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TECHNIK
LEIDENSCHAFT

Hydrogen IC Engines in On- and Off Road Applications

Opportunities and Challenges

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24.10.2022

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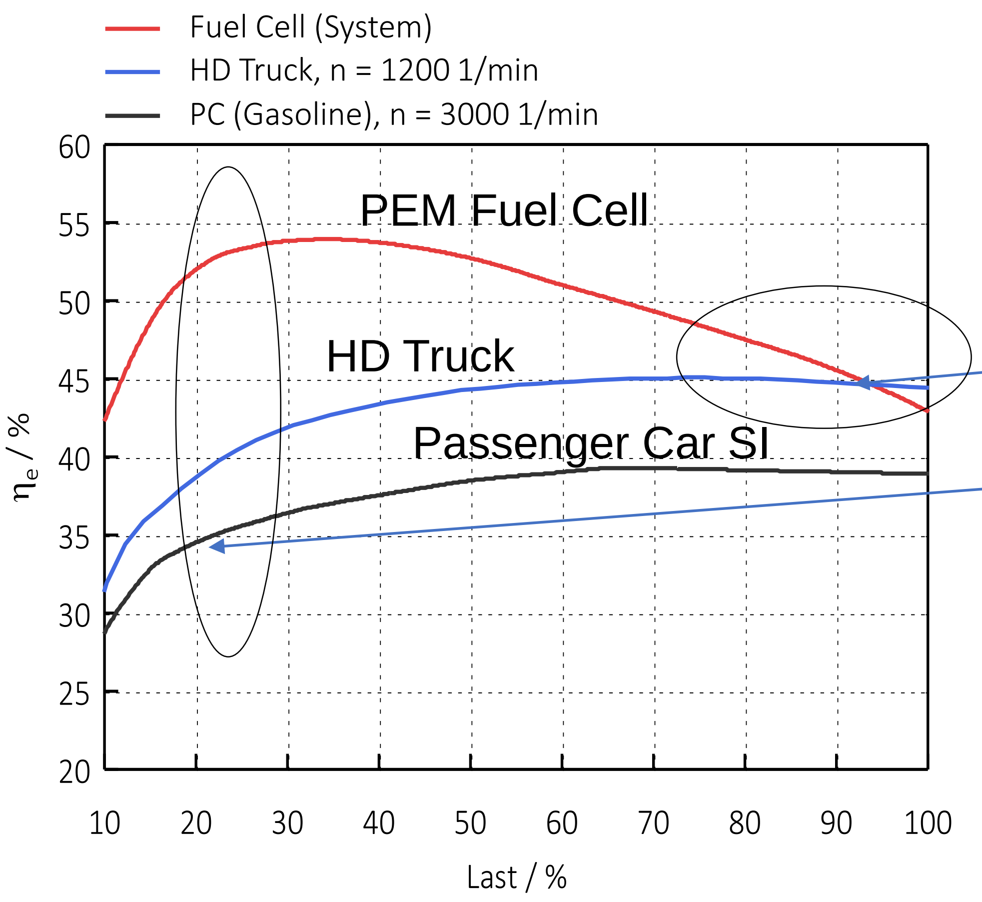
Hydrogen ICE - Opportunities and Challenges

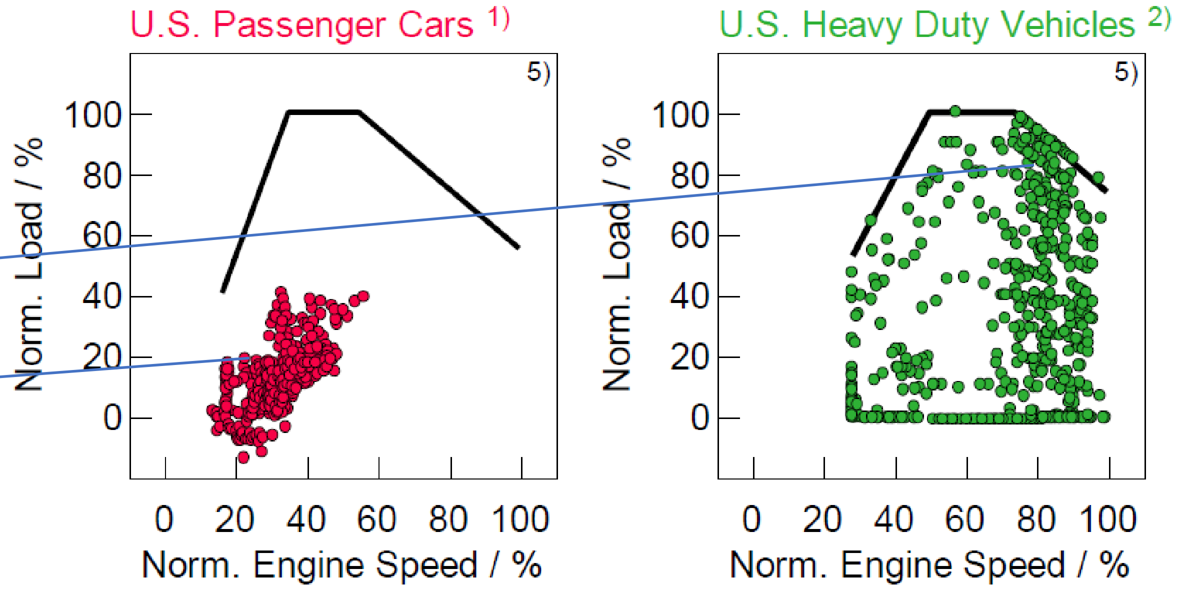
- Hydrogen ICE specific boundary conditions and opportunities
- Combustion concepts
- State of the art
- Challenges remaining
- Key technologies and further development activities

Hydrogen ICE - Opportunities

- CO_2-free operation
  - Based on regenerative production of hydrogen
  - Vanishing quantities from lubricants/SCR ? (< 1 g/kWh)
  - Assessment in legislation ?
- Minimum pollutant emission (Zero Impact)
- Low requirements regarding H2 quality, no battery required
- Mature, affordable and robust (cooling !) technology
- Use of existing production facilities and vehicle architecture

Efficiency characteristic Fuel Cell / ICE





Normalized load: 100 % corresponds to the maximum BMEP.
Normalized engine speed: 100 % corresponds to the rated speed.

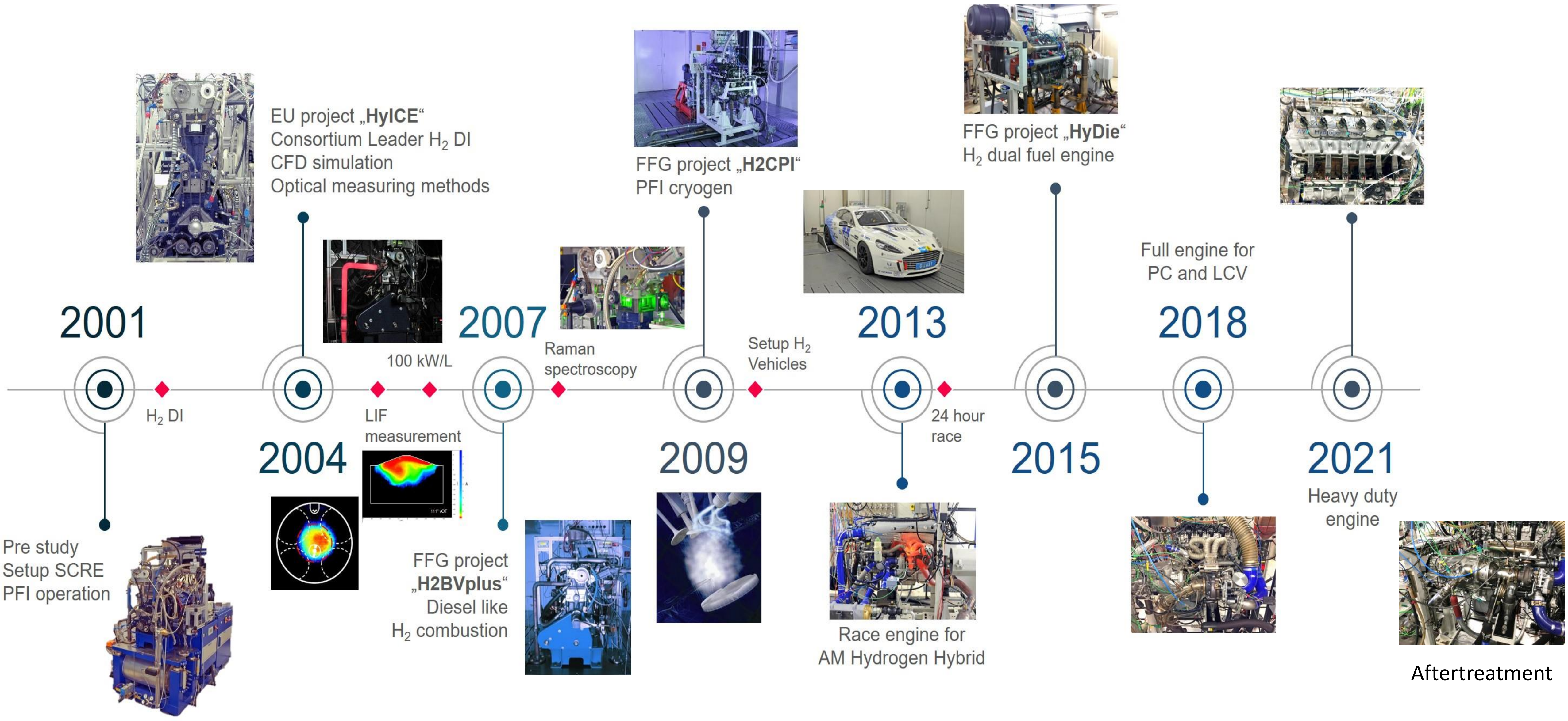
[1] U.S. EPA: FTP75
[2] U.S. EPA: HDDTC
[3] U.S. EPA: 5-mode duty cycle D2

