Hydrogen – Methane Blend as an Internal Combustion Engine Fuel

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CENTRUM VOZIDEL UDRŽITELNÉ MOBILITY
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INVESTICE DO VAŠÍ BUDOUCNOSTI
OP Výzkum a vývoj pro inovace
Technology Agency of the Czech Republic
... from ideas to applications

Outline

- Motivation
- Methodology
- Experimental results – engine test bench
  - combustion phasing
  - power and efficiency
  - emissions
- Conclusions

Motivation for use of hydrogen-methane blends as smart energy carriers for ICE in transportation

- Support of inquiry for hydrogen production and distribution infrastructure
- Exploitation of hydrogen for energy accumulation from:
  - large difficult-to-control power plants
  - renewable sources
- Reduction of fossil fuel consumption
- Internal Combustion Engines
  - most wide spread, available technology, best performance-to-cost ratio

Instantaneous positive impact on greenhouse gases emission

Methodology

Approach

- experimental study
- onsite fuel blending (H_2 + NG)
- complete low speed data acquisition system
- detailed analysis of engine working cycle and online combustion diagnostics based on high speed data acquisition of in-cylinder pressure
- combustion chemical efficiency assessment based on raw exhaust gas analysis
  - CO, CH_4, CO_2 (NDIR)
  - O_2 (PMD)
  - NO, NO_2 (NDUV)
- study focused on investigation at low load

Methodology

Contribution of Emitted Gaseous HC (VOC) on Global Warming Index

$$GWI = \Sigma K_i m_i$$

K_i - Global Warming Potential, depends on:

- Absorption Activity of i-Component
- Absorption Spectra of i-Component
- Lifetime of i-Component in Atmosphere

$K_{CO2} = 1$ (i.e. for Each GHG: K_i represents its CO_2 equivalent)
$K_{CH4} = 23$ - Time Horizon: 100 years (Kyoto Protocol Amendment)
$K_{CH4} = 62$ - Time Horizon: 20 years (CARB – The most strict version)

Therefore:

