HYDROGEN – NATURAL GAS (HCNG) MIXTURES AS FUELS IN INTERNAL COMBUSTION ENGINES

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WICaC 2012

Outline

- Context of the presentation
- Natural gas
- HCNG mixtures
  1. Chassis dynamometer tests
     →Experimental setup
     →Combustion
     →Fuel consumption
  2. On road tests
     →Experimental setup
- Real–life cases of HCNG uses
- Conclusions

Context

Effects of adopting natural gas-hydrogen blends (HCNG) as fuels in spark ignition internal combustion engines:

- combustion characteristics
- fuel consumption
- exhaust emissions

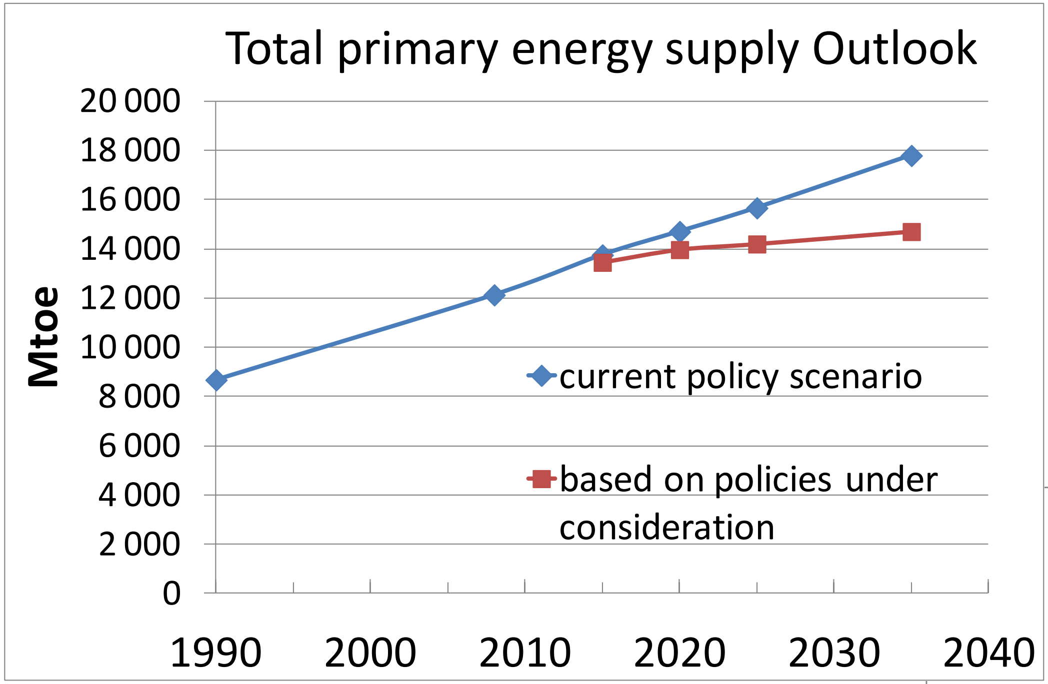
Partners

- Regione Lombardia
- Fiat Research Center
- Sapio Group
- Istituto Motori – CNR – Napoli, Italy
- Dipartimento di Ingegneria Industriale e dell’Informazione

  Seconda Università degli studi di Napoli – Aversa Italy

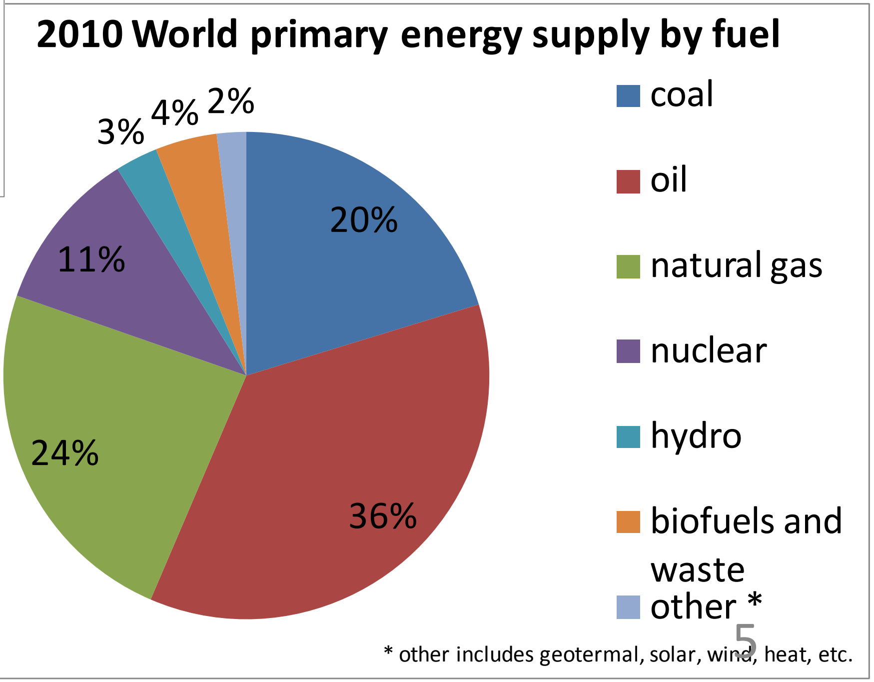
The Energy problem

International Energy Agency
www.iea.org



Increasing energy demand…

…dependence from fossil fuels…



Transport

- 95% of the primary energy comes from oil
- Pollutant emissions (great urban areas)
- Natural gas – Hydrogen blends is an attractive fuel option
- HCNG as transition fuels towards the use of pure hydrogen

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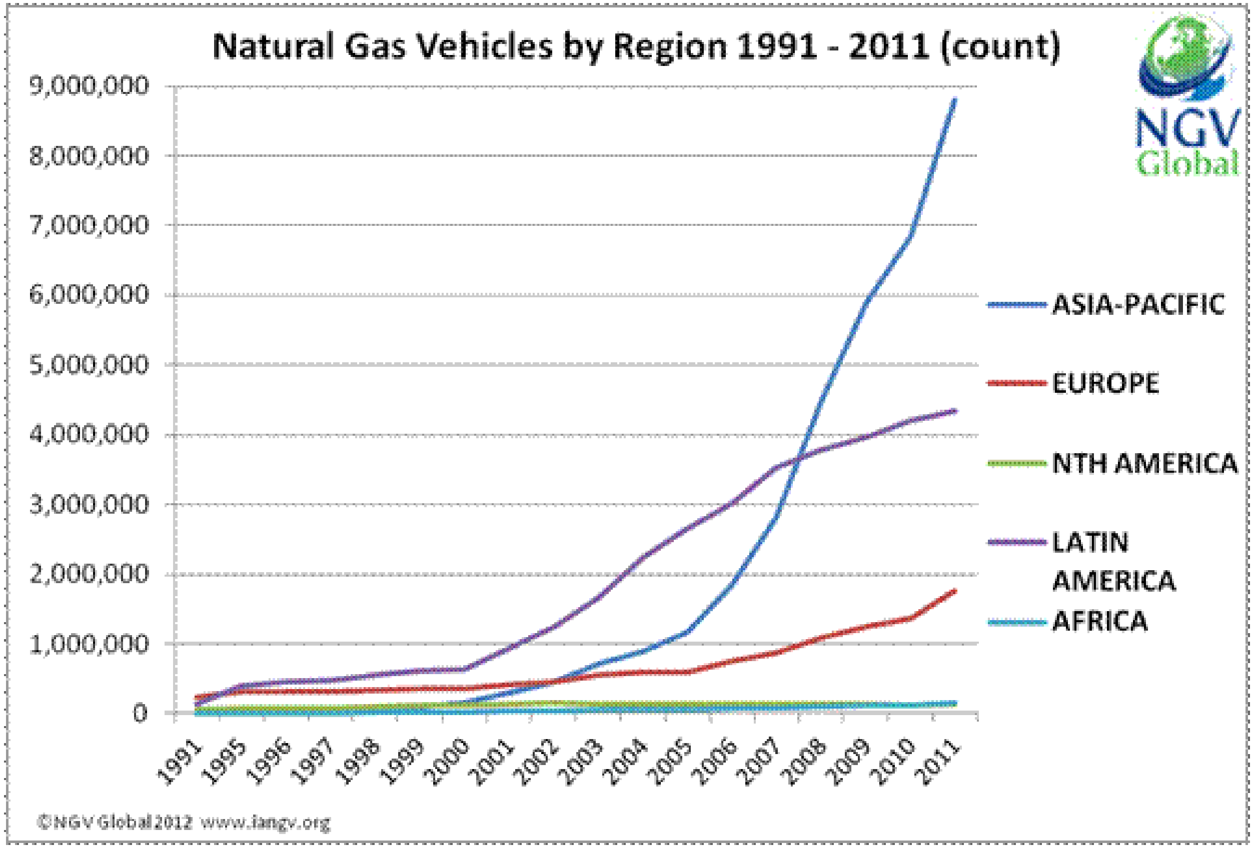
Natural gas

Data as at Dec 31 2011
www.iangv.org



- 15.2 million natural gas vehicles operating around the world
- Almost 20,000 natural gas fueling stations

Brazil 1.7 million of NG vehicles

Natural gas

- Natural gas is less affected by price fluctuations with more evenly widespread resources than crude oil
- Natural gas is the "*cleanest*" fossil fuel, with exhaust emissions lower than those of gasoline-powered vehicles
- Some governments provide incentives to stimulate the use of natural gas

Natural gas in internal combustion engines

BENEFITS

- Easy mixture formation
- Engine cold start
- More complete burning
- High research octane number
- High thermal efficiency
- Low exhaust emissions

Natural gas in internal combustion engines

DRAWBACKS

- Natural gas compositions changes
- Methane is a greenhouse gas
- Methane catalytic oxidation is difficult
- Reduced engine power
- Combustion rate is lower than gasoline
- NG spark ignition engines have a lower efficiency than Diesel engines

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Hydrogen – Natural Gas blends (HCNG)

- Hydrogen can be mixed together with natural gas forming a blend called HCNG
- HCNG can be distributed by present NG refueling infrastructures
- HCNG can be used in current natural gas vehicles
- Immediate application is possible

HCNG in internal combustion engines

BENEFITS

- Reduced combustion duration
- Enhanced combustion stability at part load
- Extended lean limits
- Higher engine efficiency
- Lower CO_2 emissions

HCNG in internal combustion engines

DRAWBACKS

- Higher fuel cost
- Lower vehicle range
- NOx emissions increase (for a given equivalence ratio) $NO_x \approx \exp(T)$

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Description of the experimental activity

- The vehicle has been installed on a chassis dynamometer, fuelled alternatively by NG and HCNG blends and tested over different driving cycles
- The <u>same ignition timing</u> has been adopted for the tested fuels