→ FC Cooling requirements !

Comparison of relevant fuel properties

Property	Unit	H_2	CH_4	Gasoline
Density (at 15 °C)	kg/m^3	0.085	0.680	750
Lower heating value	MJ/kg	120	50	42.1
Stoichiometric air demand	kg_{air}/kg_{fuel}	34.3	17.2	14.1
Mixture calorific value (PFI)	MJ/m^3	3.2	3.4	3.8
Mixture calorific value (DI)	MJ/m^3	4.5	3.8	3.9
RON (MN)	–	(0)	130 (100)	98
Min. ignition energy	mJ	0.02	0.29	0.24
Ignition limits (λ-area)	–	0.13 – 10	0.6 – 2.1	0.4 – 1.4
Self ignition temperature	°C	585	595	230 – 450

Hydrogen ICE Development Activities at iTnA



Wide variety of mixture formation and ignition concepts

Mixture formation

- external
  - continuous
  - sequential
- combined
- internal
  - single
  - multiple

ambient

cryogen

homogeneous

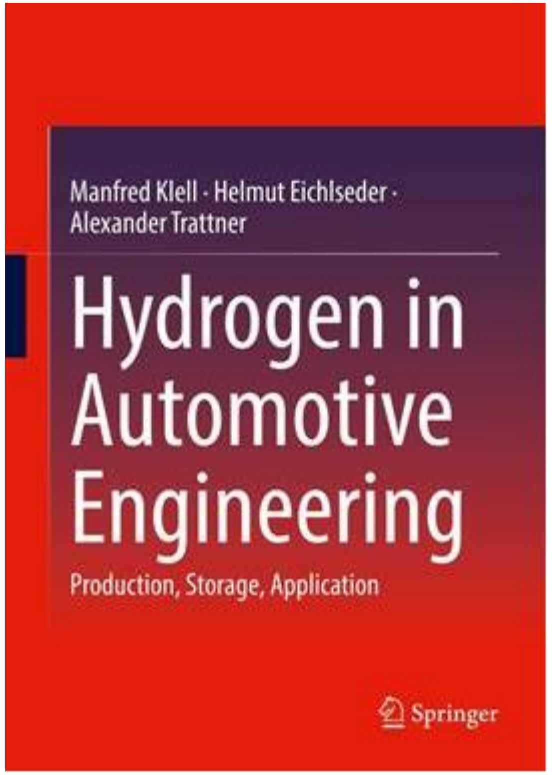
stratified

(non-)premixed

combustion control

Ignition

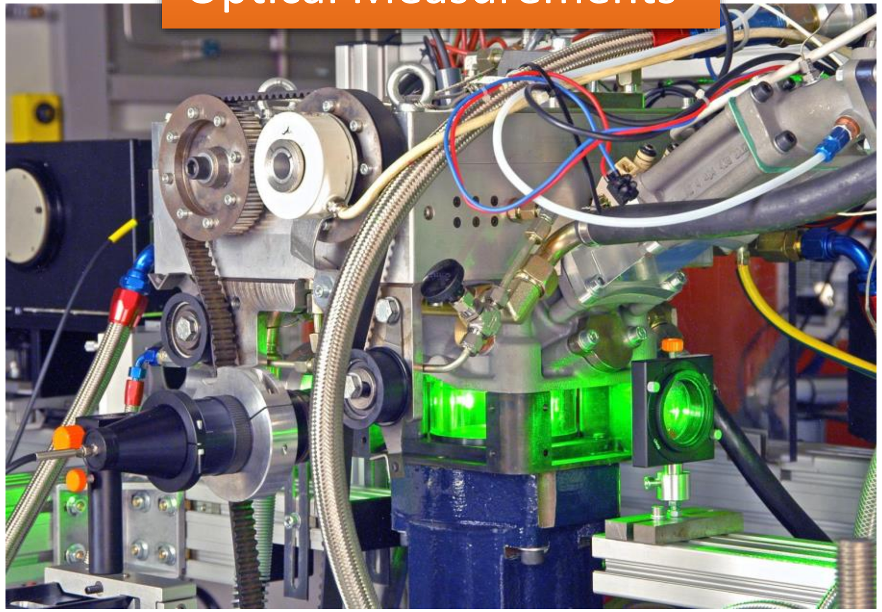
- Spark plug
- Auto ignition
- Pilot ignition
- Glow plug

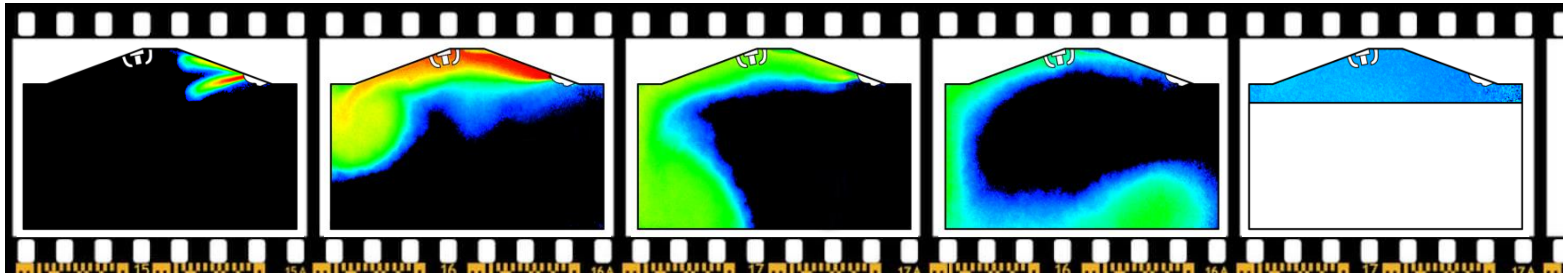


https://link.springer.com/book/10.1007/978-3-658-35061-1

History at the institute.