$$GWI_{23} = mCO_2 + 23 \times mCH_4,$$

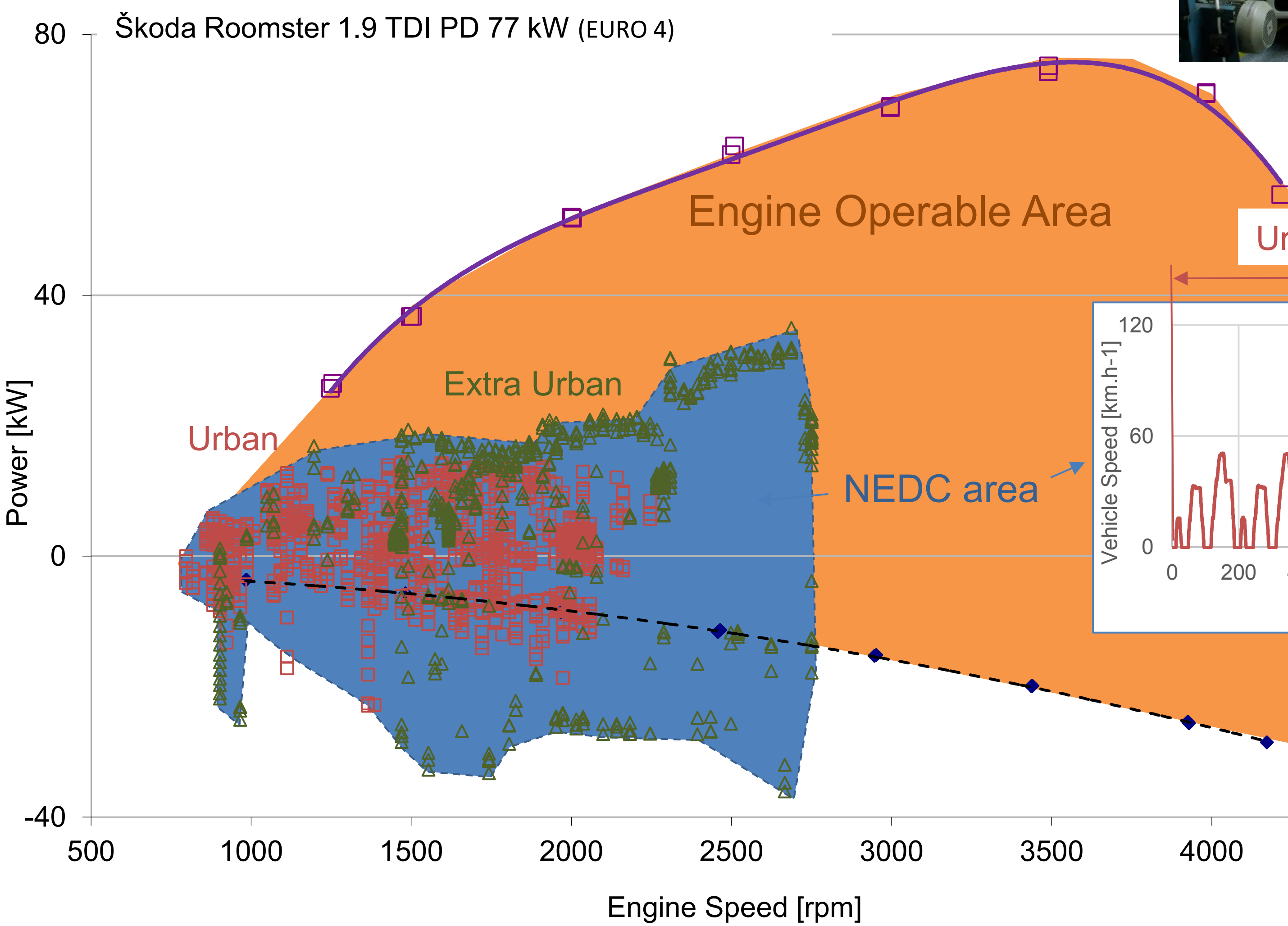
or

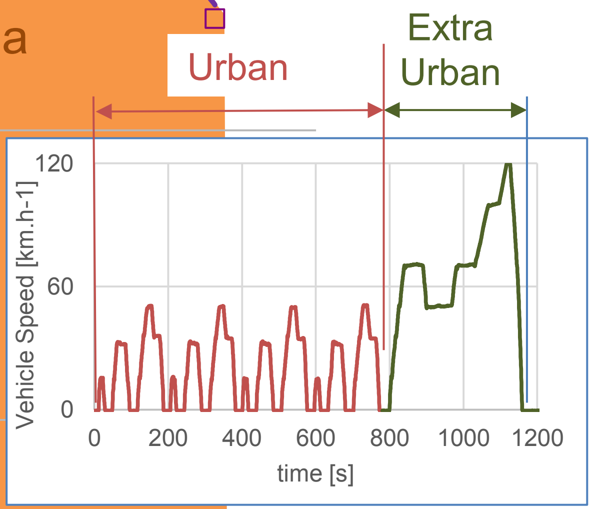
$$GWI_{62} = mCO_2 + 62 \times mCH_4$$

Contribution of emitted gaseous HC is not negligible in a CNG fueled engine.
($THC = CH_4$)

Importance of Low Load Conditions

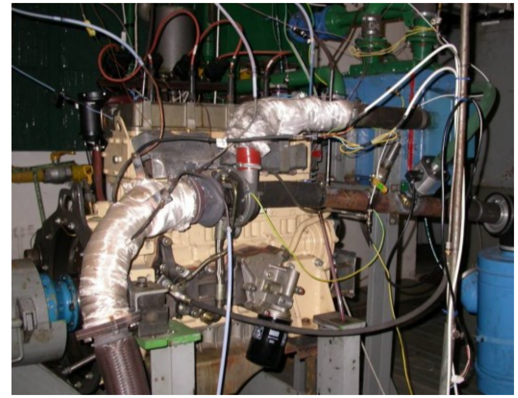
results from chassis dynamometer - combination of steady state and transient measurement

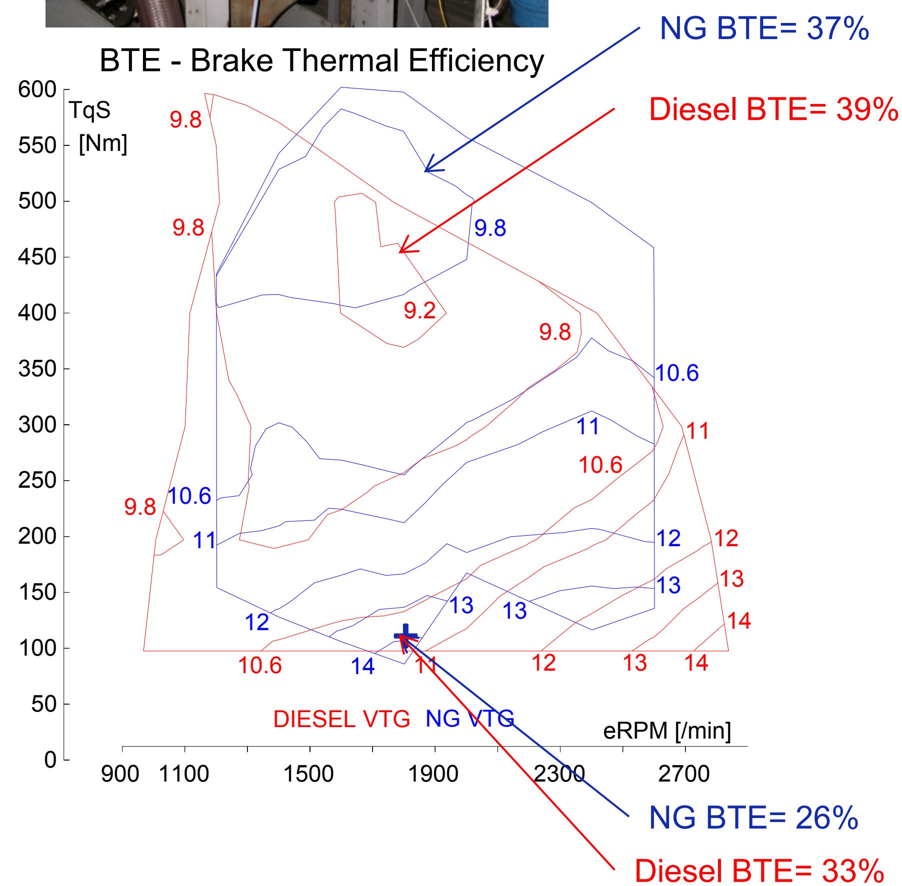




Experimental Setup – engine test bench steady state measurements

Engine Manufacturer	AVIA
Basic Engine Geometry	
Cylinder #	4
Bore	102
Stroke	120
Displacement	3.92 dm^3
Compression Ratio	12:1
Valve # / Cylinder	4
Engine Performance	
Maximum Torque	600 Nm @ 1600 - 1800 rpm
Maximum Power	125 kW @ 2400 - 2700 rpm
Turbocharger	
Control	VTG (Variable Turbine Geometry)
Mixture Formation	
Arrangement	Common (central) mixer
Excess-Air Ratio Control	Manual (any value) or Closed Loop ($\lambda = 1$)
Control units	
In-house build fully open electronic control unit	Independent: λ-control; Ignition control; Mixture throttle control; VTG control; EGR control

