - 785	770 – 785	≈ 885	≈ 835	800 - 820
Viscosity @ + 40ºC (mm^2/s)	2.9 – 3.5	3.2 – 4.5	≈ 4.5	≈ 3.5	1.5 - 4
Cetane number	84 – 99	≈ 73 – 81	≈ 51	≈ 53	≈ 51
10% distillation (ºC)	260 – 270	≈260	≈ 340	≈ 200	≈ 210
90% distillation (ºC)	295 – 300	325 – 330	≈ 355	≈ 350	≈ 275
Cloud point (ºC)	-5 to -30	0 to -25	≈ -5	≈ -5	-22 to –36
Heating value (low) (MJ/kg)	≈ 44	≈ 44	≈ 38	≈ 43	≈ 44
Heating value (MJ/l)	≈ 34	≈ 34	≈ 34	≈ 36	≈ 35
Polyaromatic content (wt%)	0	0	0	≈ 4	0
Oxygen content (wt%)	0	0	≈ 11	0	0
Sulfur content (mg/kg)	≈ 0	< 10	< 10	< 10	< 10

HVO properties, density



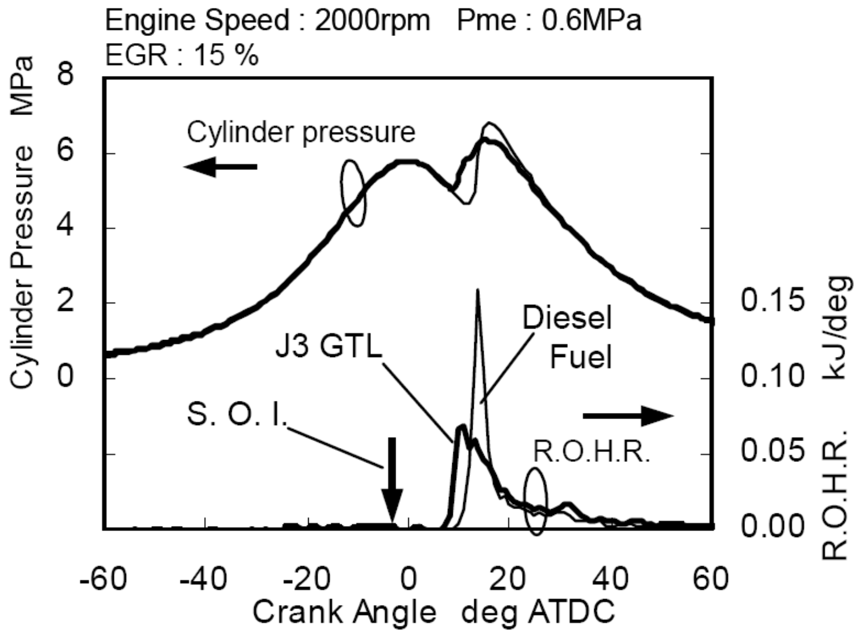
High cetane number in the literature

- **High CN => better combustion => lower HC and CO (60-70 %, SAE 2005-01-3763 etc.), reduction of unburnt emissions, combustion noise**

⇒Lower NOx by very high EGR rate o extreme Miller timing

- **short ignition delay => low heat release peak due to the decrease of premixture**
- **But: short ignition delay => shorter mixing time before ignition => smoke and PM (“too good a fuel”)**

⇒ smoke level of fuel is low _despite_ high CN! Causes: paraffinic nature of the fuel (no aromatics) and low viscosity



(SAE2005-01-3763)

High CN effects (GTL fuel)

- **Lower viscosity: wider spray angle, SMD reduced => better droplet dispersion => enhanced mixing (SAE 2005-01-3763)**
- **Lower distillation temperatures: early evaporation => enhanced mixing**

⇒ **better combustion, possibilities...**

- **Lower density: less energy per unit volume => performance loss?**
  - Not necessarily, because of better combustion!