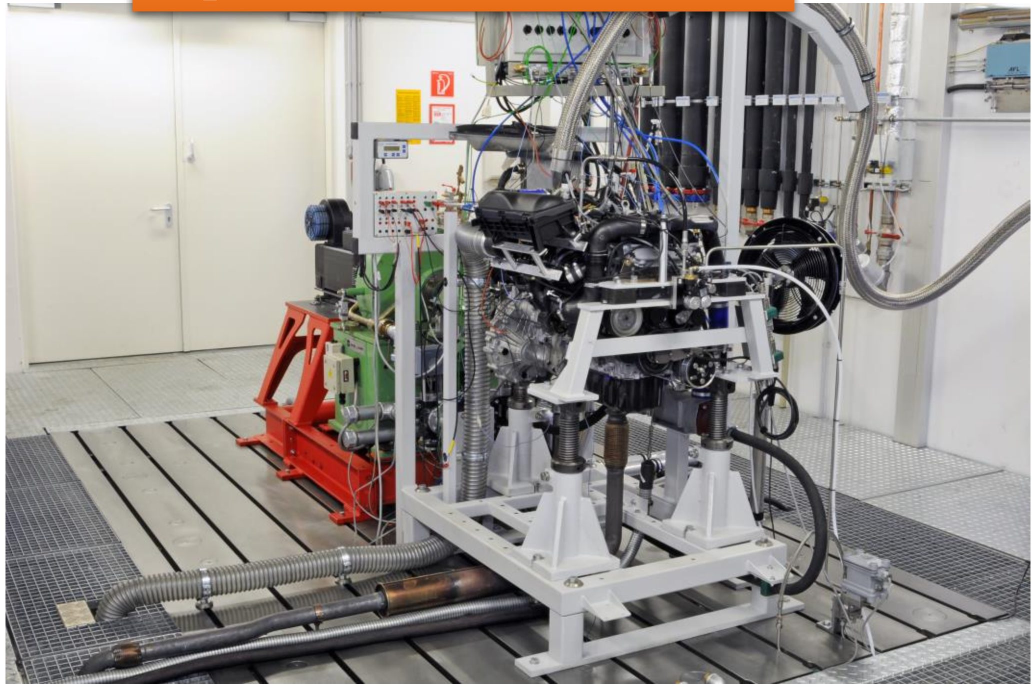
H_2 DI
Optical Measurements

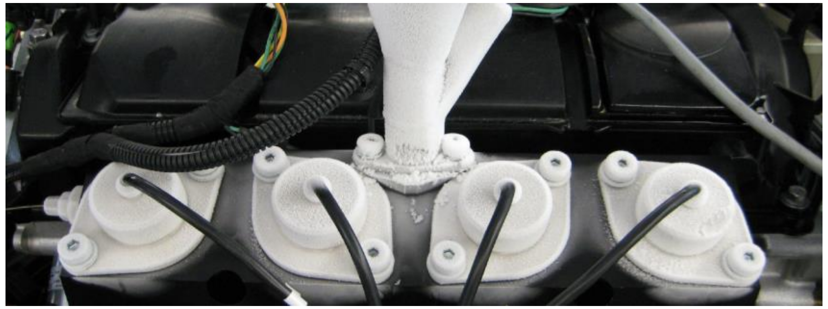




LIF measurements (mixture formation)

H_2 PFI cryo (spark ignition)

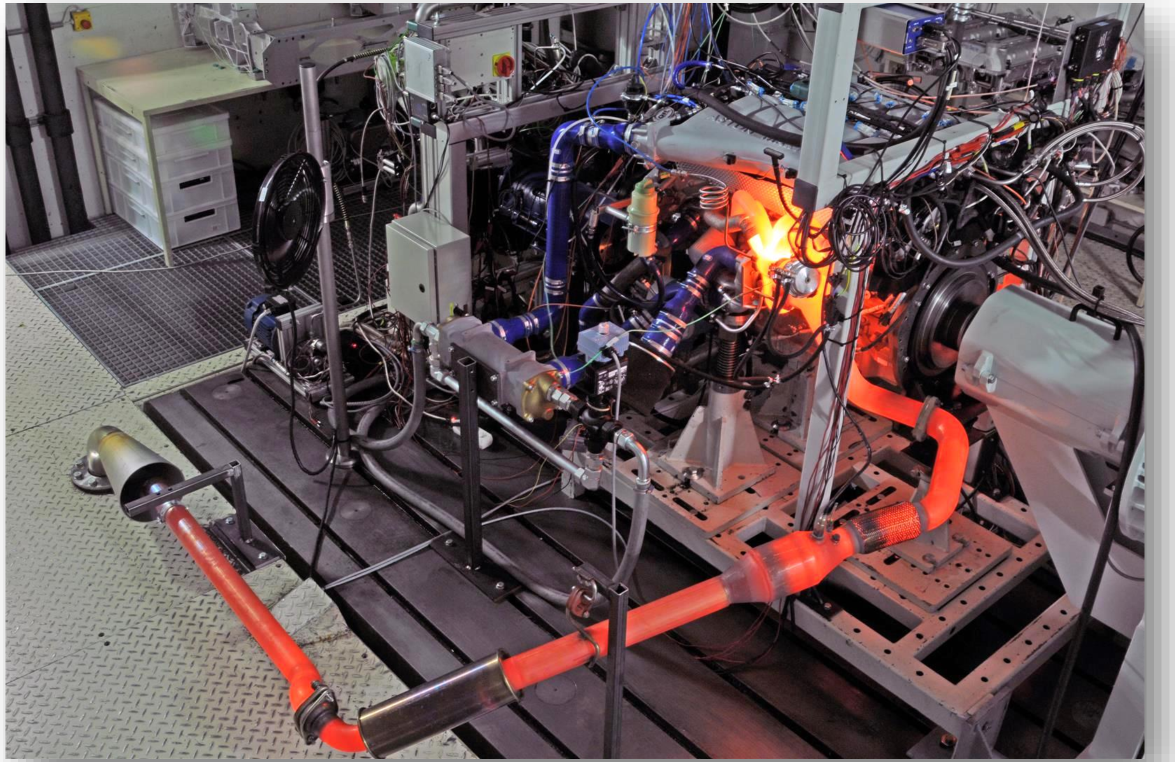




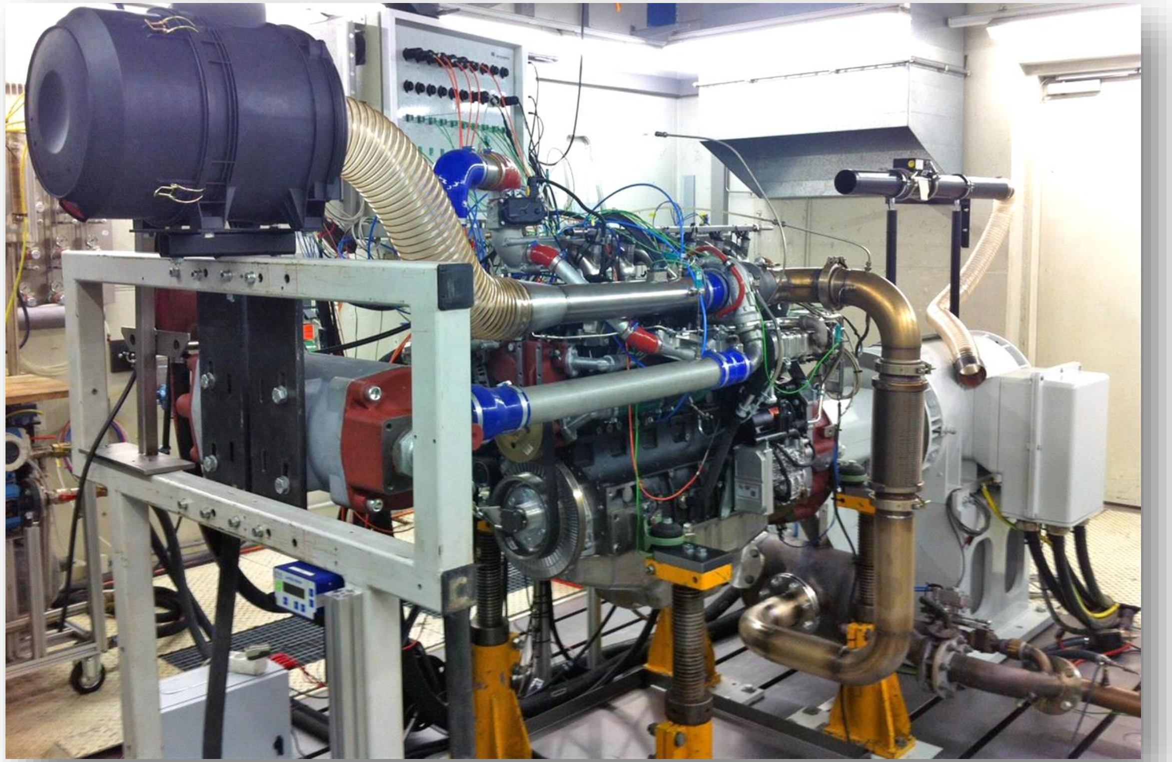
Source: Grabner (ITNA)

History at the institute.