Experimental setup

Experimental setup: combustion analysis

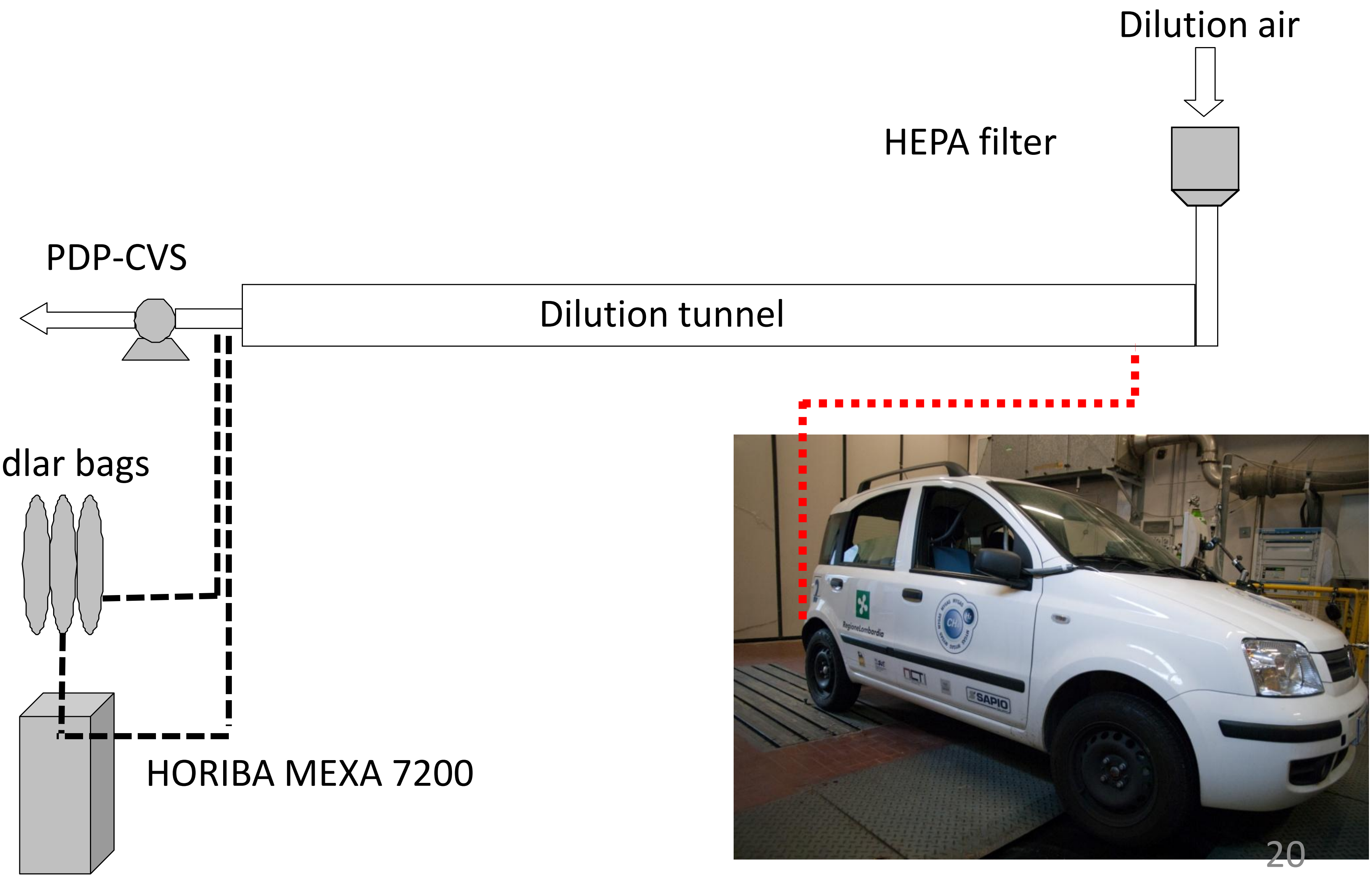
Amplifier

ethernet

Spark plug with piezoelectric sensor embedded

Chassis dynamometer

Experimental setup: fuel consumption and emission measurements



Automatic Driving System

Vehicle characteristics

MAKE MODEL	**Fiat Panda 1.2 NP**
FUEL	**Bifuel Gasoline - NG**
DISPLACEMENT	**1242 cm^3**
COMPRESSION RATIO	**9.8:1**
RATED POWER	**38 kW @ 5000 rpm**
REFERENCE MASS	**1025 kg**

Fuels properties

	NATURAL GAS	HCNG15	HCNG30
H_2[% vol.]	-	14.0	29.3
H_2 [% energy]	-	4.61	11.4
LHV [MJ/kg]	45.3	46.6	48.5
LHV vol. [MJ/Nm^3]	36.9	33.2 -10%	29.2 -21%
AFR $_{stoic.}$	15.6	15.9	16.4
LHV vol. stoic. mix. [MJ/Nm^3]	3.37	3.36	3.35

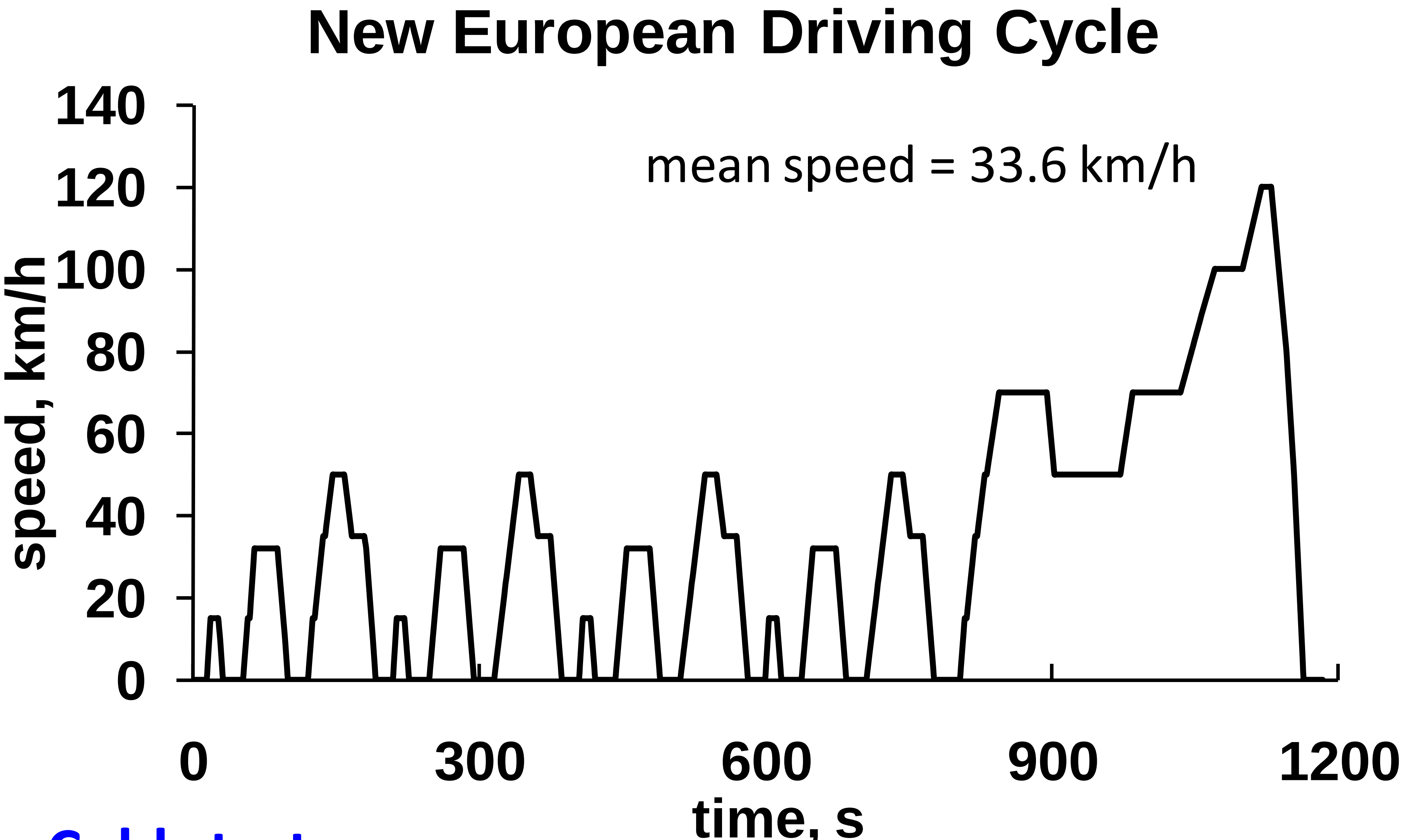
HCNG fuelling system

- Easy integration with existing natural gas refuelling stations
- Suitable for vehicle fleets
- Low mantainance costs

Driving cycles

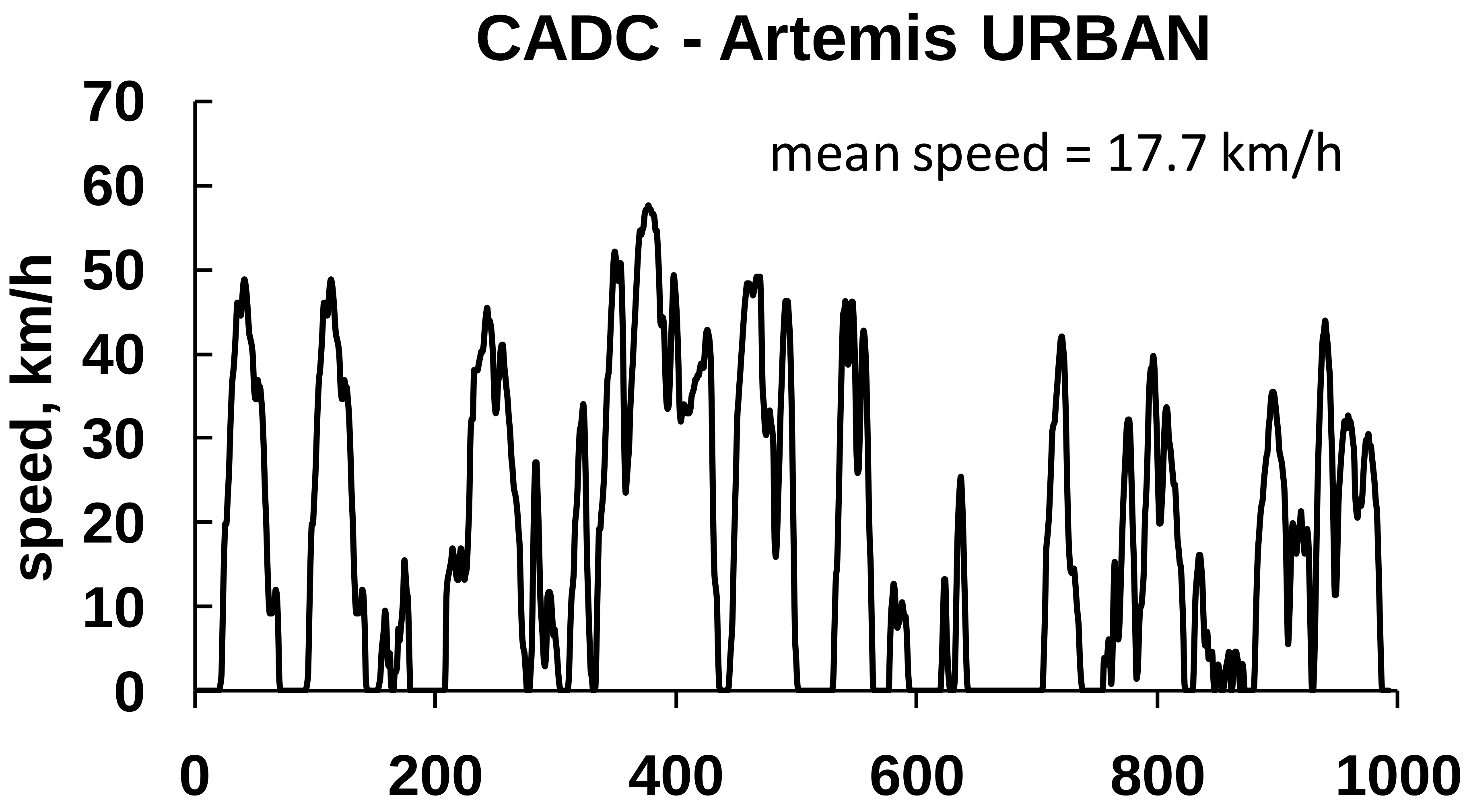
	Average speed	*Idle*	*Cruising*	*Accelerat.*
	km/h	*%*	*%*	*%*
NEDC	33.6	20.4	38.8	23.6
Artemis urban	17.7	20.7	9.6	36.0
Artemis road	57.5	1.5	21.6	39.7
Artemis motorway	96.9	0.7	26.0	40.6