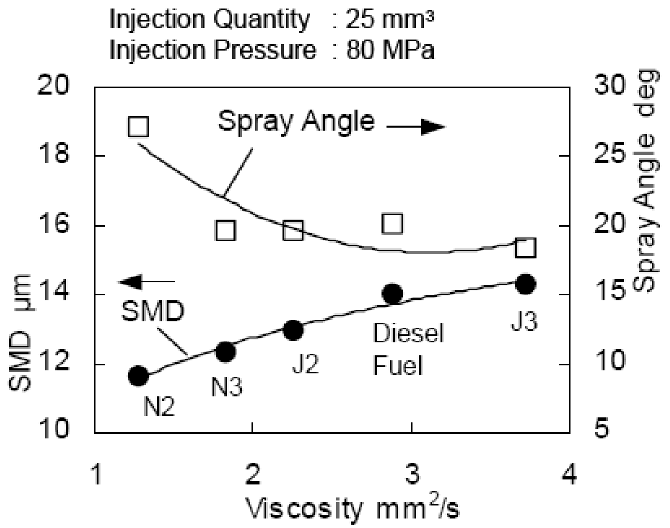
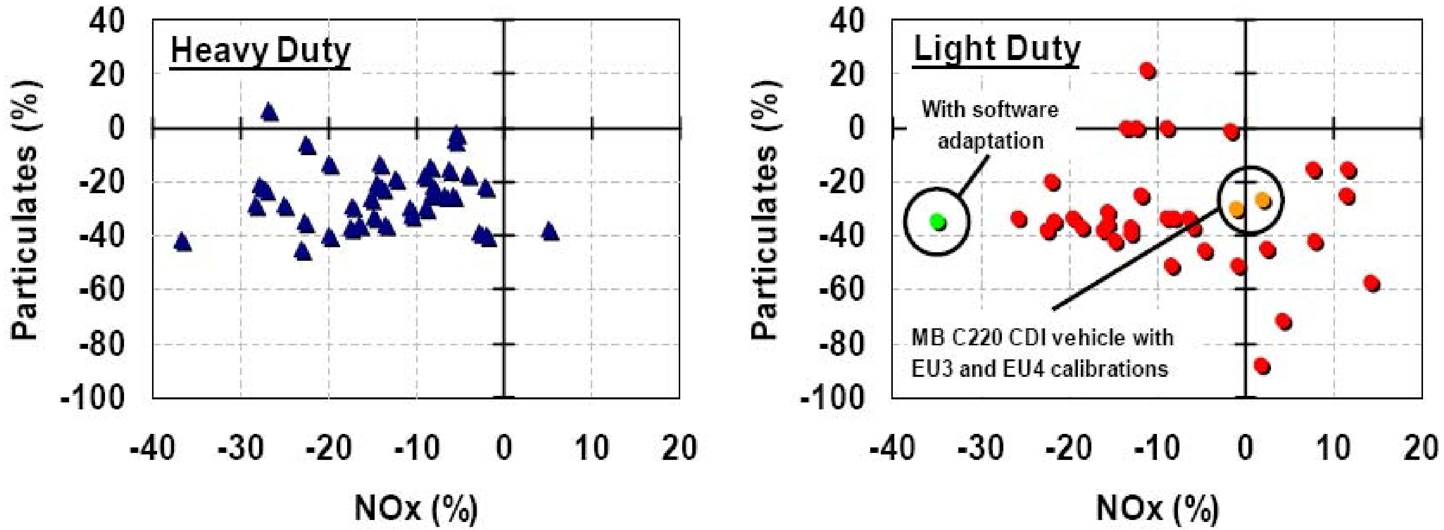