H_2 PFI
Race engine turbocharged



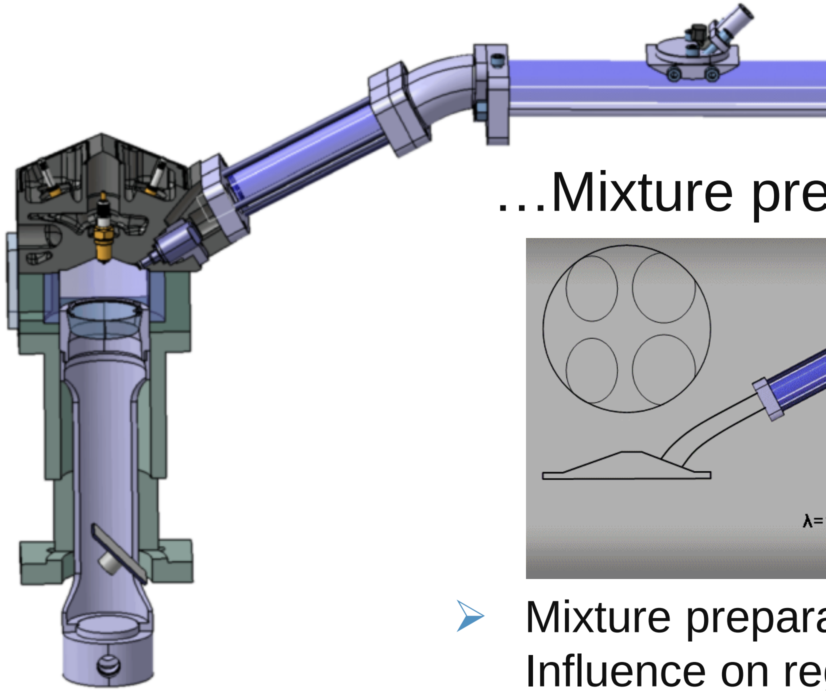
H_2 PFI
Dual fuel engine



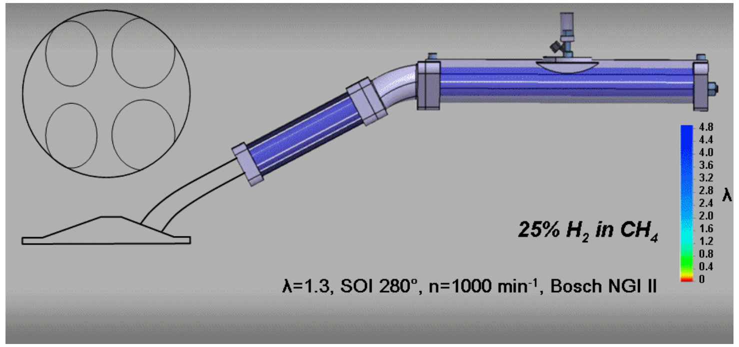
Source: Grabner, Schaffer (ITNA)

Basic research for Hydrogen based combustion systems

- Fuel properties H_2 /(mixtures) under engine conditions
- Combustion systems for Hydrogen, CNG/Hydrogen Mixtures, … with internal and external mixture preparation systems
- Dual fuel systems with Diesel/Hydrogen and Gasoline/Hydrogen

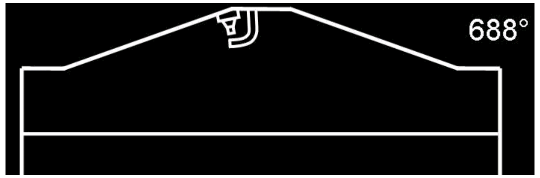


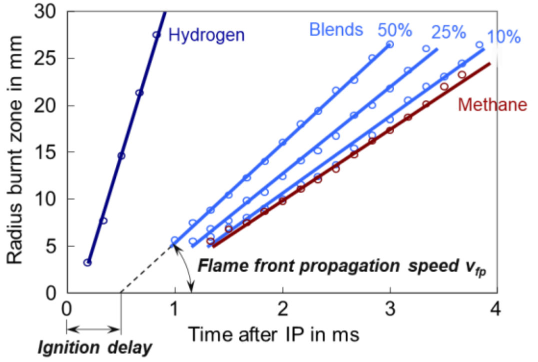
…Mixture preparation



- Mixture preparation, Stratification, Influence on regular and irregular combustion

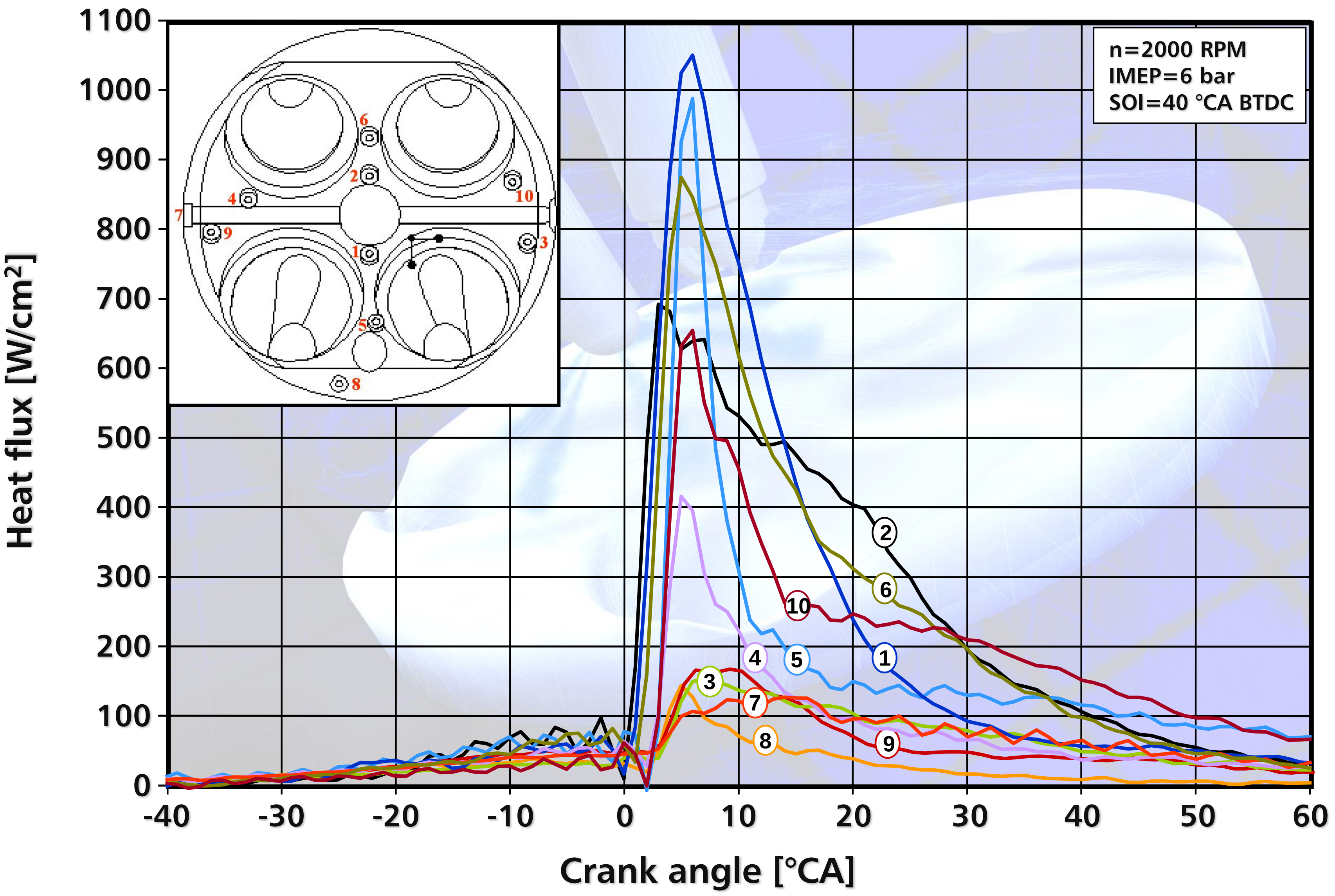
…Combustion





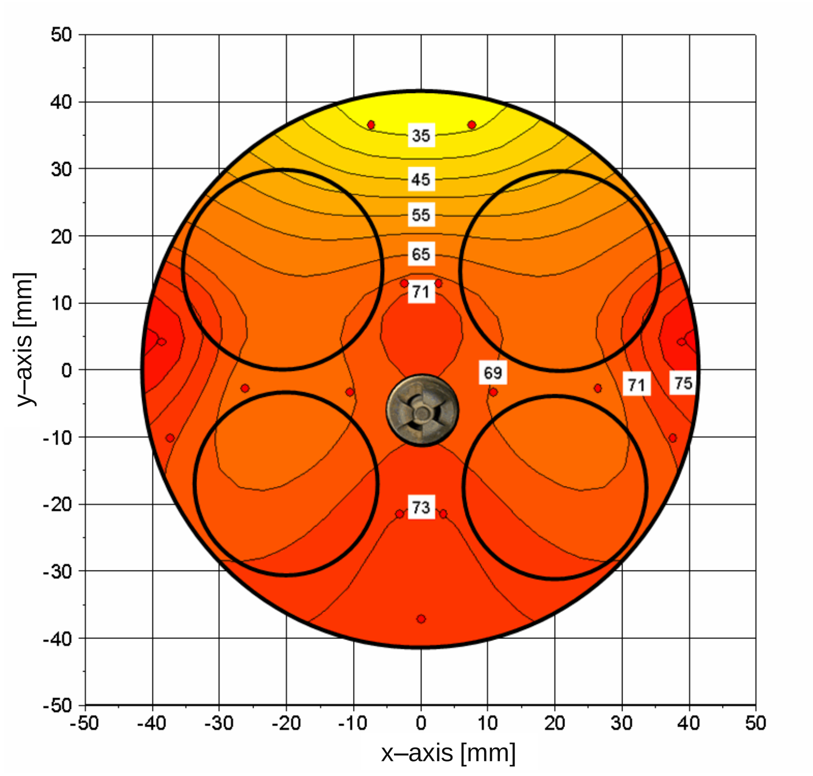
- Performance of the combustion, key indicators, efficiency and emissions