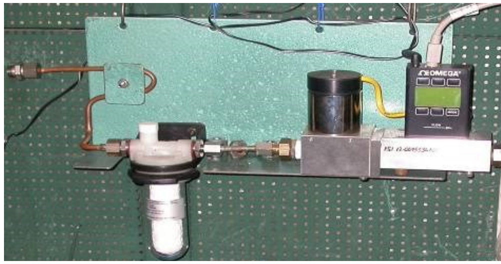


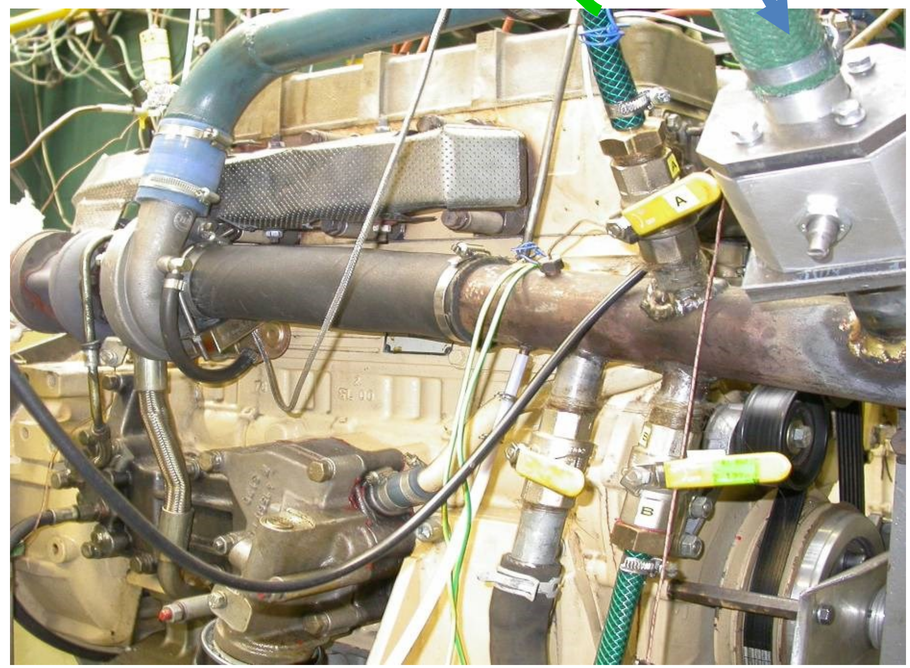


Experimental Setup

Hydrogen Addition

Grid NG delivery, remotely controlled





Base fuel (Grid Natural Gas) delivered into intake manifold

- Independent base fuel metering
- closed loop λ-control

Additional fuel (Hydrogen) independent metering

Two studies:

1. $\lambda = 1$ (closed loop λ control active) – compatible with a TWC, engine performance in dependence of H_2 fraction in a fuel blend (0 – 50% by volume)

2. H_2 / NG = 1 / 1 by volume, engine performance depending on λ – lean burn concept

Methodology

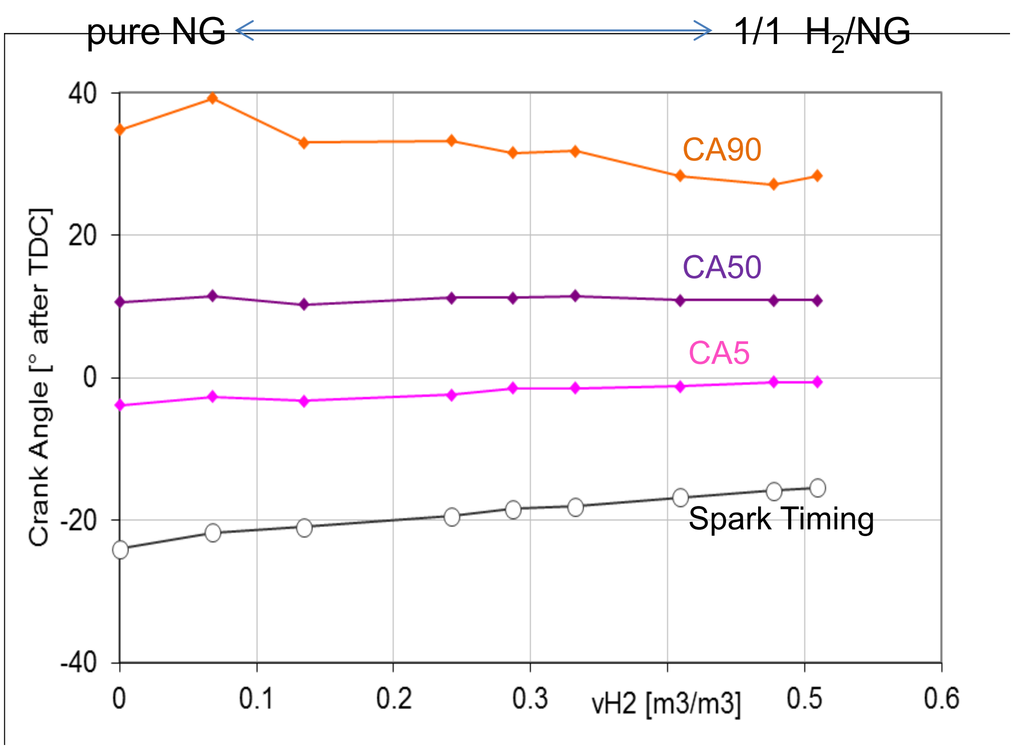
- Constant power output 17.8 kW @ 1800 rpm (BMEP 3.0 bar) - typical load in urban driving
  - controlled by throttle valve