Driving cycles



Cold start

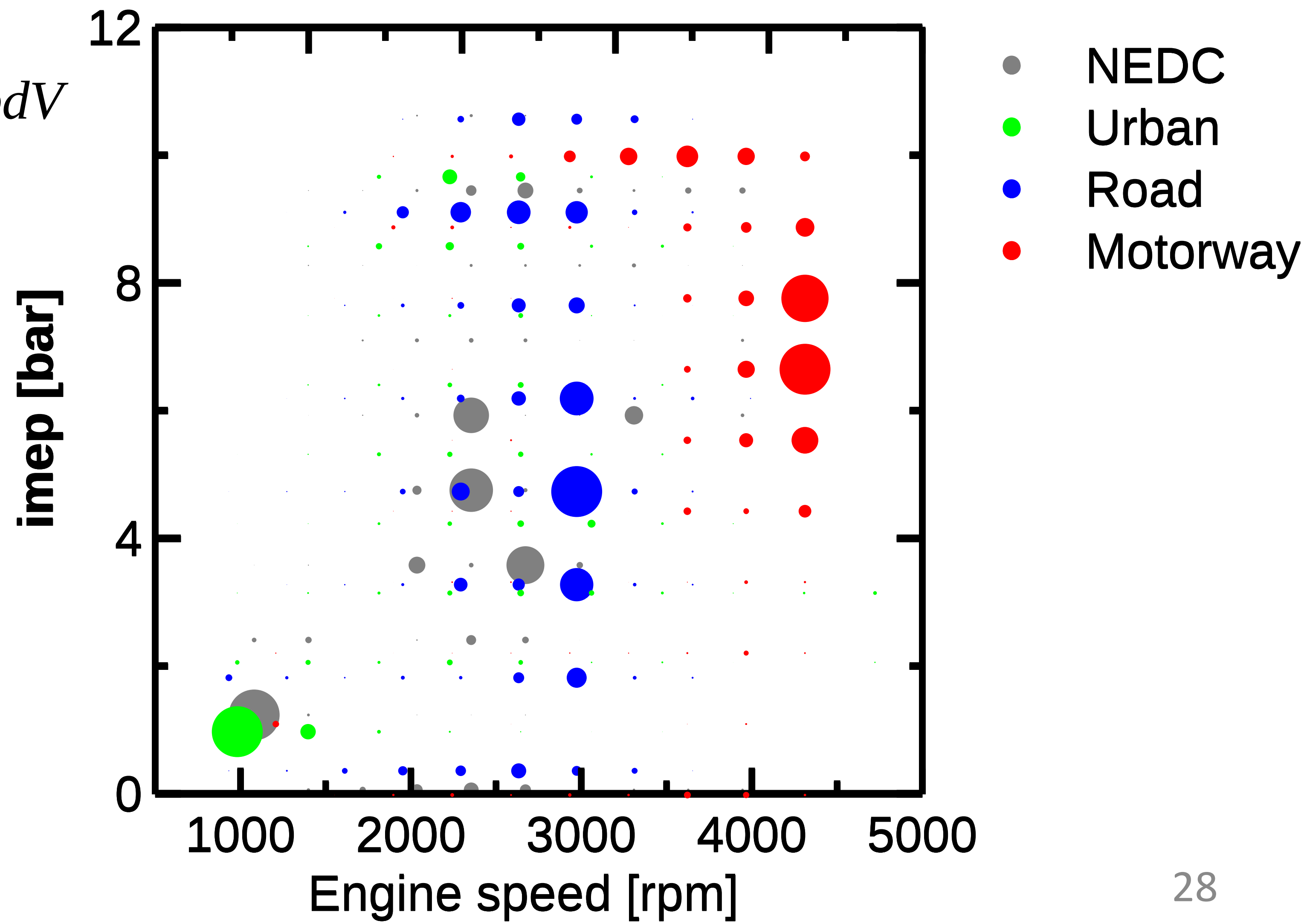
Driving cycles



Vehicle previously warmed up

Engine operating conditions over driving cycles

$$imep = \frac{1}{V_d} \oint pdV$$



Bubble diameter proportional to the frequency of the imep-n value

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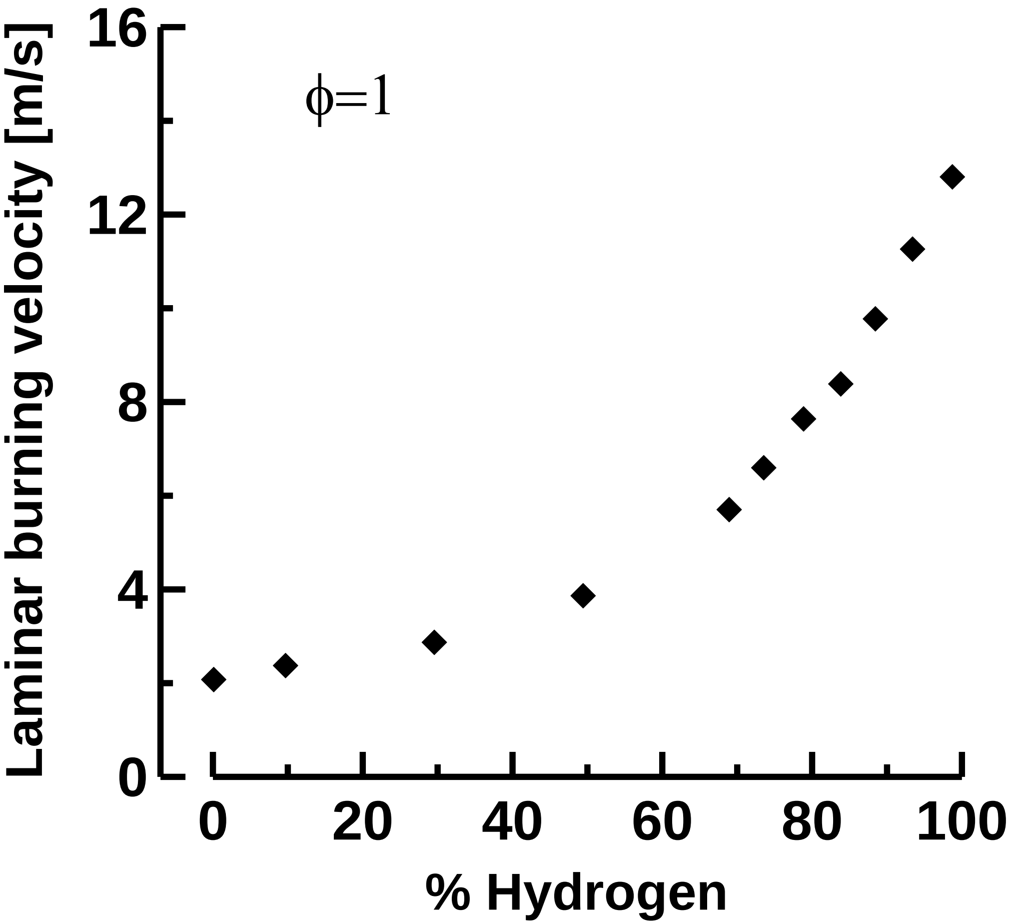
HCNG laminar burning velocity

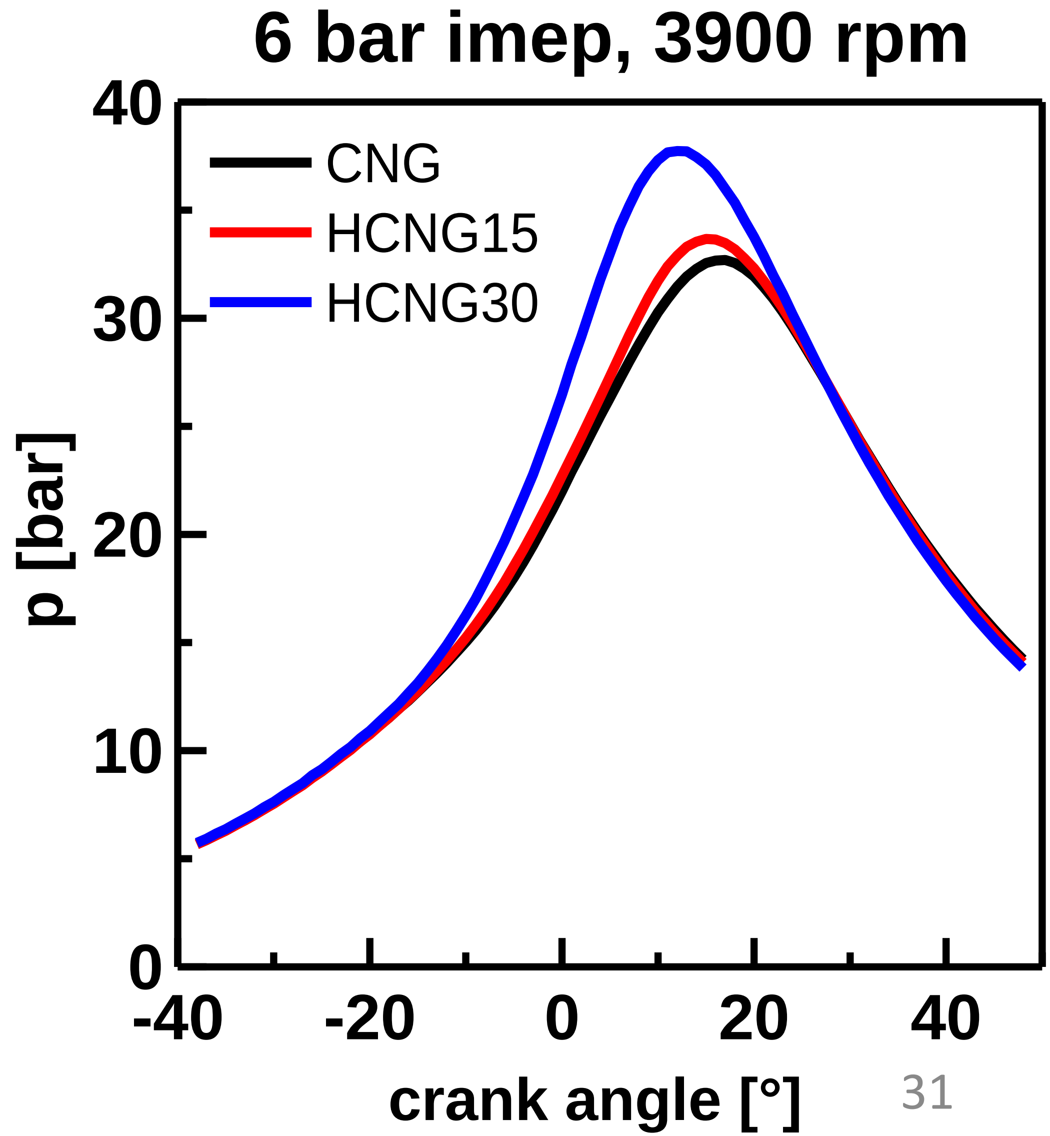
[1]



[1] Ilbas, M., Crayford, A., Yilmaz, I., Bowen, P. & Syred, N. (2006). Laminar-burning velocities of hydrogen-air and hydrogen-methane-air mixtures: An experimental study, Int. J. Hydrogen Energy 31: 1768–1779.

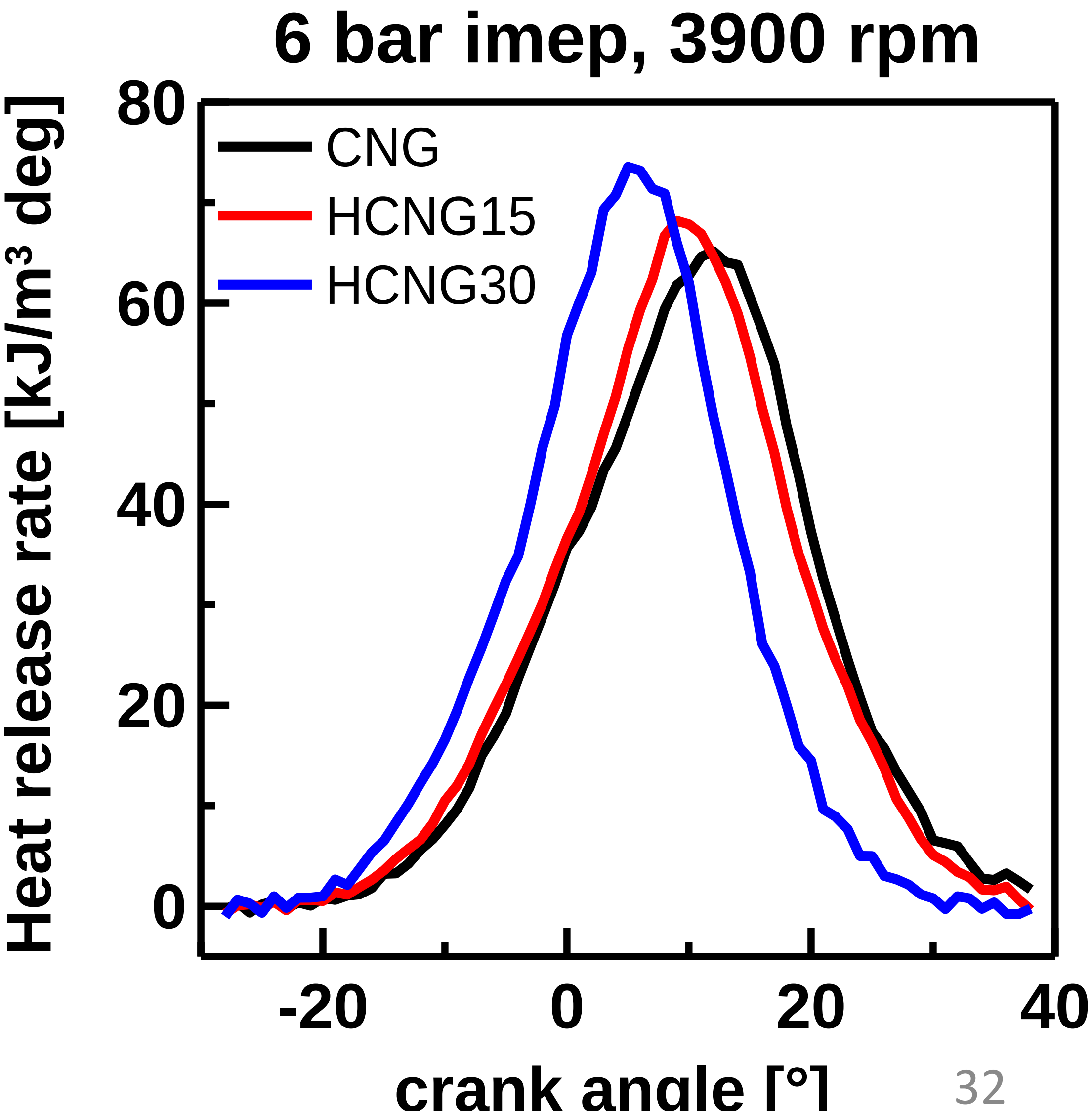
In-cylinder pressure

- The same ignition timing has been adopted for the tested fuels
- Peak pressure values increse
- Peak pressure positions shift toward TDC
- The combustion speed increased