Local wall heat flux



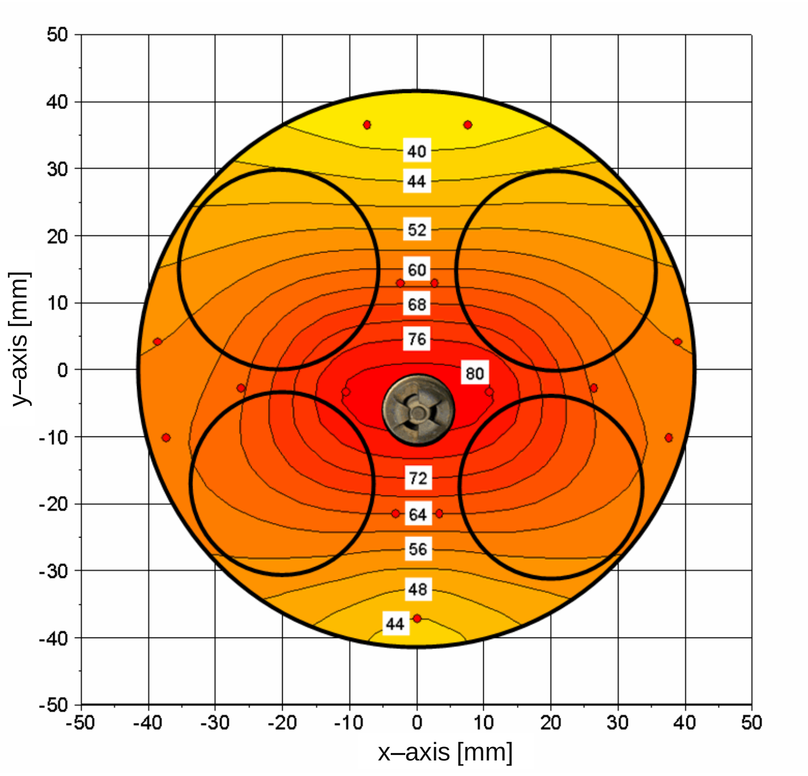
Reduction of wall heat losses

Starting basis



high heat flux in the peripheral zone

Optimized nozzle



central location of combustion

Local distribution of the heat flux [W/cm²]

Late injection

n = 2000 min^{-1}

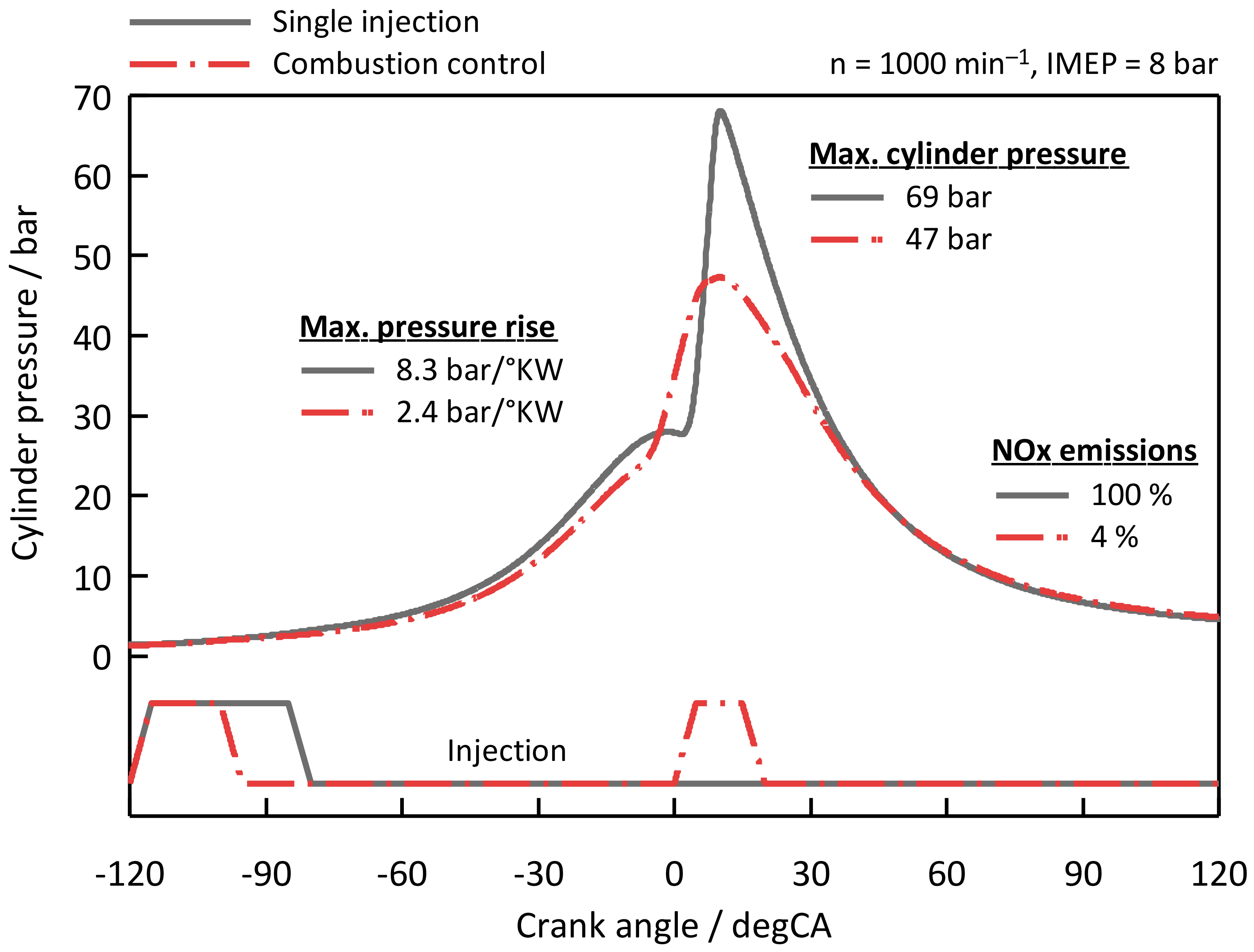
ε = 10.5

λ ≈ 1.4

Σ WH = –14 %

Source: Eichlseder, FISITA 2008

Combustion Control (NOx- and noise reduction)



Source: Eichlseder, FISITA 2008

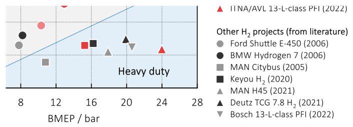
Hydrogen Vehicle Projects at our institute