Figure 17. Fuel influence on SMD and spray angle

Previous studies: Direct comparisons, no calibration

Impact of GTL diesel fuel on performance and emissions : Review

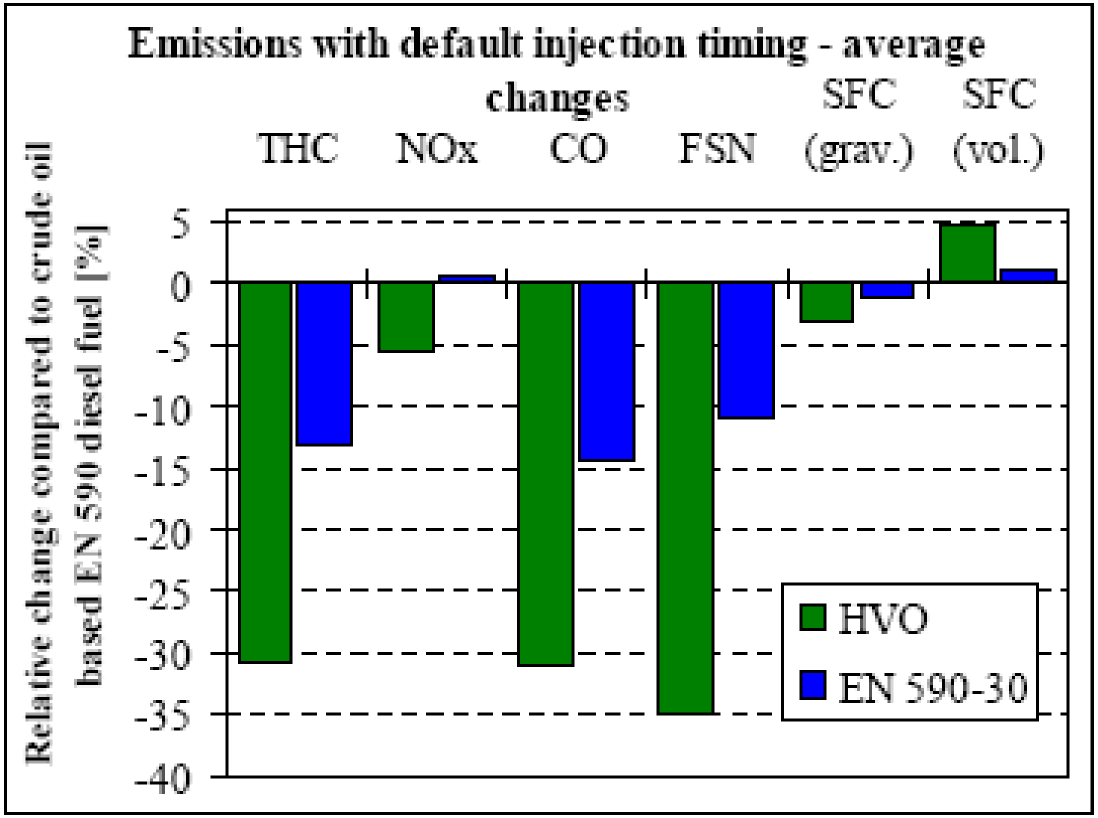


Potential reductions in all regulated emissions (HC, CO, NO_X, PM), as well as in CO_2 and other unregulated emissions

(Schaberg, Sasol Technology)

Source : SAE Paper 2003-01-0763, NREL

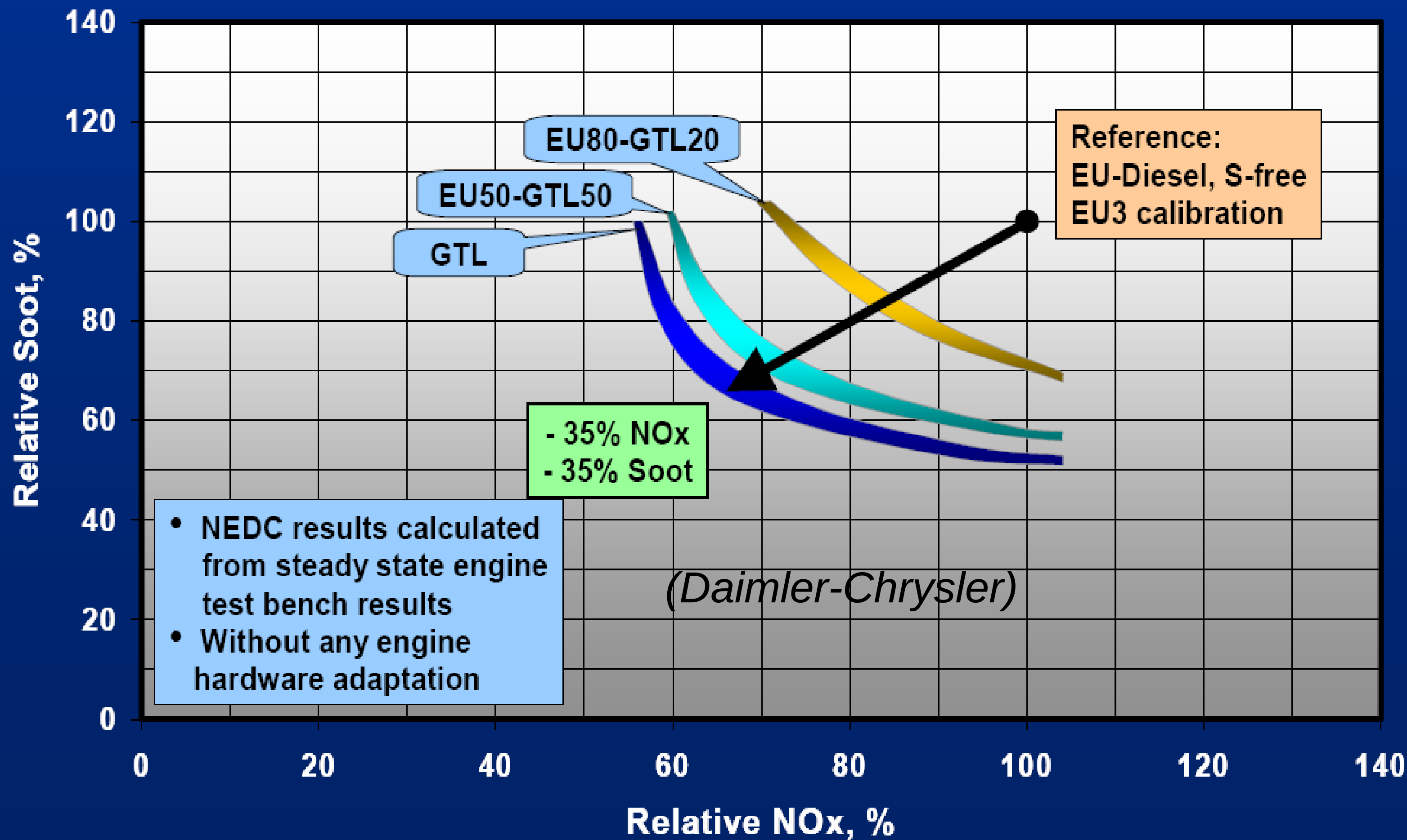
Previous studies: Heavy Duty Engine Performance