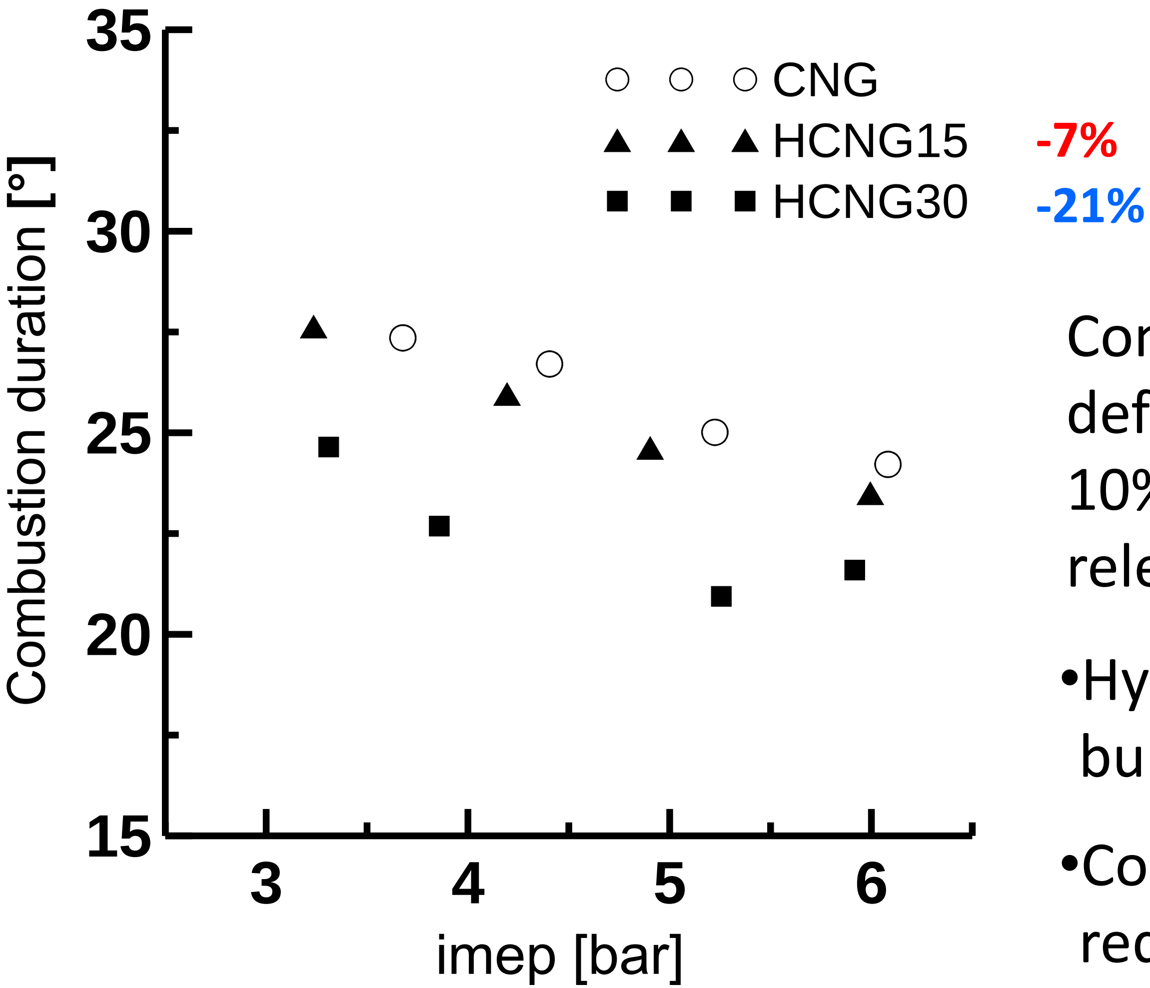


Heat Release Rate

•HCNG blends attain values higher than CNG.



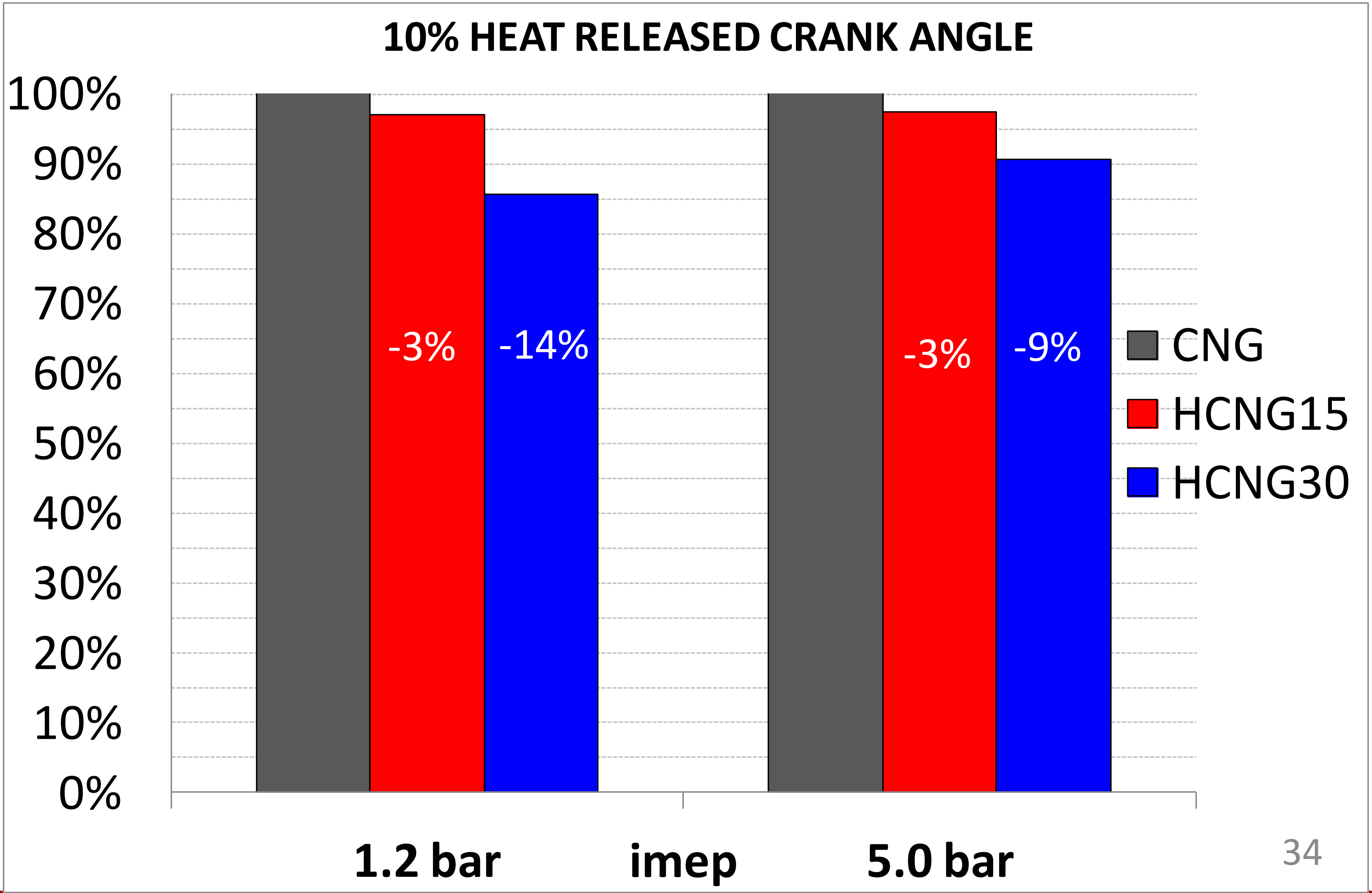
Combustion duration vs. Indicated Mean Effective Pressure (imep)



Combustion duration here defined as the angle between 10% and 90% of heat released

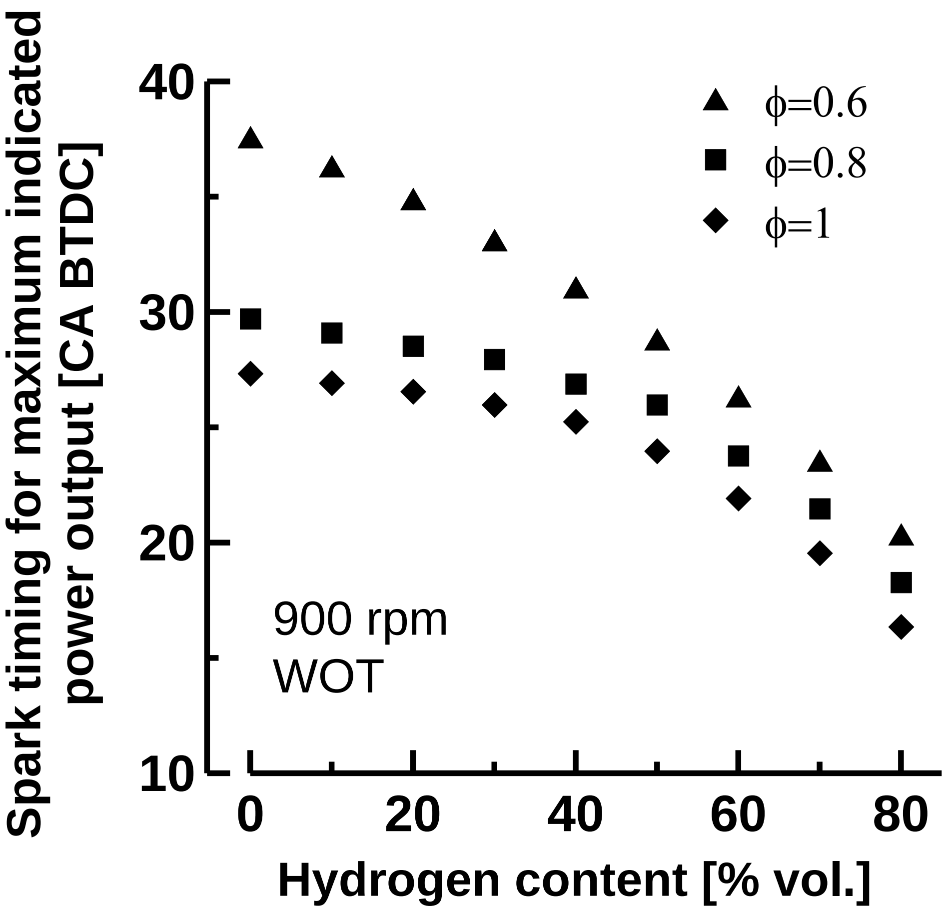
- Hydrogen addition increases burning rate
- Combustion duration is reduced respect to CNG at any loads

Early stages of combustion

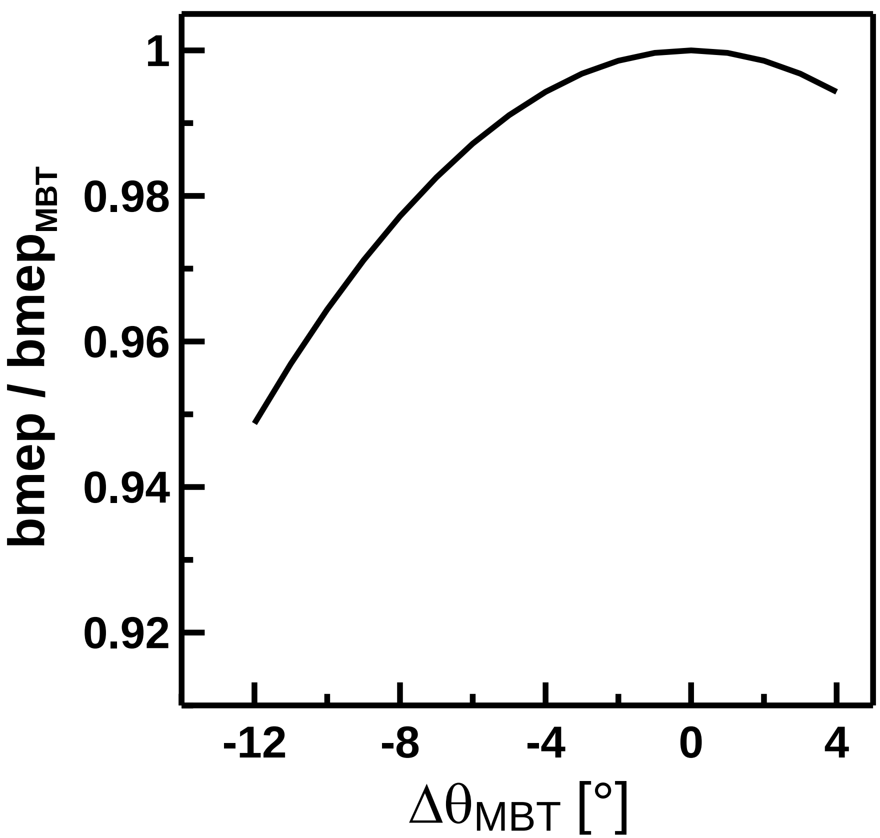


Maximum Brake Torque (MBT) ignition timing

[2]