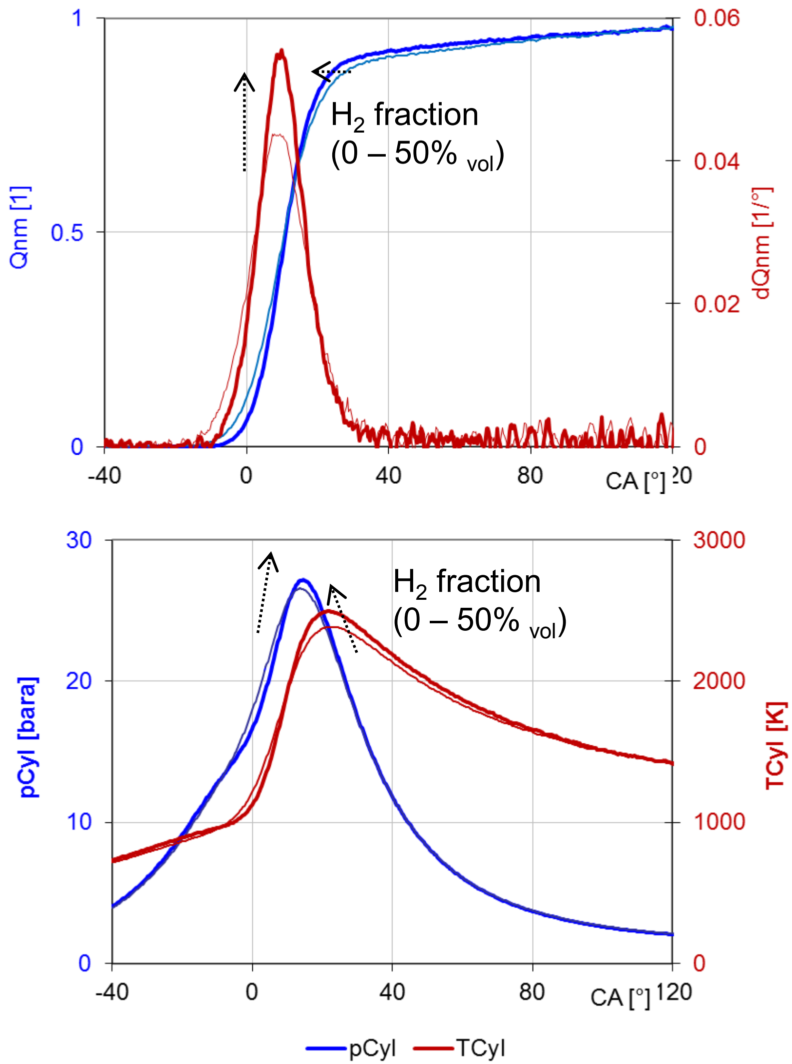
- Constant combustion phasing CA50 (mass fraction burned = 50%) 10° after TDC – best efficiency combustion phasing
  - controlled by ignition timing

Study 1

$\lambda = 1$ (closed loop λ control active), engine performance depending on H_2 fraction in fuel blend (0 – 50% by volume)