base engine
CNG/gasoline

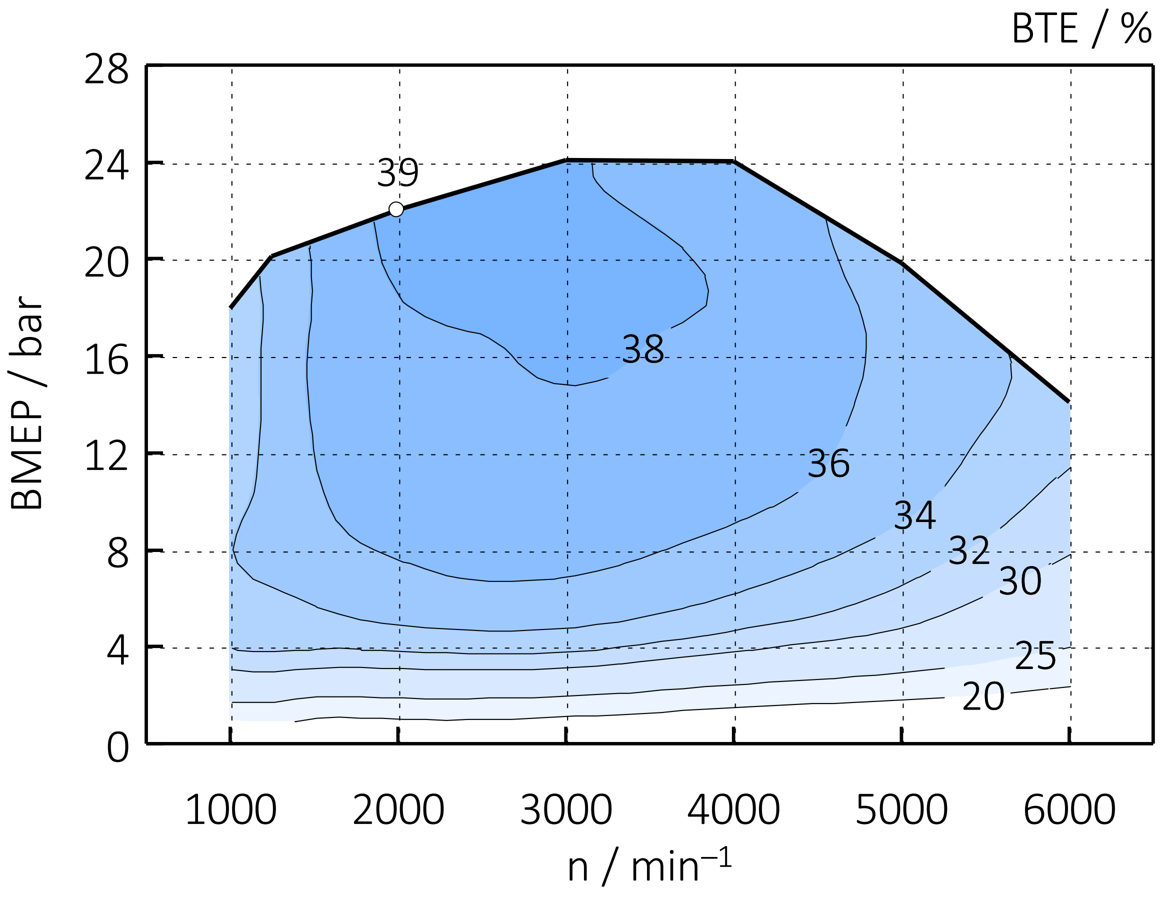
base engine
gasoline

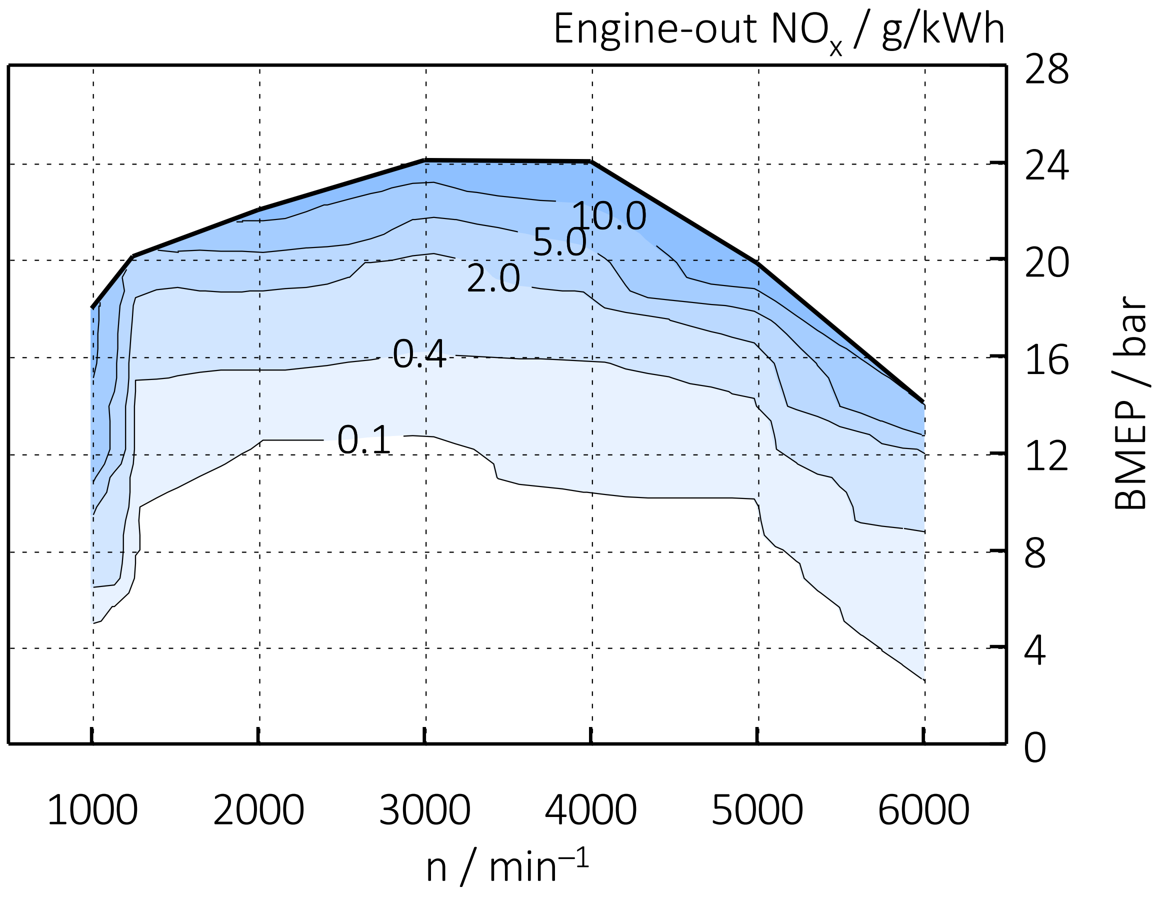
base engine
gasoline

Power density (published data)