Brake Mean Effective Pressure (bmep)

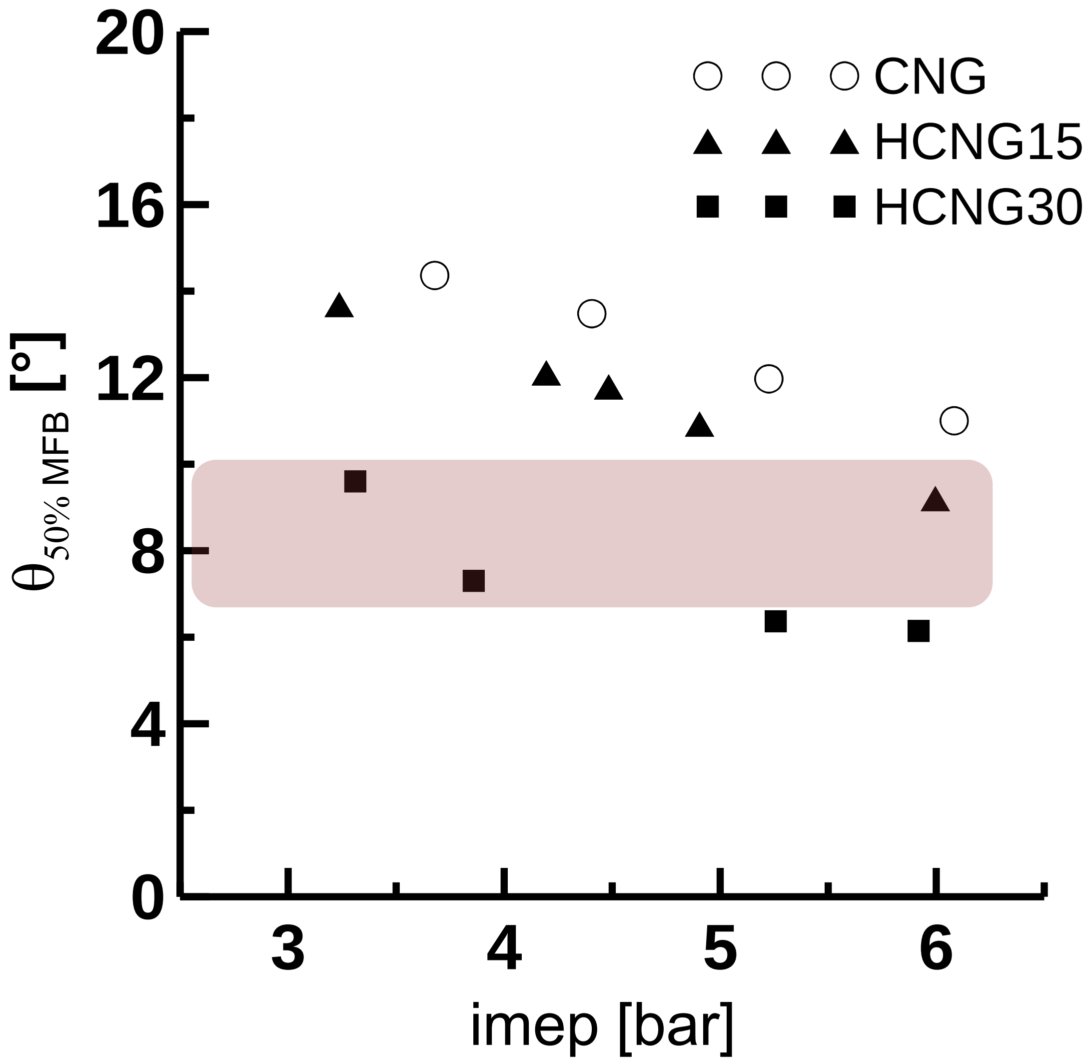


[2] Karim, G. A., Wierzba, I. & Al-Alousi, Y. (1996). Methane-hydrogen mixtures as fuels, Int. J. Hydrogen Energy 21: 625–631.

50% Crank Angle of Heat Released vs imep

Same ignition timing for tested fuels

50% CA of Heat Released reduces as hydrogen content in the blends increases



Optimal Combustion phasing angle [3]

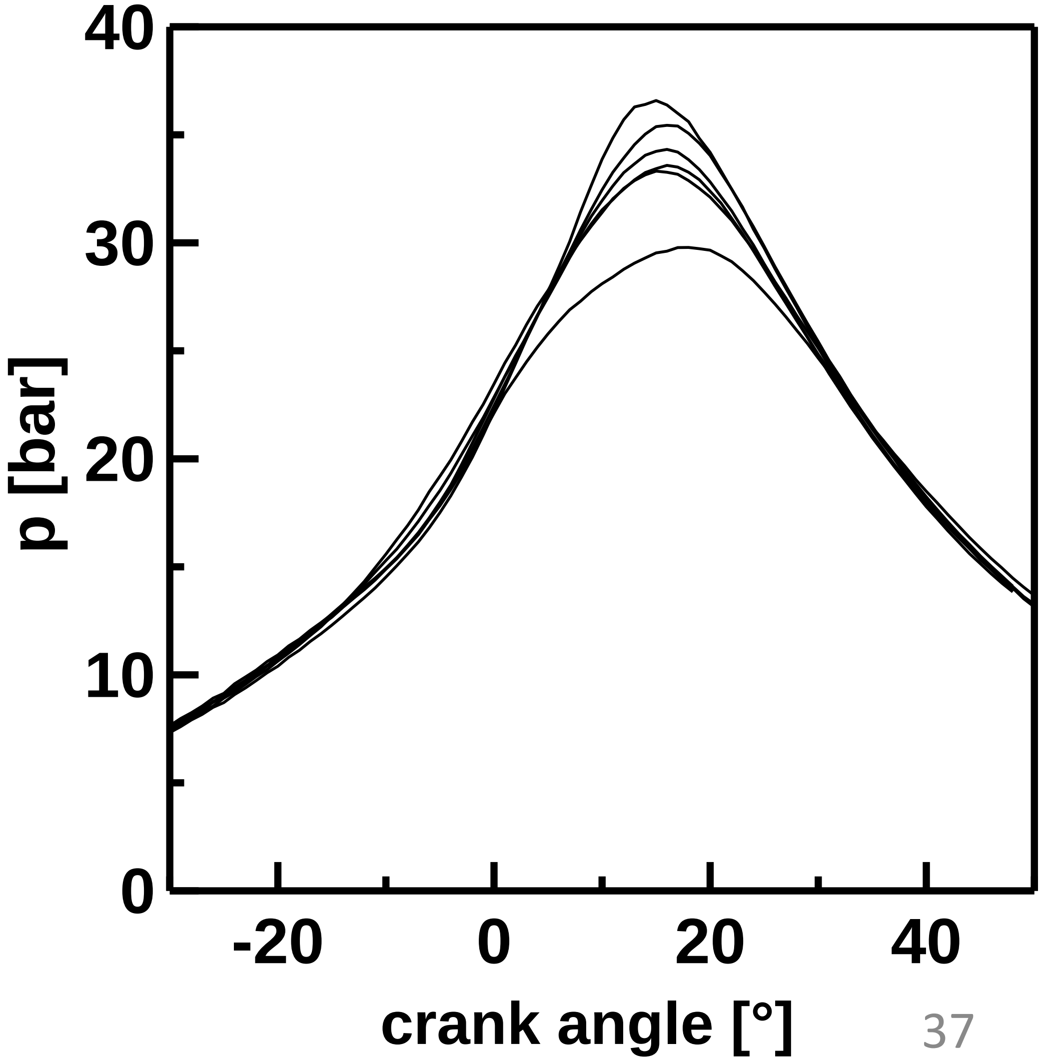
$\theta_{50\%\ MFB}$ between 8° and 10° ATDC

[3] Klimstra J. The optimal combustion phasing angle - a convenient engine tuning criterion. SAE Technical Paper 1985;(852090).

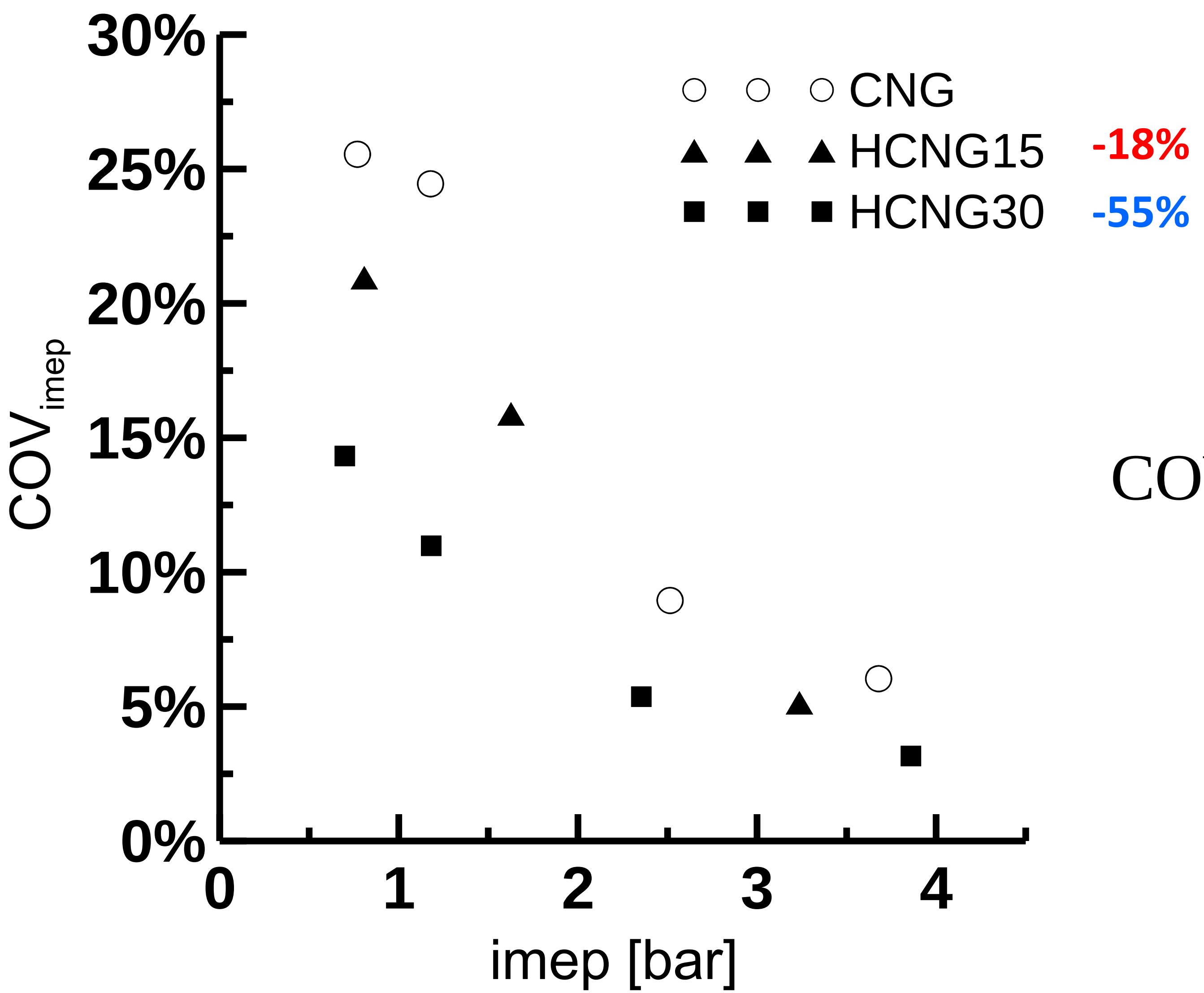
Cyclic dispersion

The combustion speed also influence the combustion stability

- Pressure measurements show that substantial variations on cycle-by-cycle basis exist
- The ignition timing is defined for an average combustion cycle
- Cyclic dispersion limits engine operations