Results – Combustion Phasing

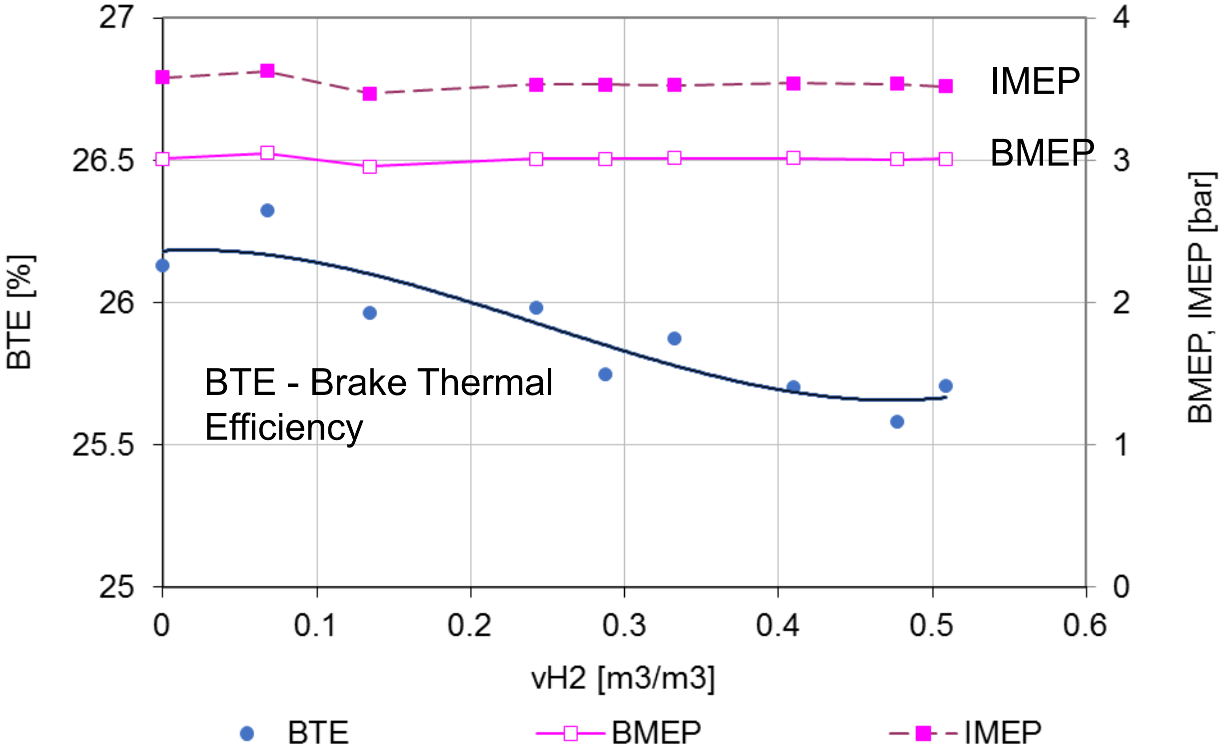


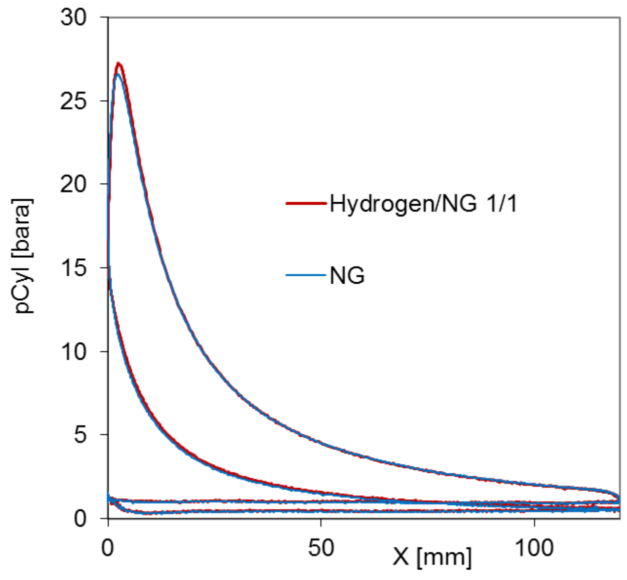


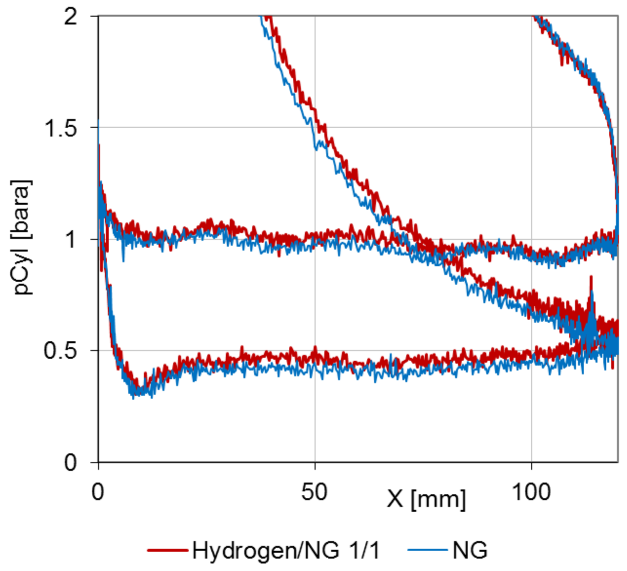
H$_2$ addition increases the rate of heat release