Concept development PC/Light duty engine
Status 2020

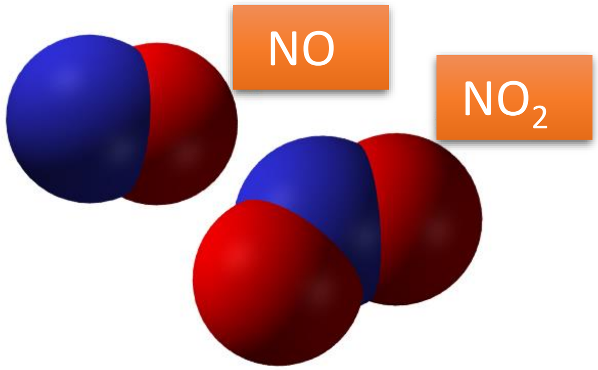




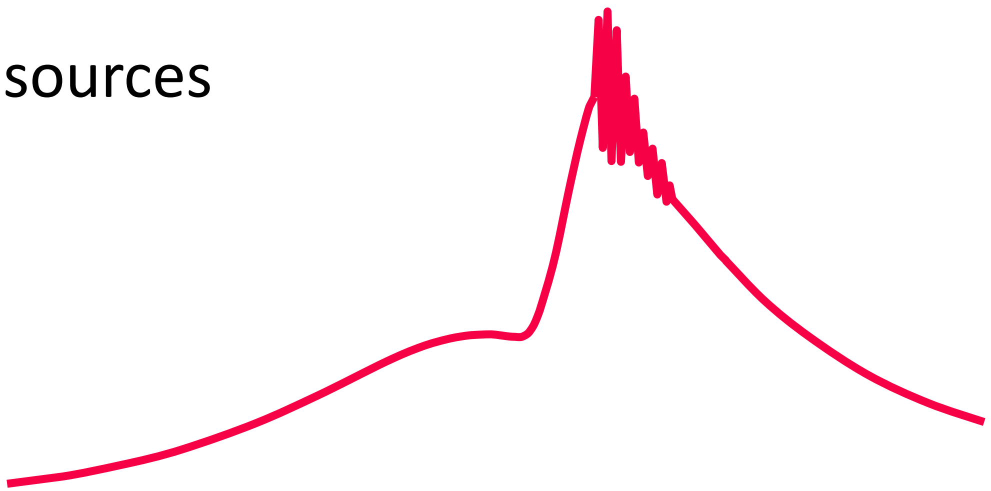
Source: ITnA TU Graz/Bosch

Challenges

- NO_x-Emission
  - Fast combustion
  - High temperatures



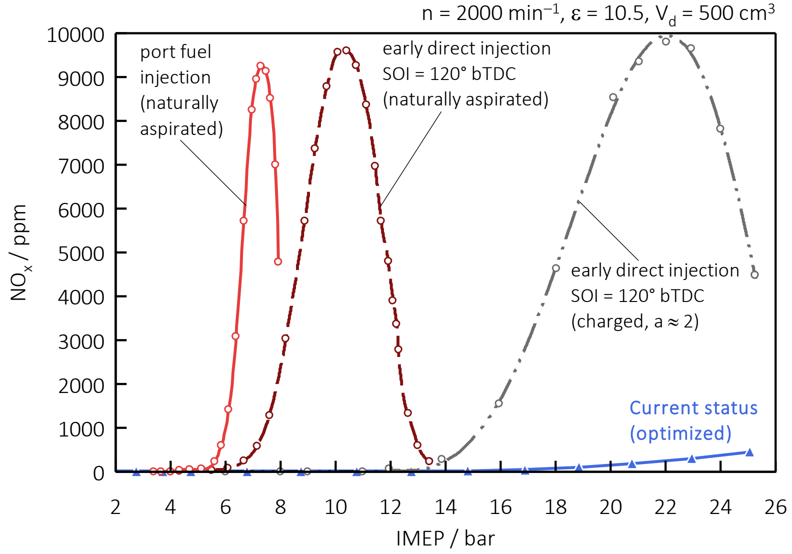
- Combustion anomalies
  → Influence of residual gas and other ignition sources
  - Backfiring
  - Knocking
  - Surface ignition
  - ….
- Mechanical engine system

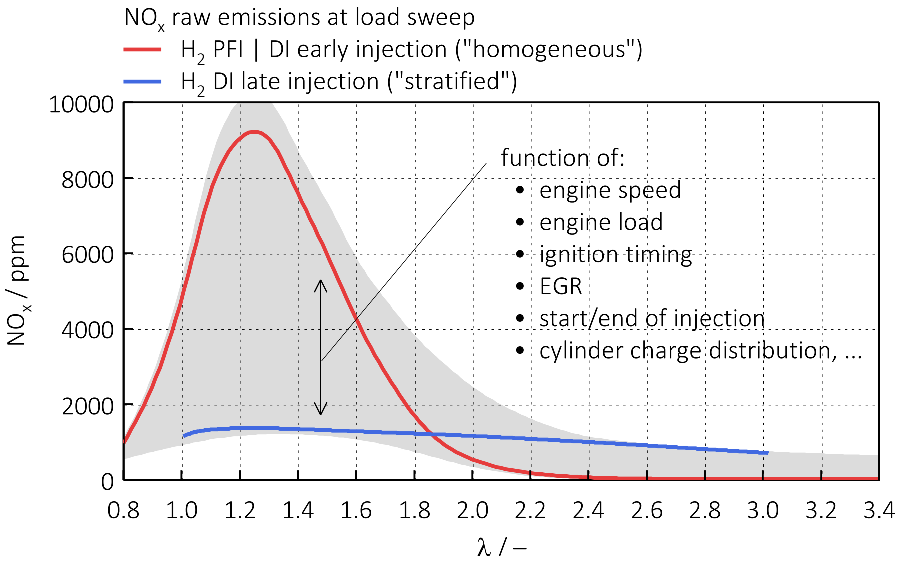


Bildquellen: www.arieggiare.it
Grabner (IVT)

Emission behavior - NO_x

- Influencing parameters
  - Global and local λ
  - Mixture preparation (homogeneity)
  - 50 % energy conversion (MFB50)
  - Start of injection (SOI)
  - …
- Internal NO_x reduction
  - Lean operation (λ >> 1)
  - DI → enables stratified charge
  - Late combustion timing
  - (EGR)





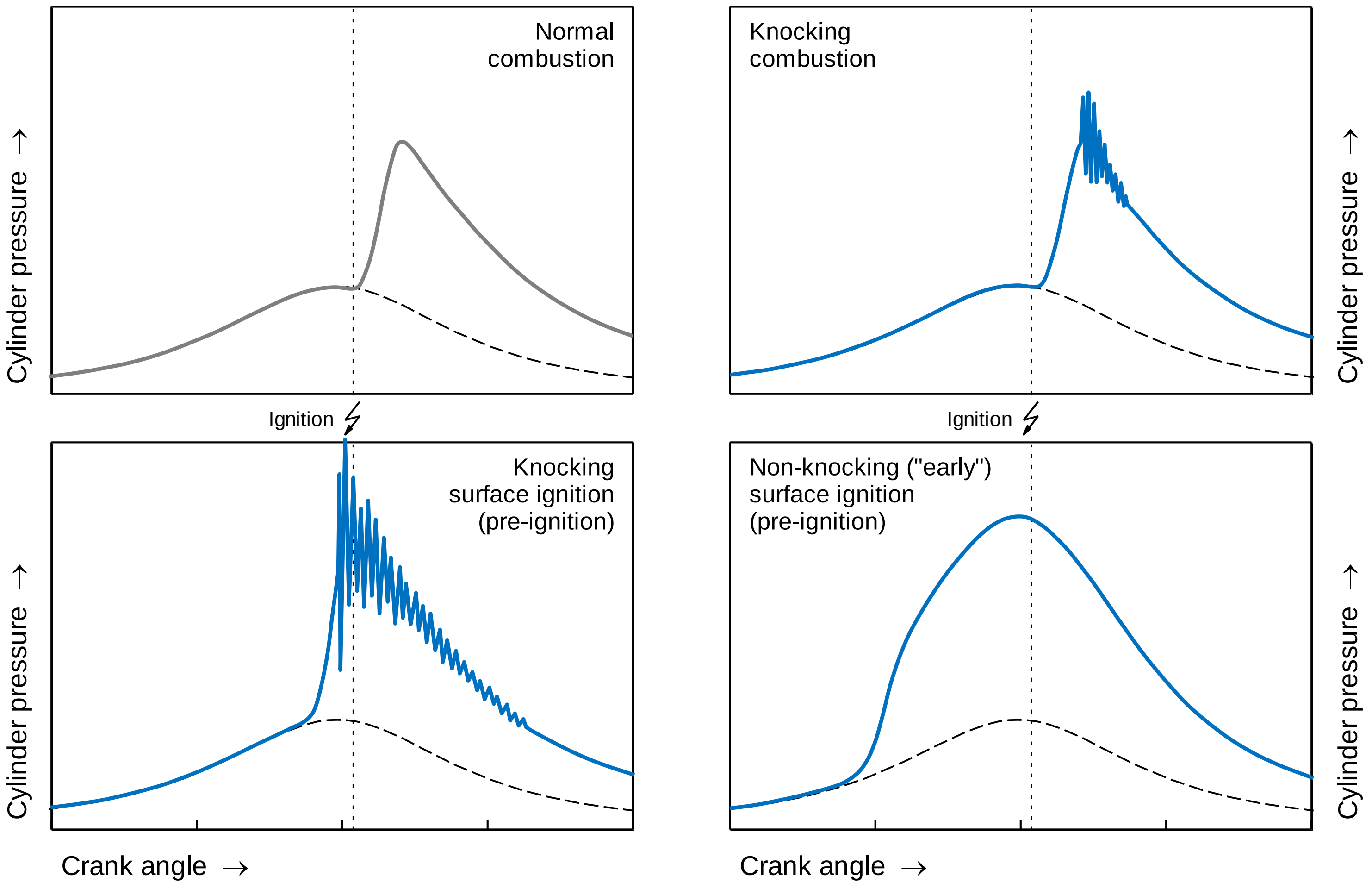
Source:
Grabner P.: "Potentiale eines Wasserstoffmotors mit innerer Gemischbildung hinsichtlich Wirkungsgrad, Emissionen und Leistung", Dissertation, Graz University of Technology, Graz, 2009

H_2 combustion in ICE

Abnormal Combustion [1)]