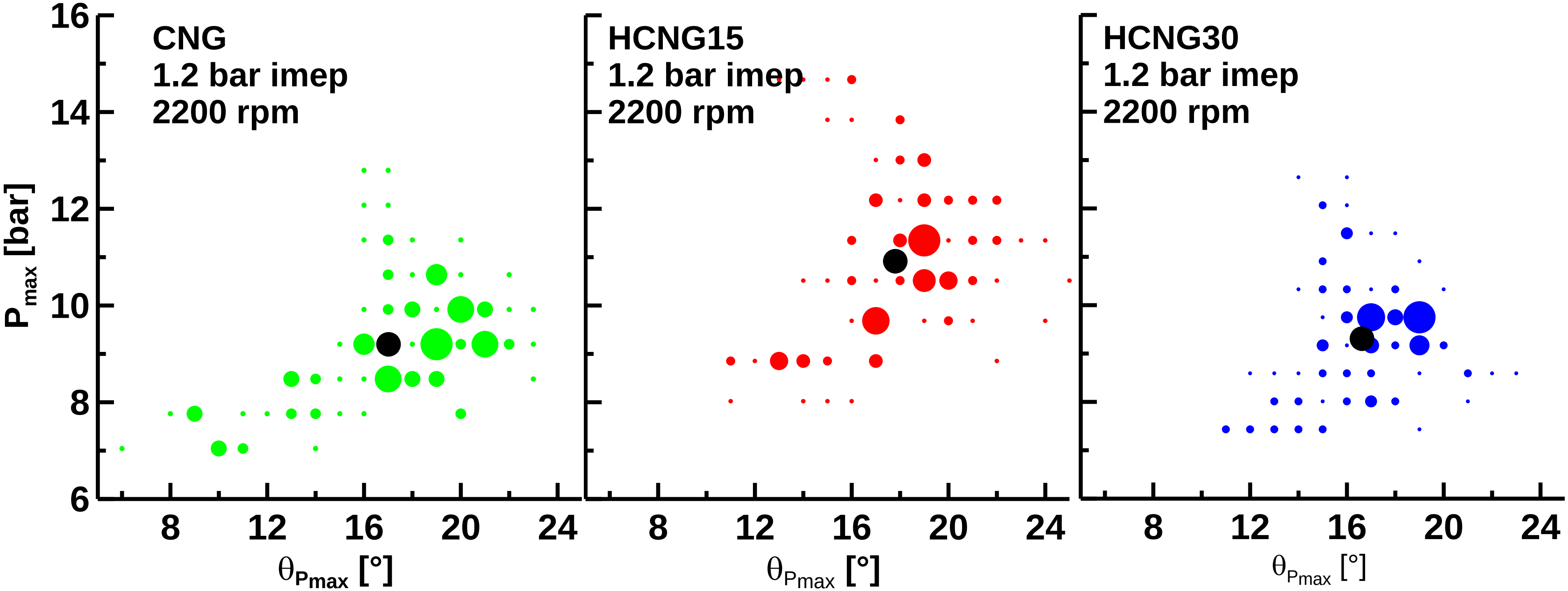


Coefficient of variation in Indicated Mean Effective Pressure vs. imep

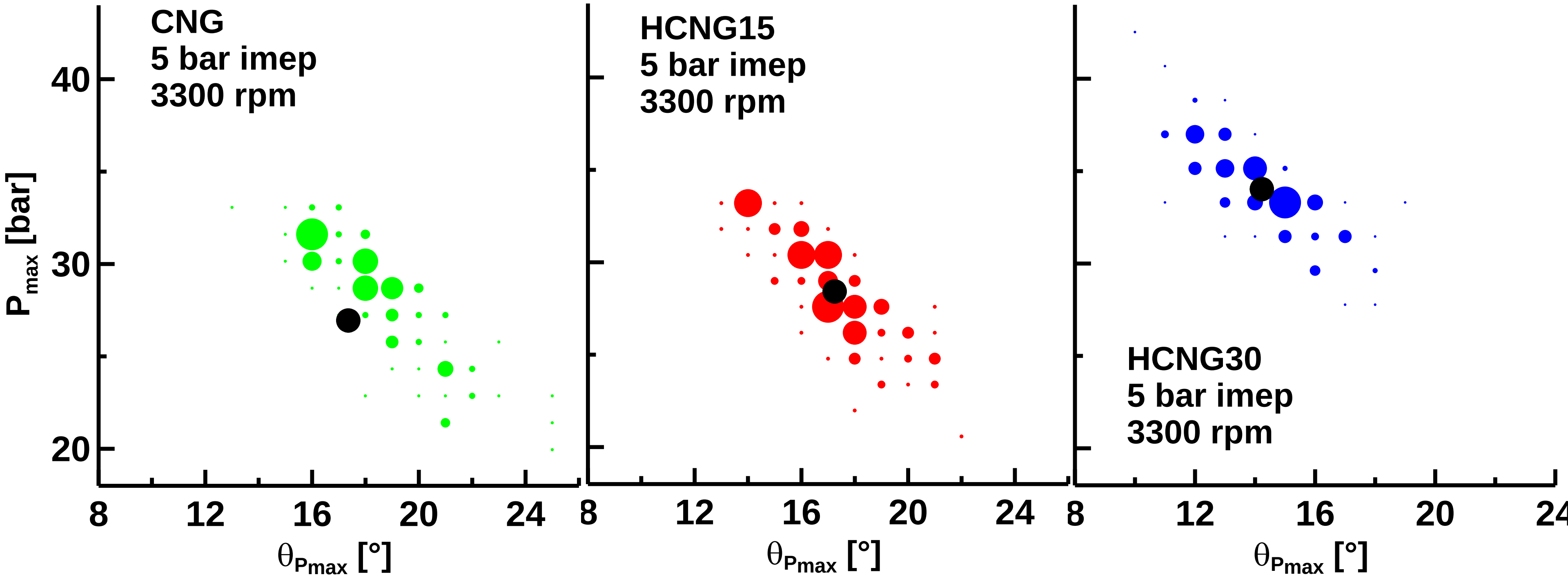


$$COV_{imep} = \frac{\sigma_{imep}}{imep_{avg}}$$

Maximum cylinder pressure vs maximum pressure crank angle



Maximum cylinder pressure vs maximum pressure crank angle



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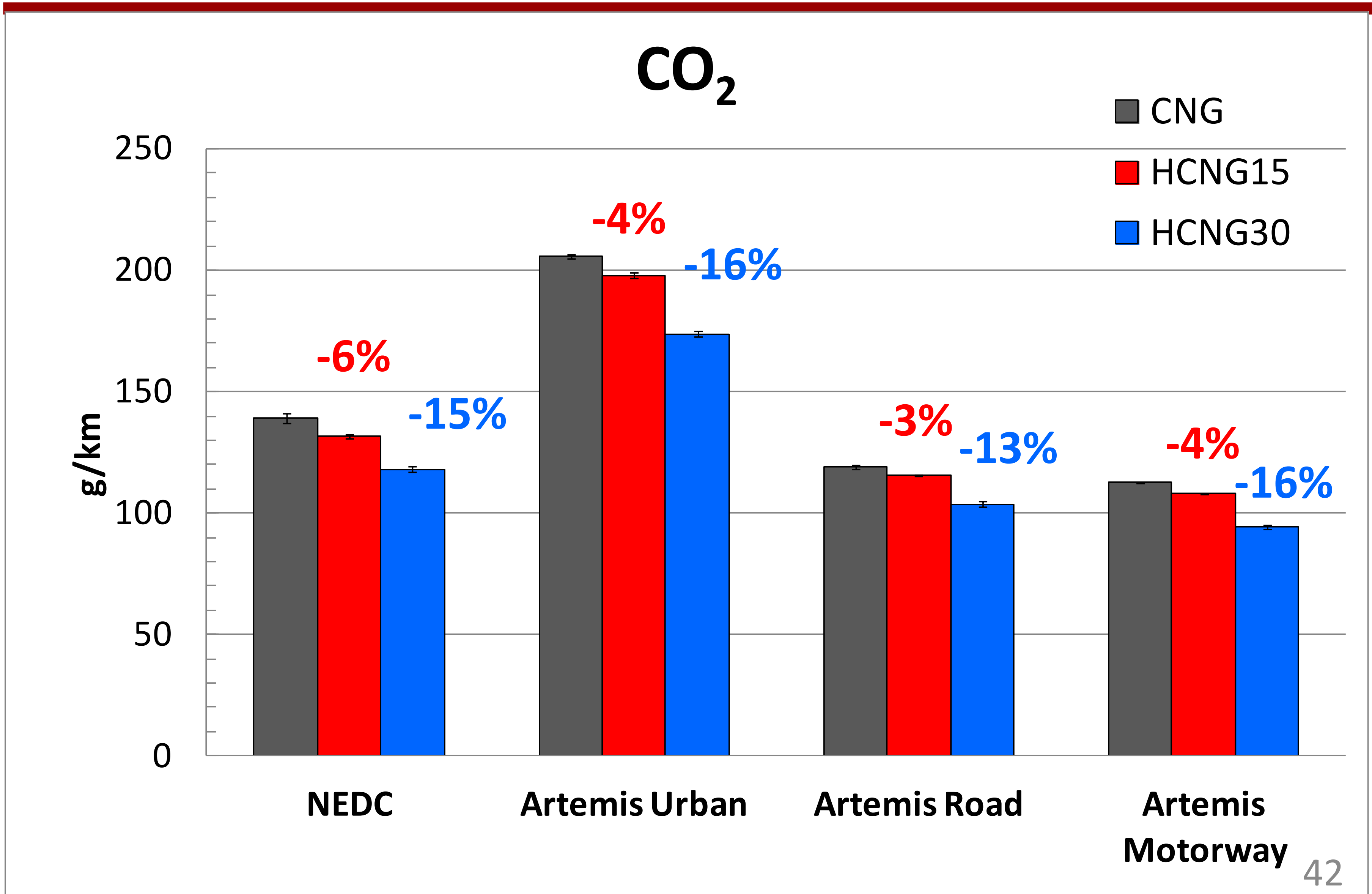
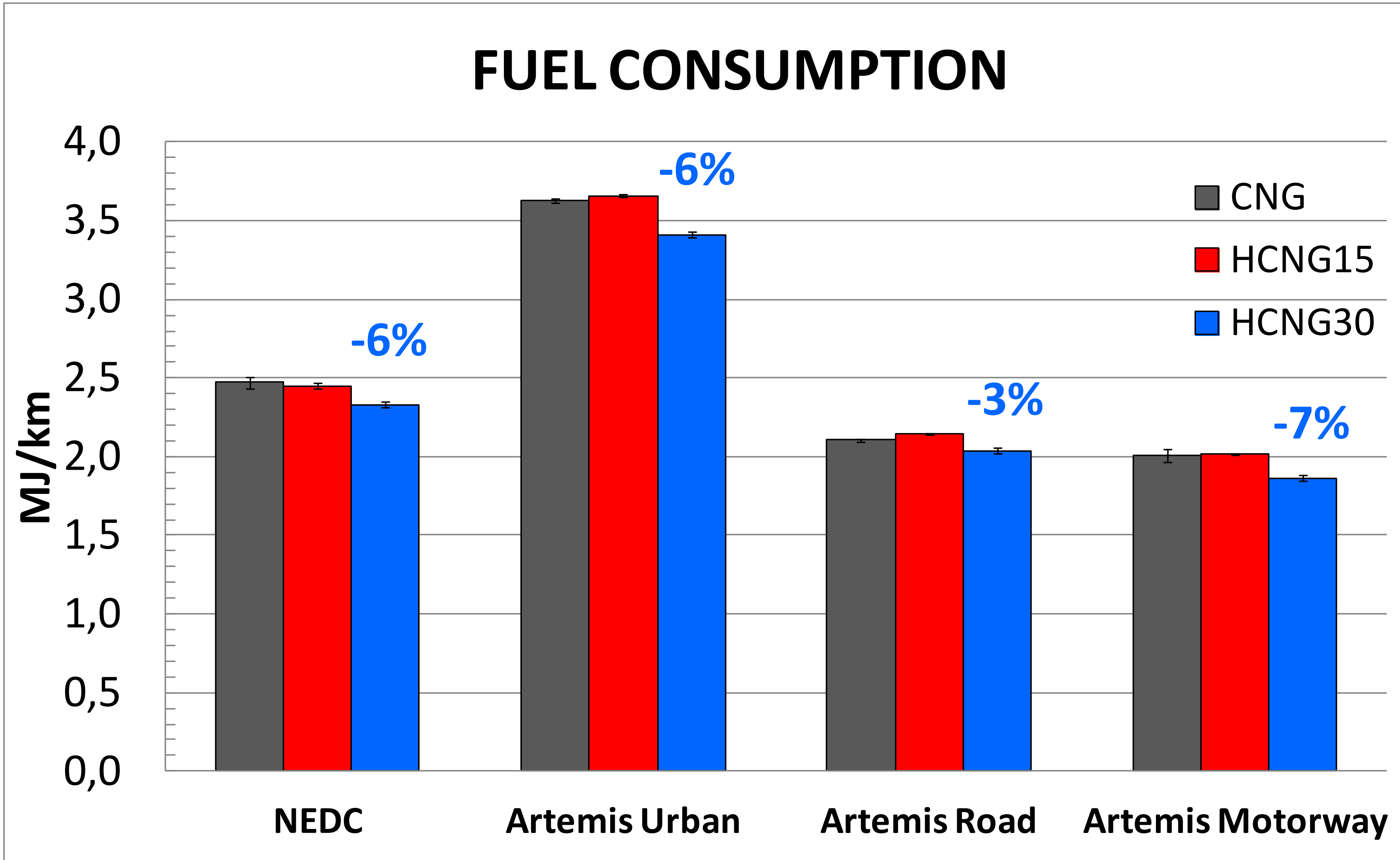
CO_2 emissions in g/km