H$_2$ addition slightly increases peak cycle temperature & pressure

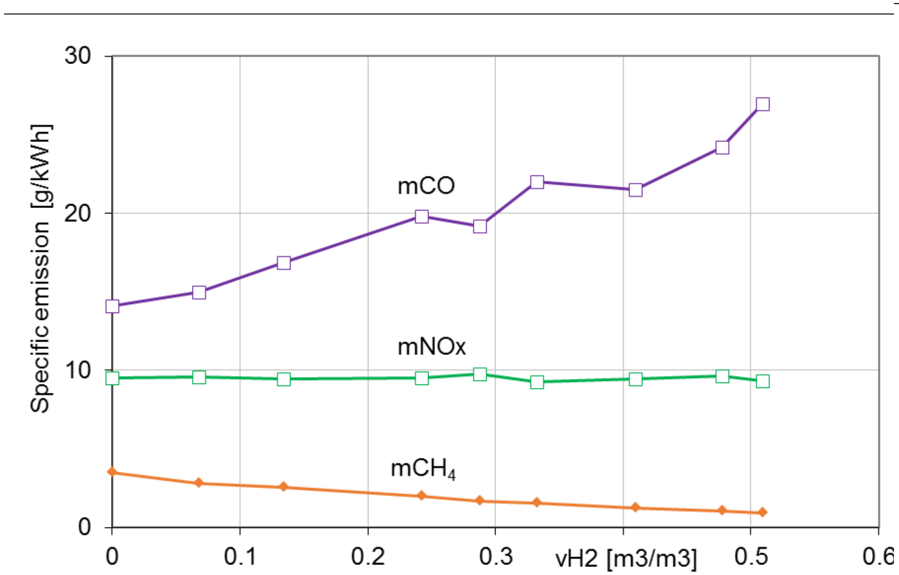
Results – Power and Efficiency

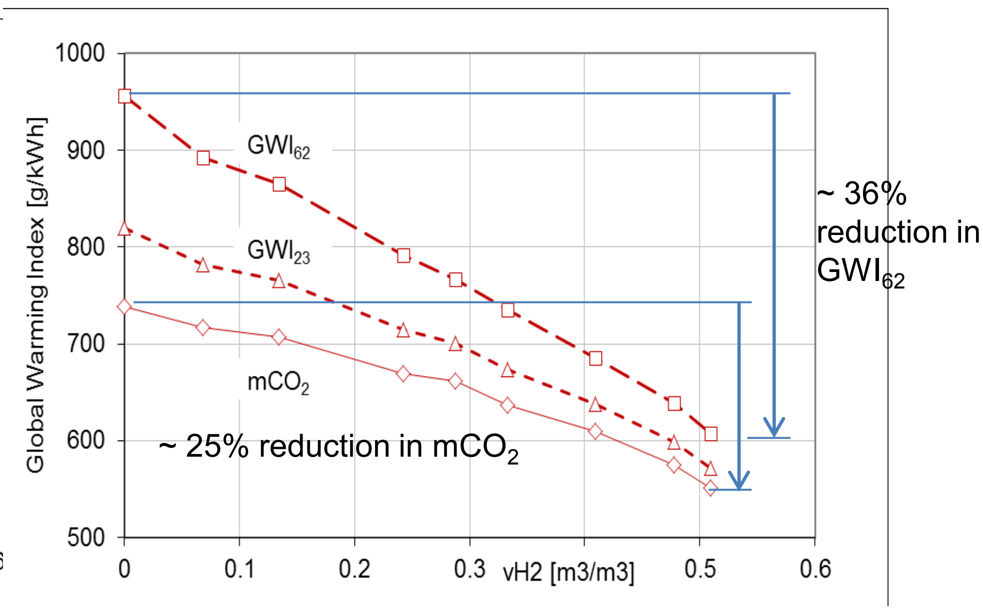






Results – Emissions – Global Impact





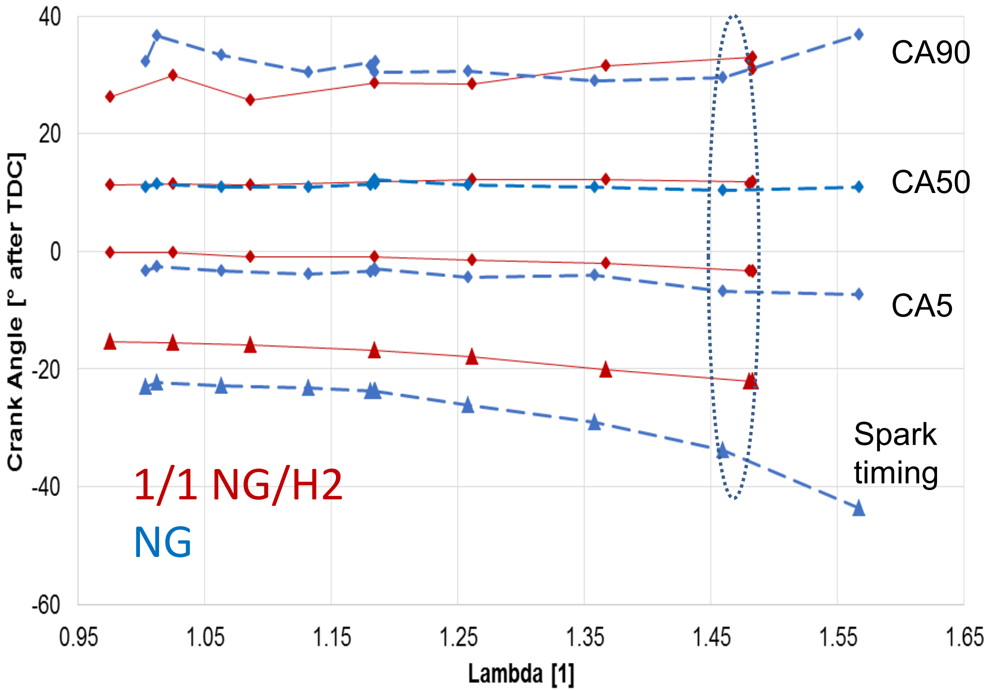
Addition of hydrogen

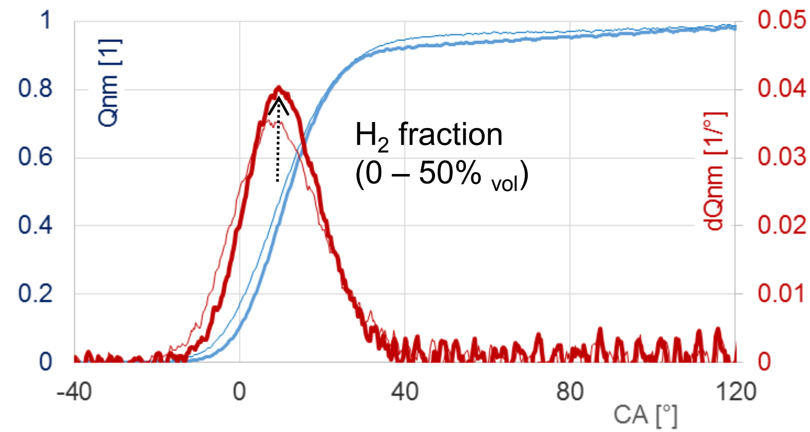
- does not affect NOx emission
- reduces hydrocarbon emissions
- increases CO emissions
- reduces specific CO_2 emission and GWI