SAE 2008-01-2500, Hannu Aatola, Martti Larmi, Teemu Sarjovaara, TKK; Seppo Mikkonen, Neste Oil

Previous studies: Potential with engine calibration

The design of experiments method predicts for the NEDC simultaneous reductions in soot and NOx by up to 35 % just by software adaptation of the CU to the GTL fuel



Previous studies: EGR

- **Over 70% emission reductions have been obtained, when focusing on one emission. Target: reduce all the emissions at the same time.**

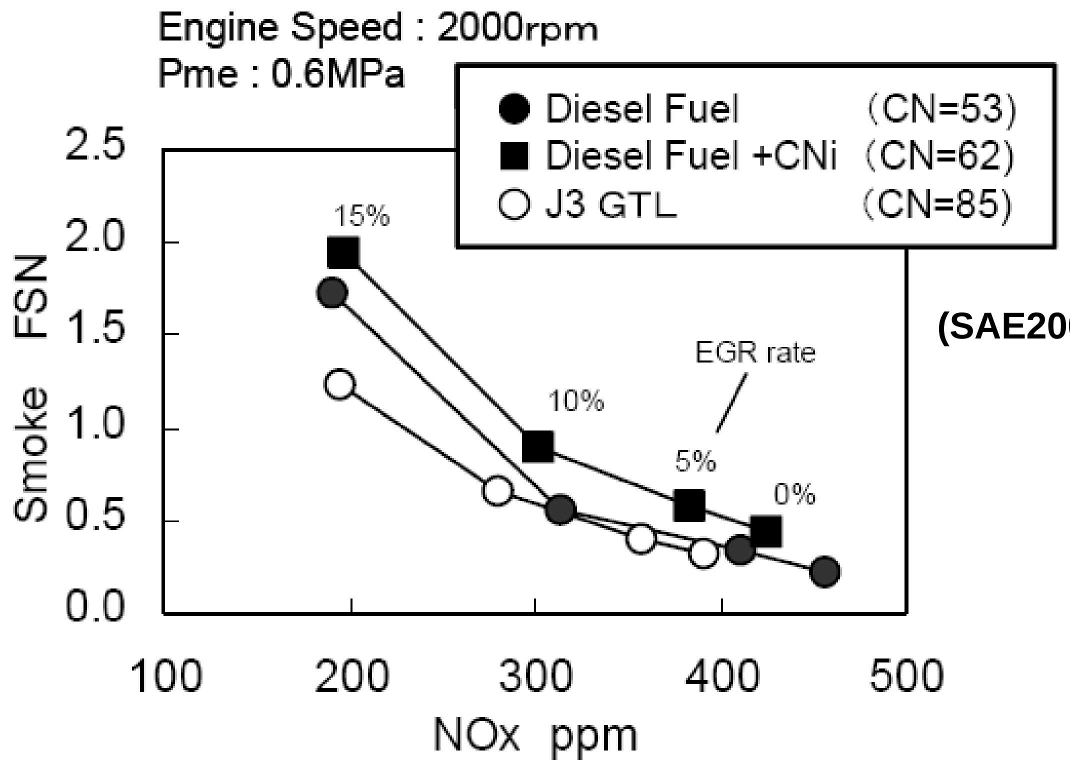


Figure 8. Effect of cetane number improvement with diesel fuel on smoke emission

(SAE2005-01-3763)