Fuel consumption in MJ/km



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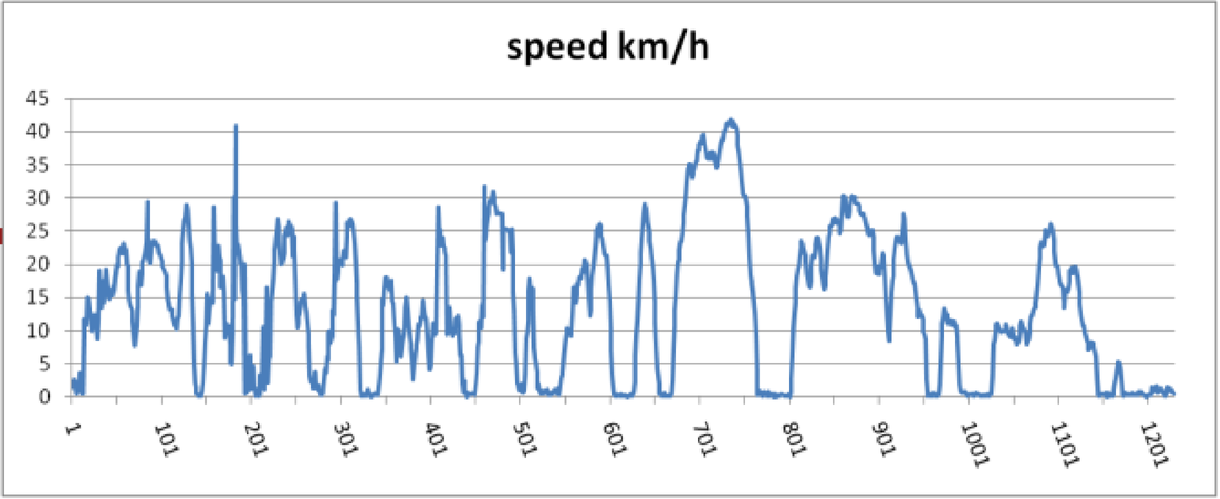
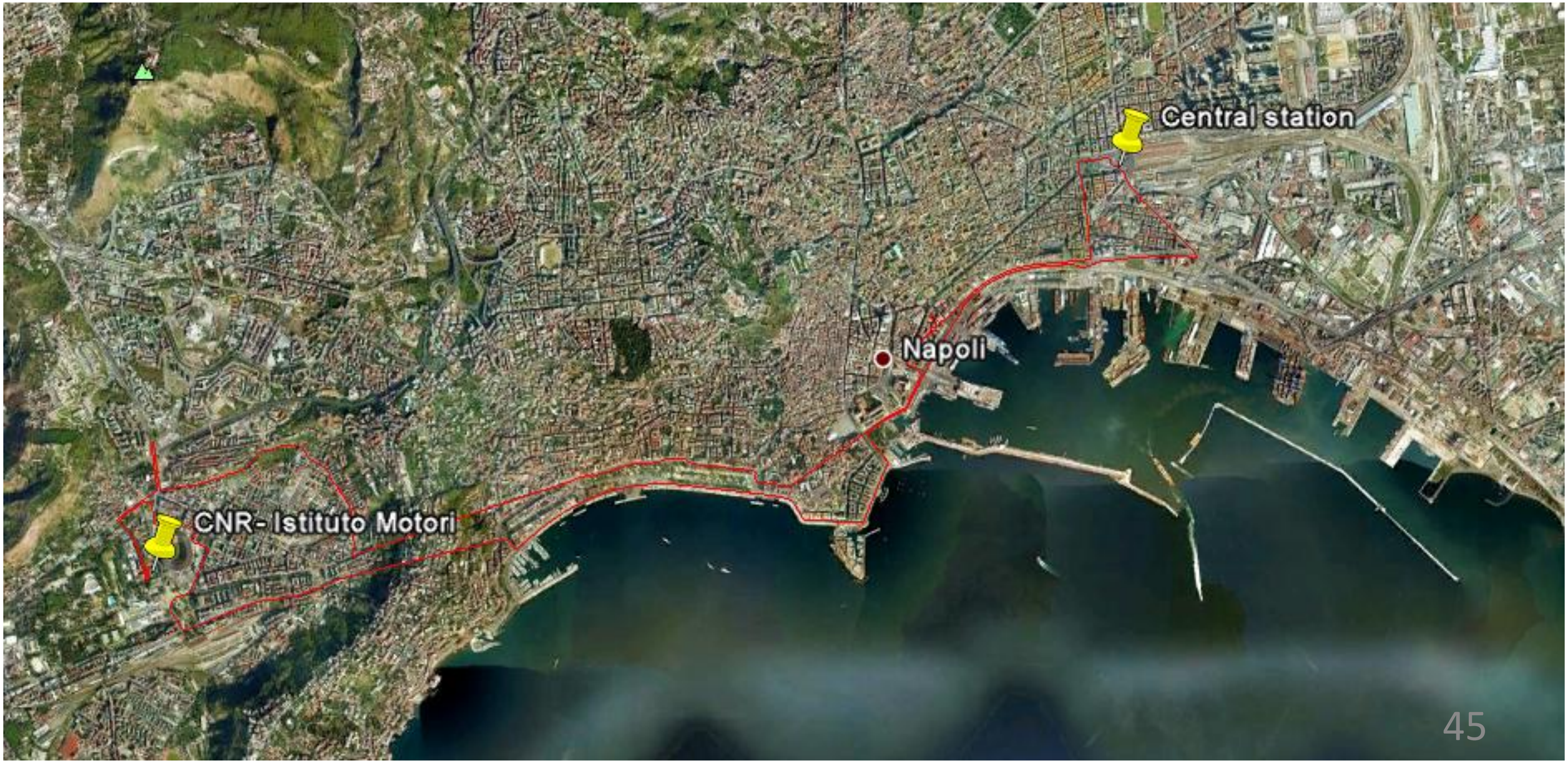
Real driving conditions



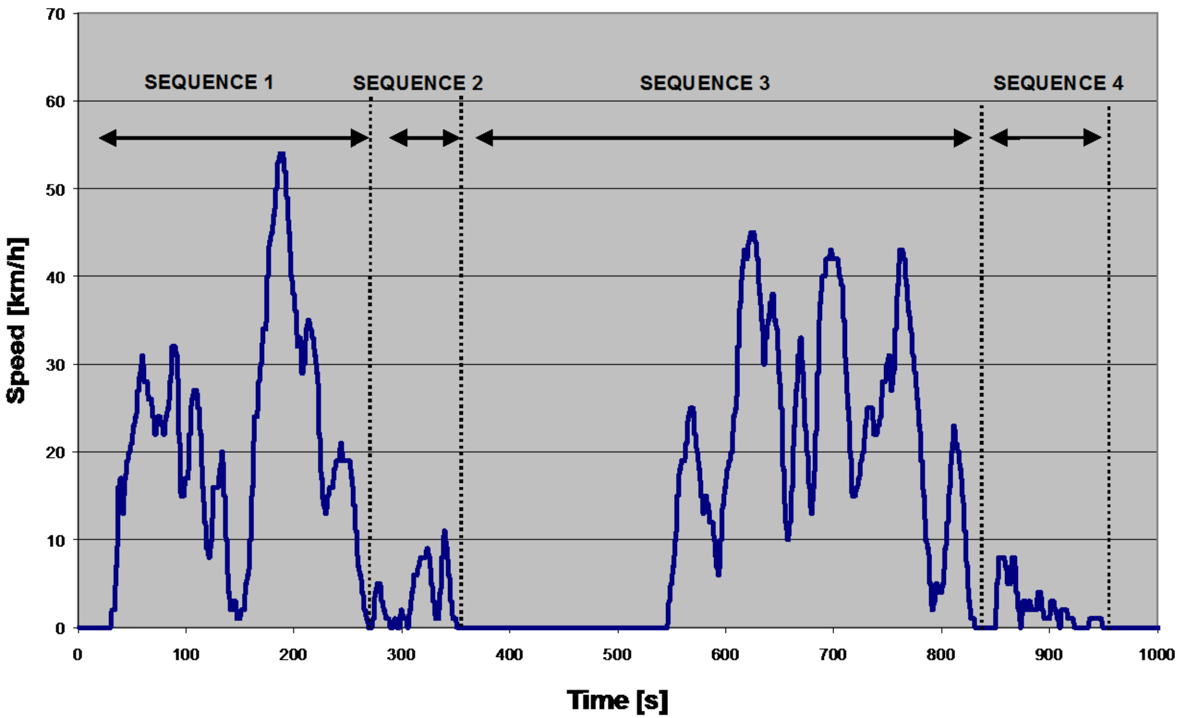


On road tests

- Portable device for exhaust emission measurements (CO, CO_2 NOx, THC)
- Fuel consumption determination
- ECU data
- GPS

Vehicle fuelled by Gasoline, CNG and HCNG30

Kinematic sequence

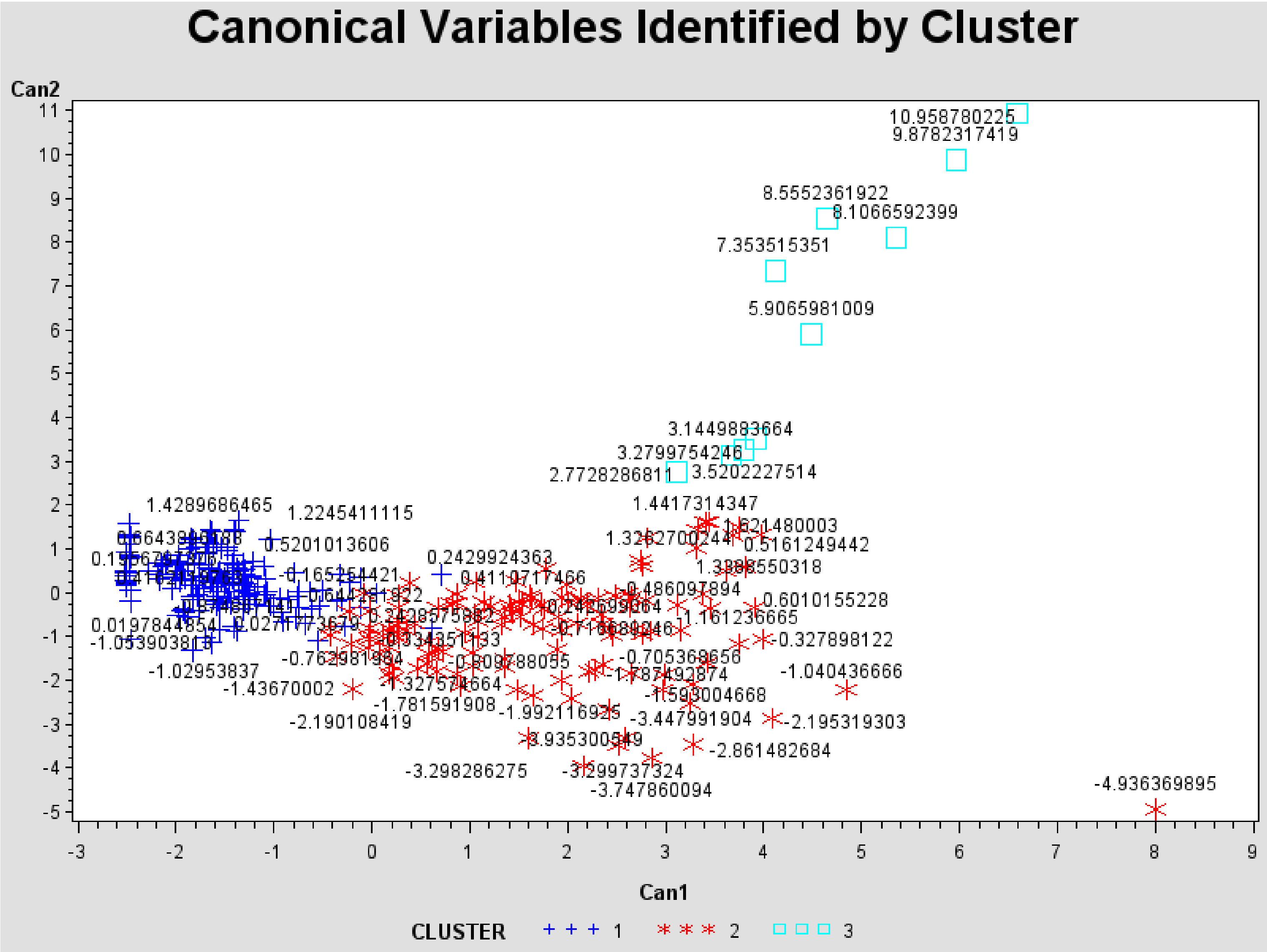


Variables for sequence definition:

- •Average speed
- •Max speed
- •Max speed/driving time
- •Gear
- •Distance
- •Time at idle
- •Total time
- •Number of speed peaks

....