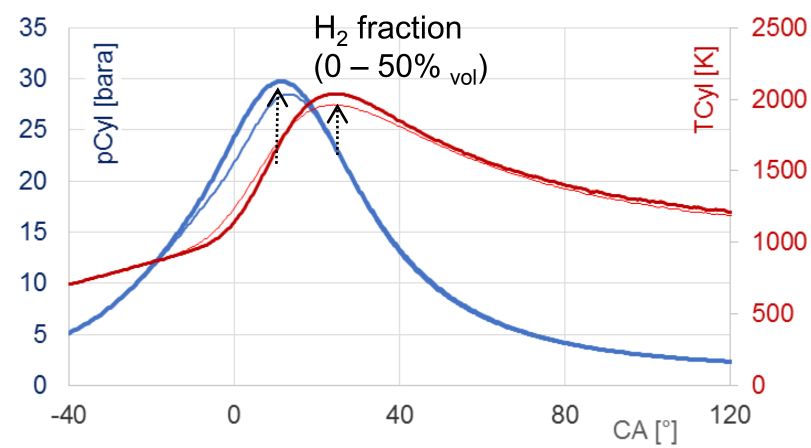
Study 2

Hydrogen / NG = 1 / 1 by volume, engine performance depending on λ – lean burn concept

Results – Combustion Phasing

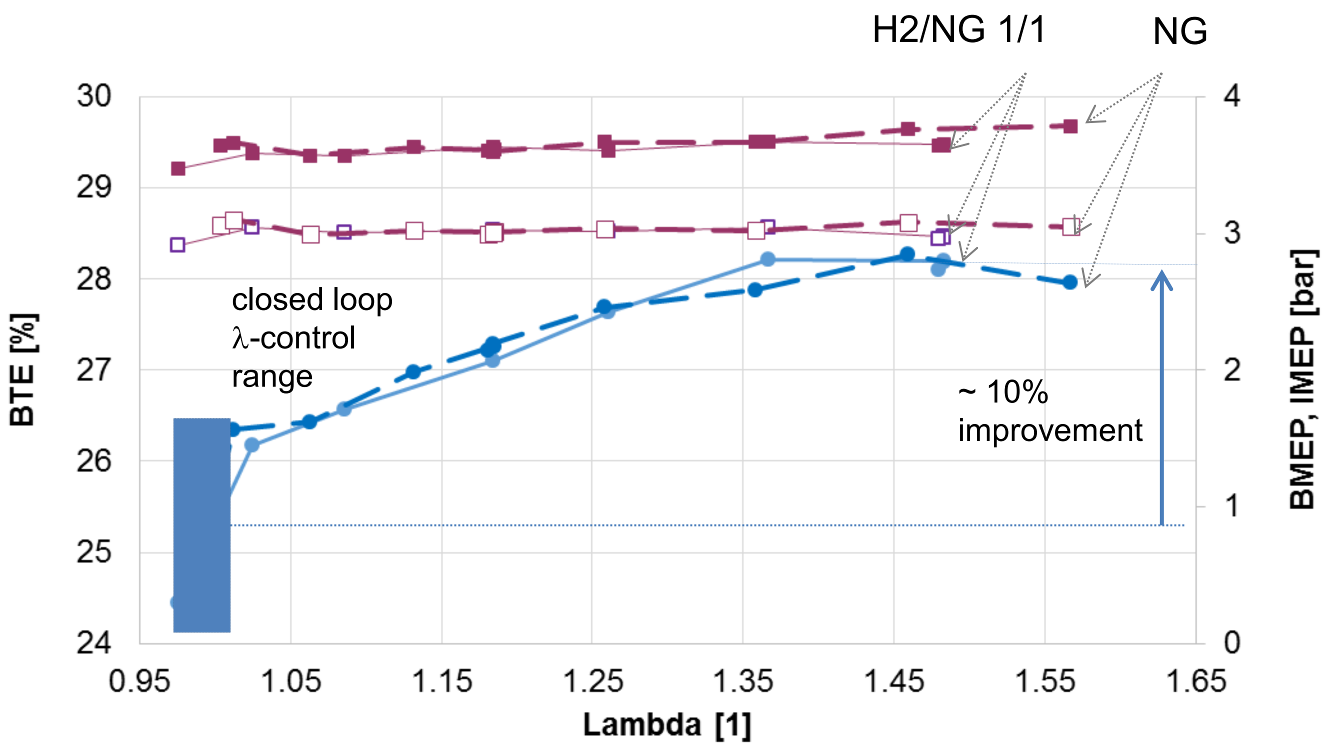






- H_2 reduces duration of initial phase of combustion
- H_2 slightly increases peak cycle temperature & pressure