Previous studies: EGR

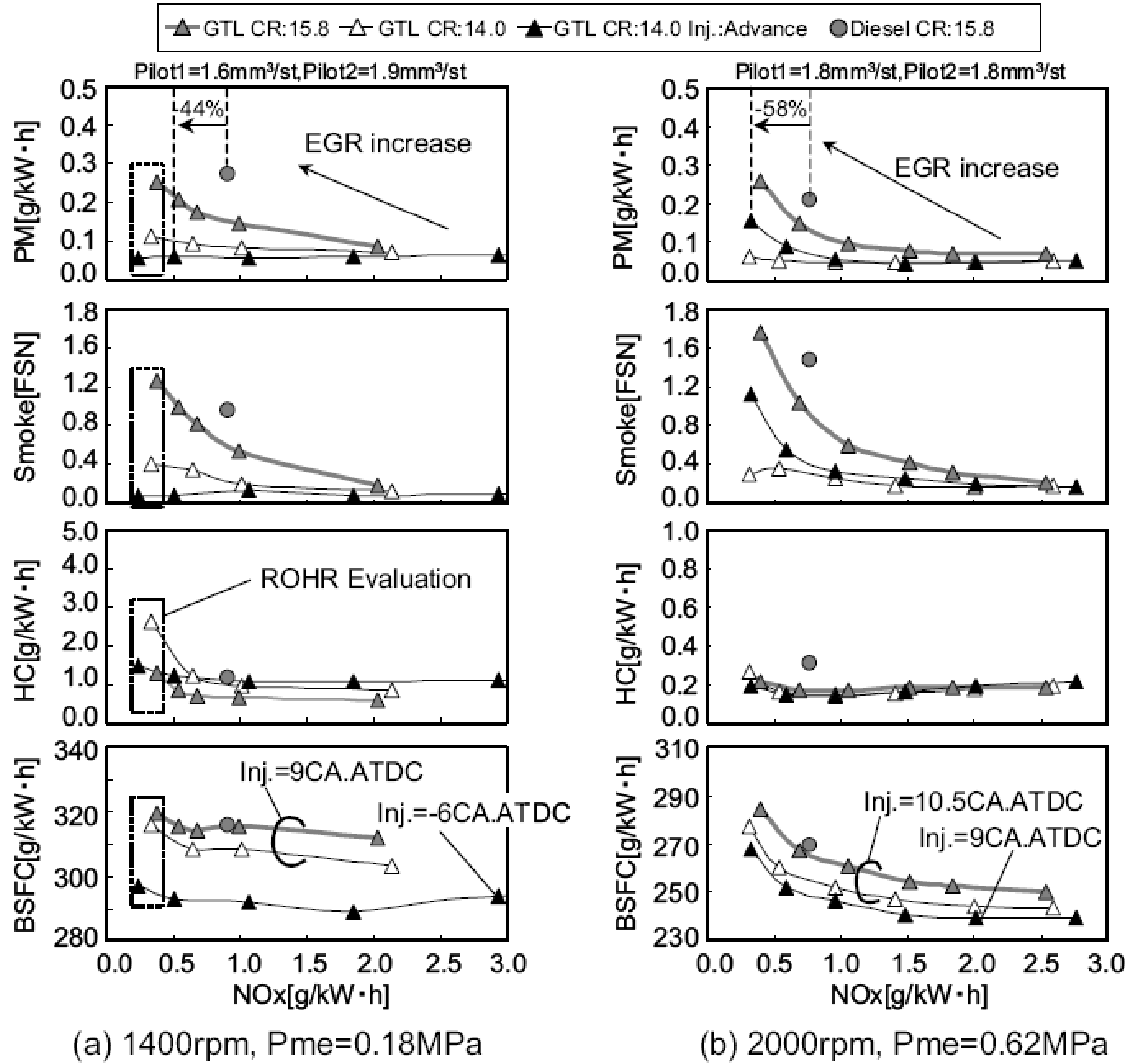


Figure 6 Effect of EGR and Injection Timing on Emission and Fuel Consumption of GTL Fuel

(SAE 2009-01-1933)

Plenty of room for new research

- Combustion Optimization for dedicated fuels in focus
- So far, mainly standard test runs have been carried out with existing engines without considering the special propertities of the fuels
- Relatively new research area => new interesting results ahead

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