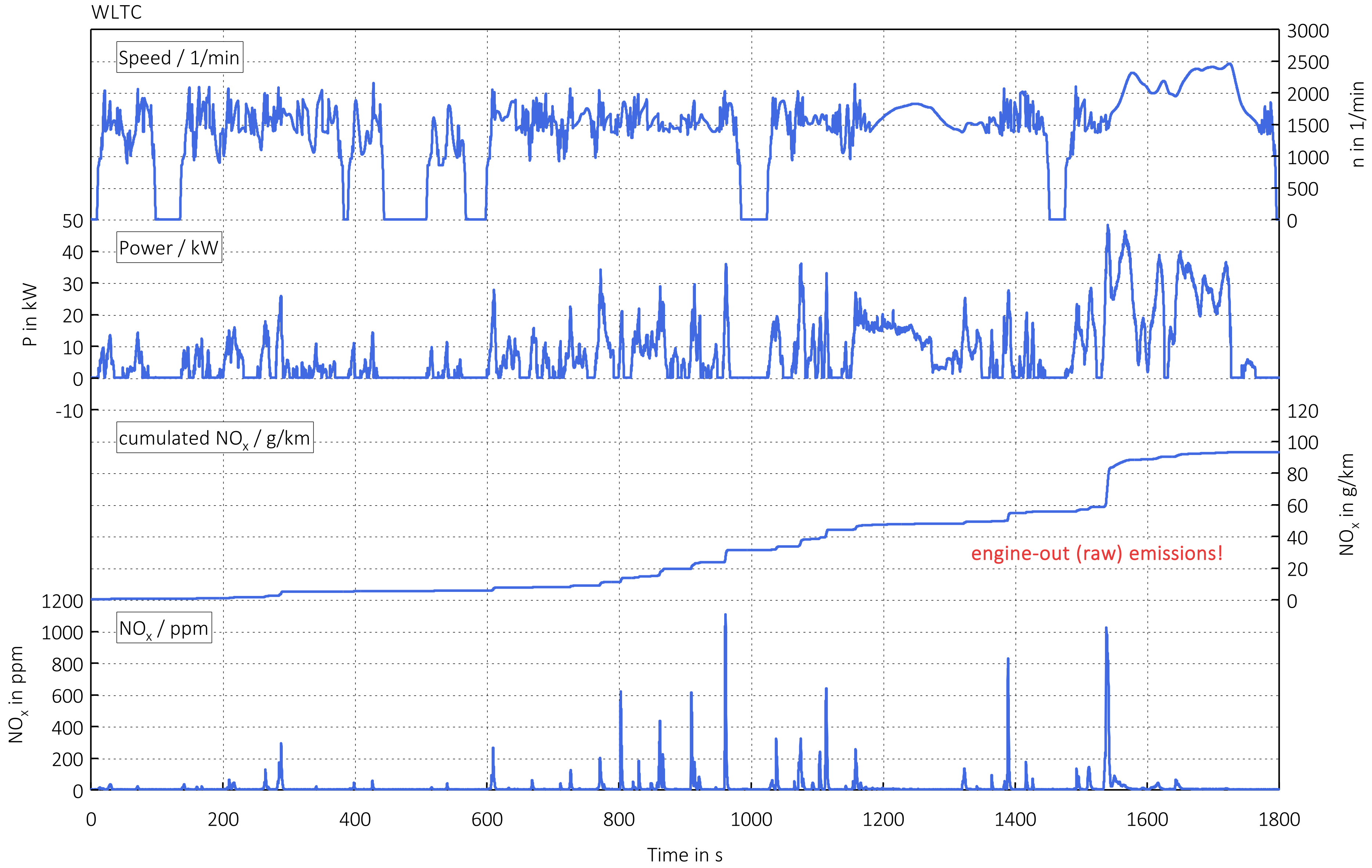
- Backfiring
- Knocking
- Surface ignition
  - knocking
  - non-knocking

[1)] in accordance with the definition of the CRC (Coordinating Research Council)

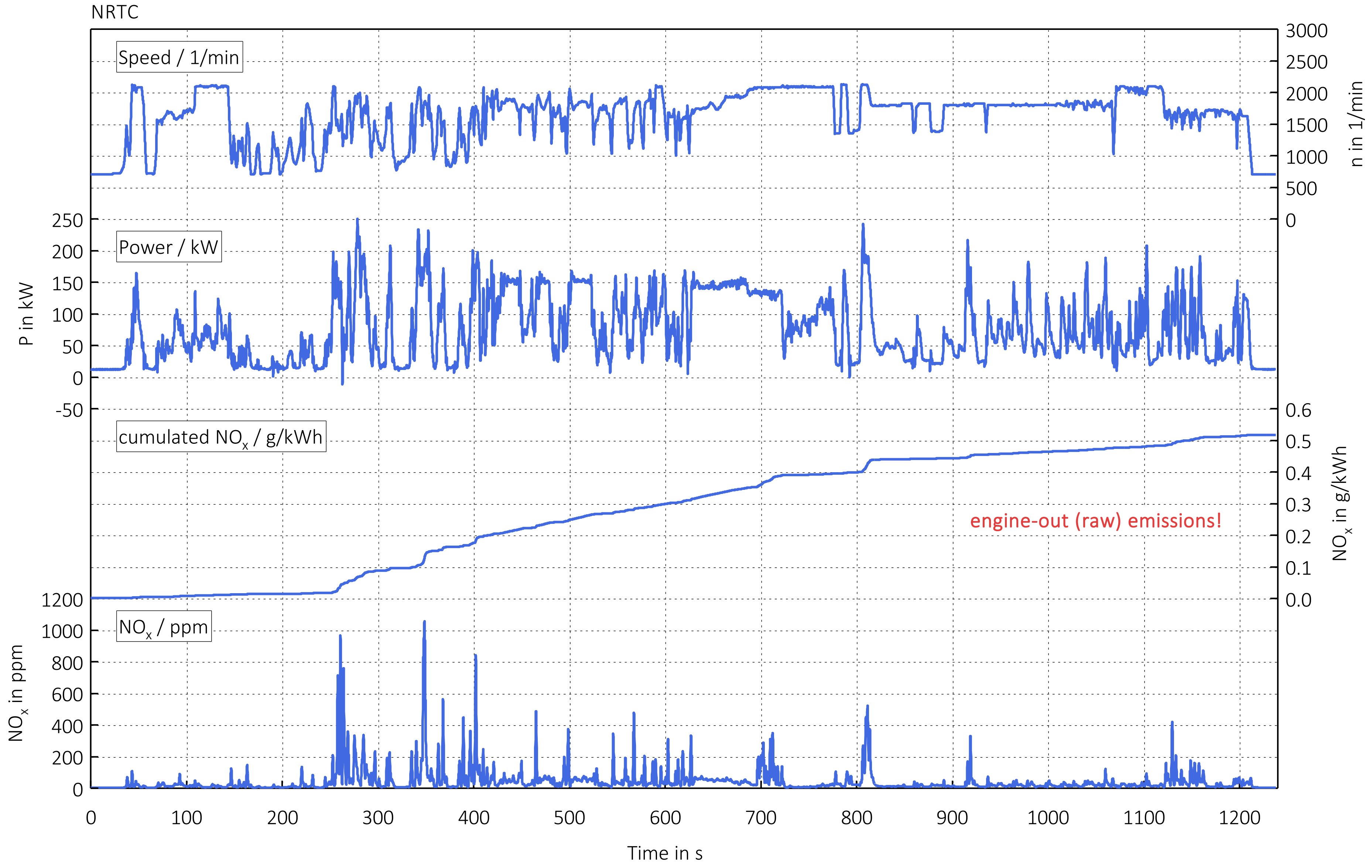


Source: Grabner P.: “Potentiale eines Wasserstoffmotors mit innerer Gemischbildung hinsichtlich Wirkungsgrad, Emissionen und Leistung”, Dissertation, Graz University of Technology, Graz, 2009

Transient behavior – Passenger car - WLTC



Transient behavior – Construction machine - NRTC



Key technologies and challenges

for high power H_2 ICE (short summary)

- Very lean operation for low emissions (mainly NO_x) required
  - powerful charging system (turbocharging, combustion control, e-booster)
- Direct injection system
  - injector lifetime, wear, tightness are major challenges
- Ignition system
  - possible source of abnormal combustion (→ pre-ignition)
  - ignition coil (residual discharges (phantom spark) must be suppressed)
  - spark plug (minimize wear, spark gap, sharp edges and high temperatures)
- Exhaust aftertreatment (mainly for NO_x emissions)
  - required for (near) zero = zero impact emissions
  - avoidance of secondary emissions like N_2O, NH_3 must be ensured

Key technologies and challenges

for high power H_2 ICE (short summary)

- Materials
  - H_2 embrittlement of steels (use of austenitic steel)
  - suitable valve seat and injector material
- Rail pressure control for transient operation
  - especially pressure decrease during rapid load reduction (fast emptying of the rail)
- Crank case ventilation
  - to prevent combustion/explosion of ignitable mixture in the crankcase
- Engine start/stop procedure
  - H_2 concentration in crankcase, (intake) and exhaust system should be close to zero
  - H_2 rail should be emptied