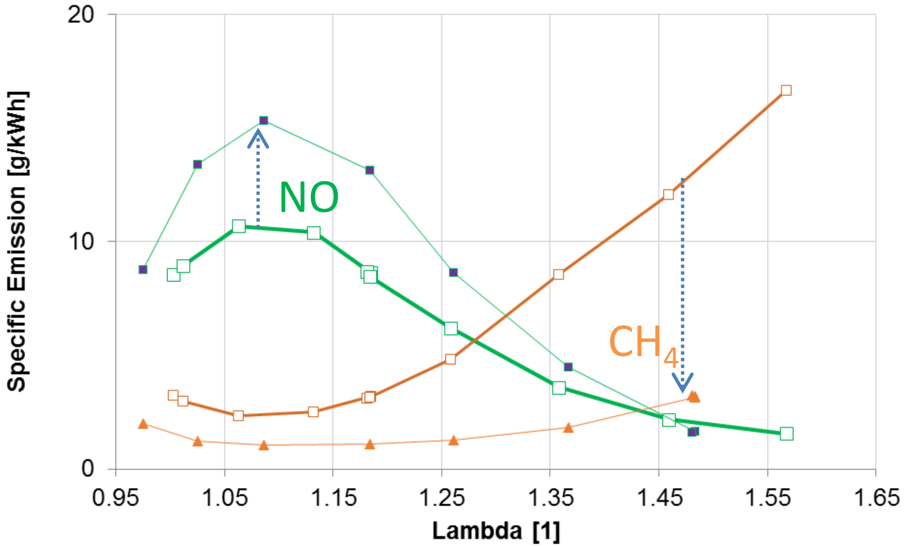
Results – Power and Efficiency

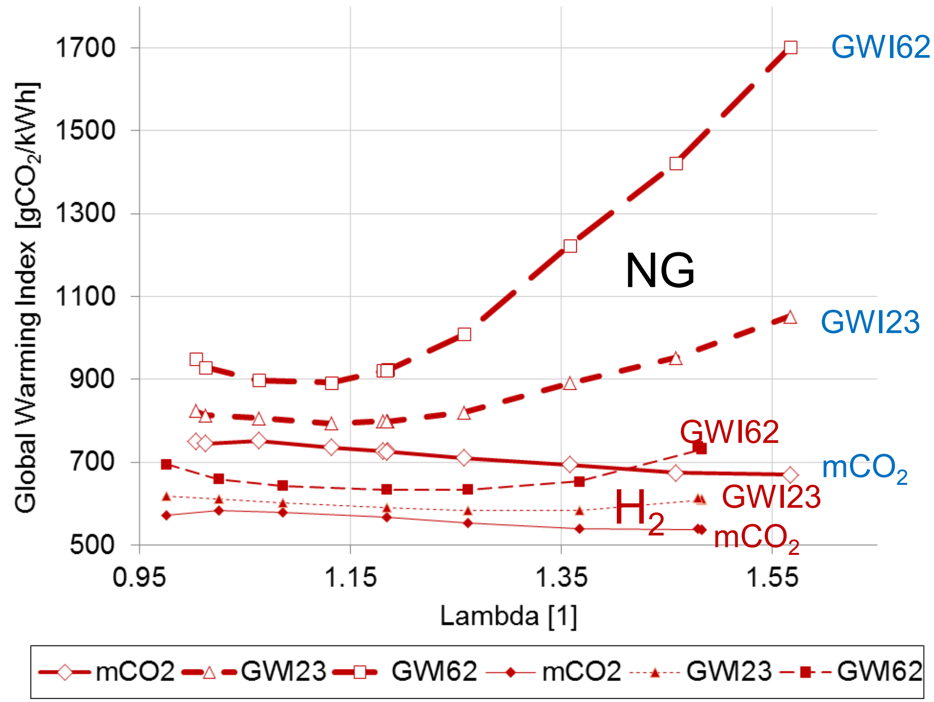


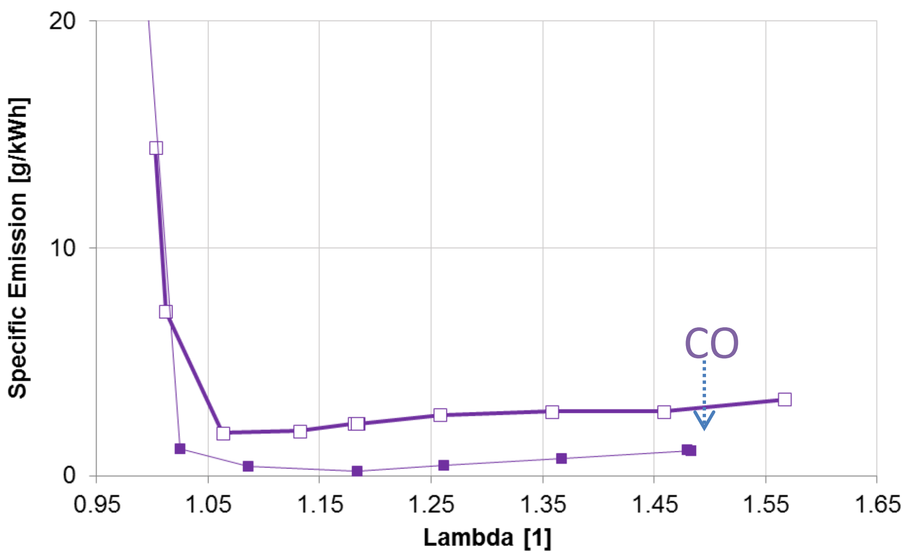
Lean concept improves efficiency significantly – benefits of low temperature combustion, air dilution, more favourable ratio of c_p/c_v

H_2 does not influence engine efficiency for lean combustion

Results – Emissions – Global Impact







Addition of H_2

increases emission of NO

reduces emission of products of incomplete oxidization

reduces emission of greenhouse gases significantly

Conclusions

- Addition of H_2 increases burning velocity especially initial phase
- Engine efficiency is not influenced by addition of H_2
- Emission of CO and THC are improved while NOx emission is rather higher by addition of H_2 – exhaust gas A/T necessary anyway
- Addition of H_2 reduces emission of greenhouse gases significantly

Thank you for your attention!

Acknowledgment

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