Cluster analysis



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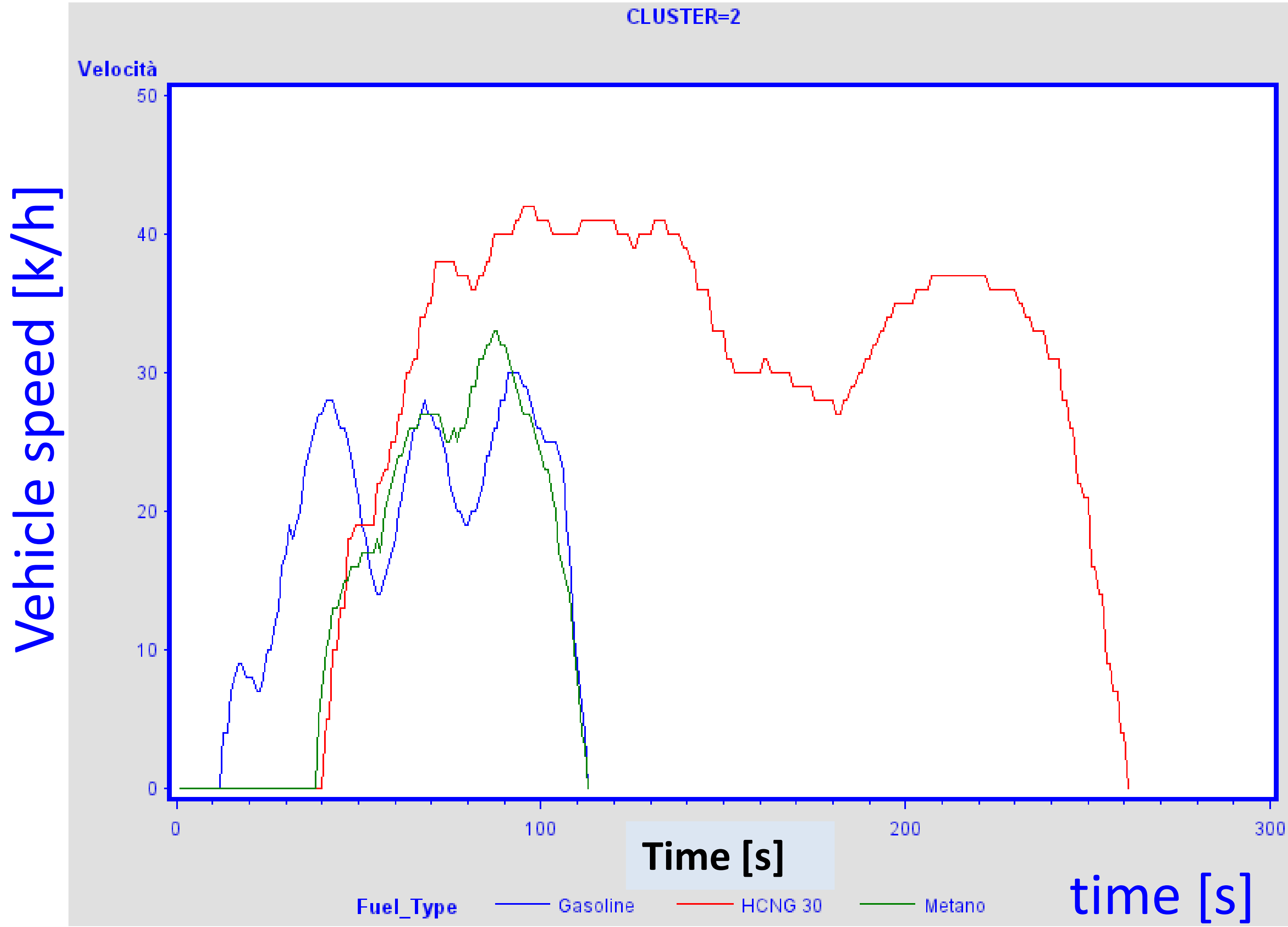
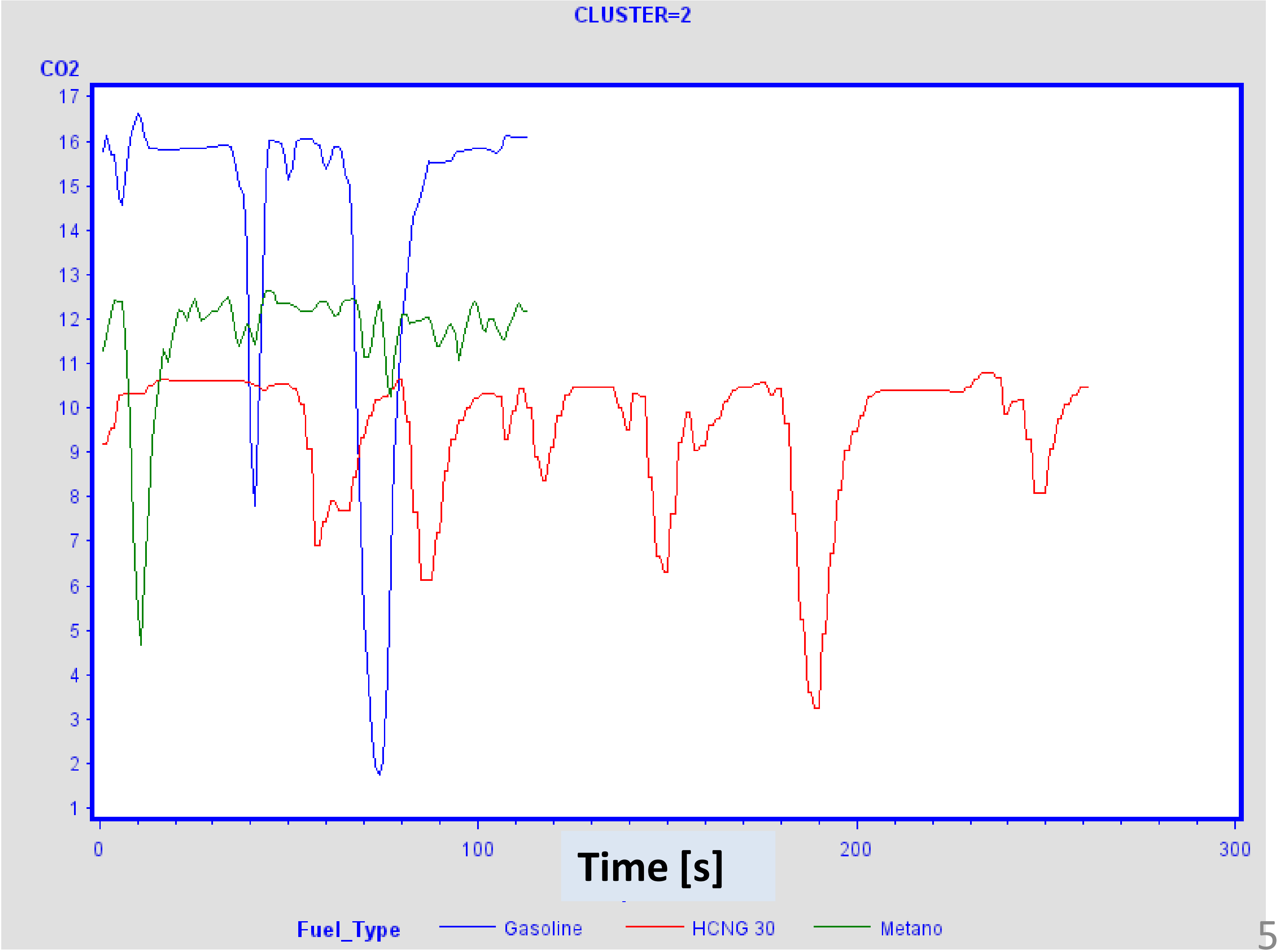
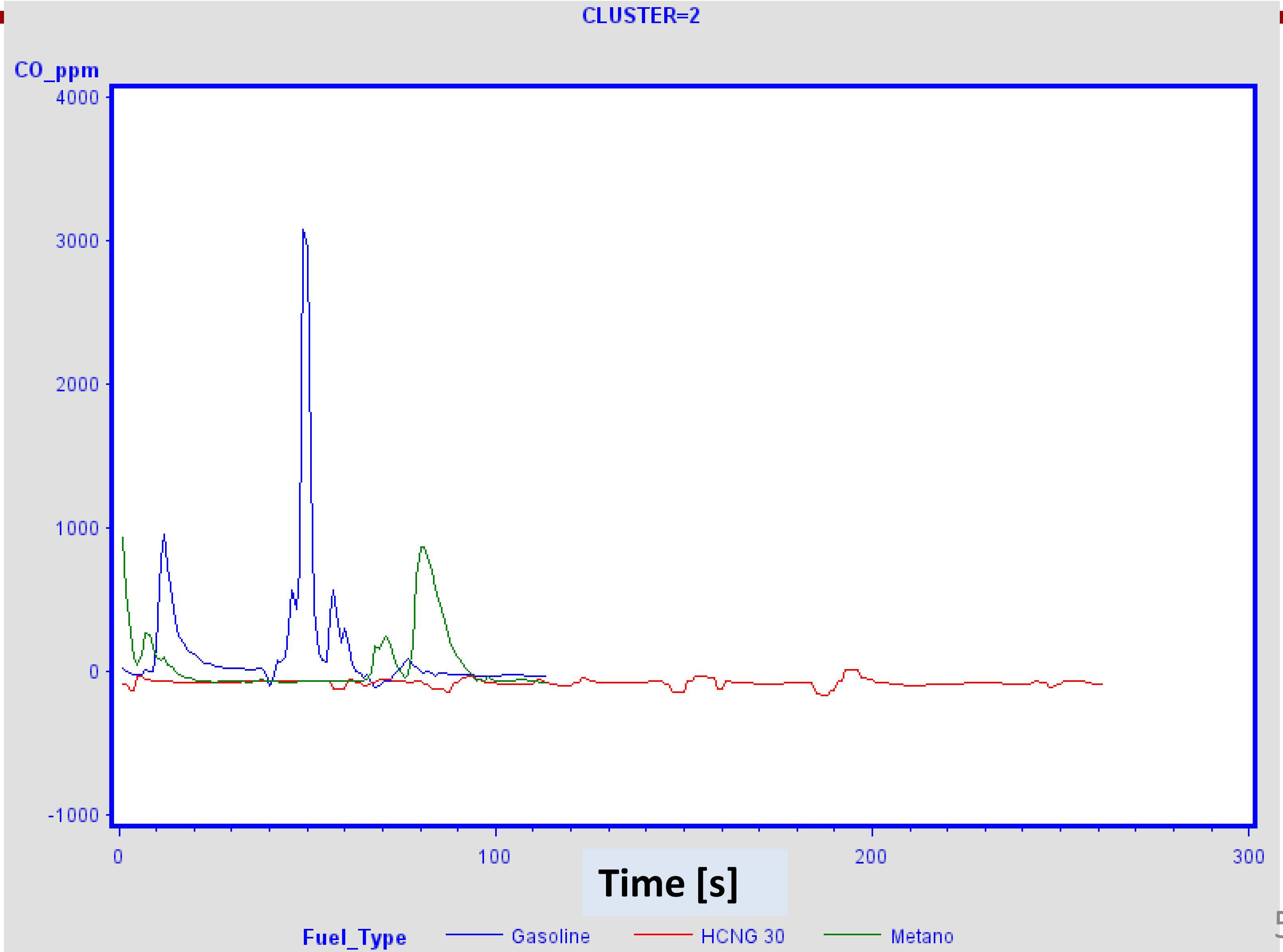


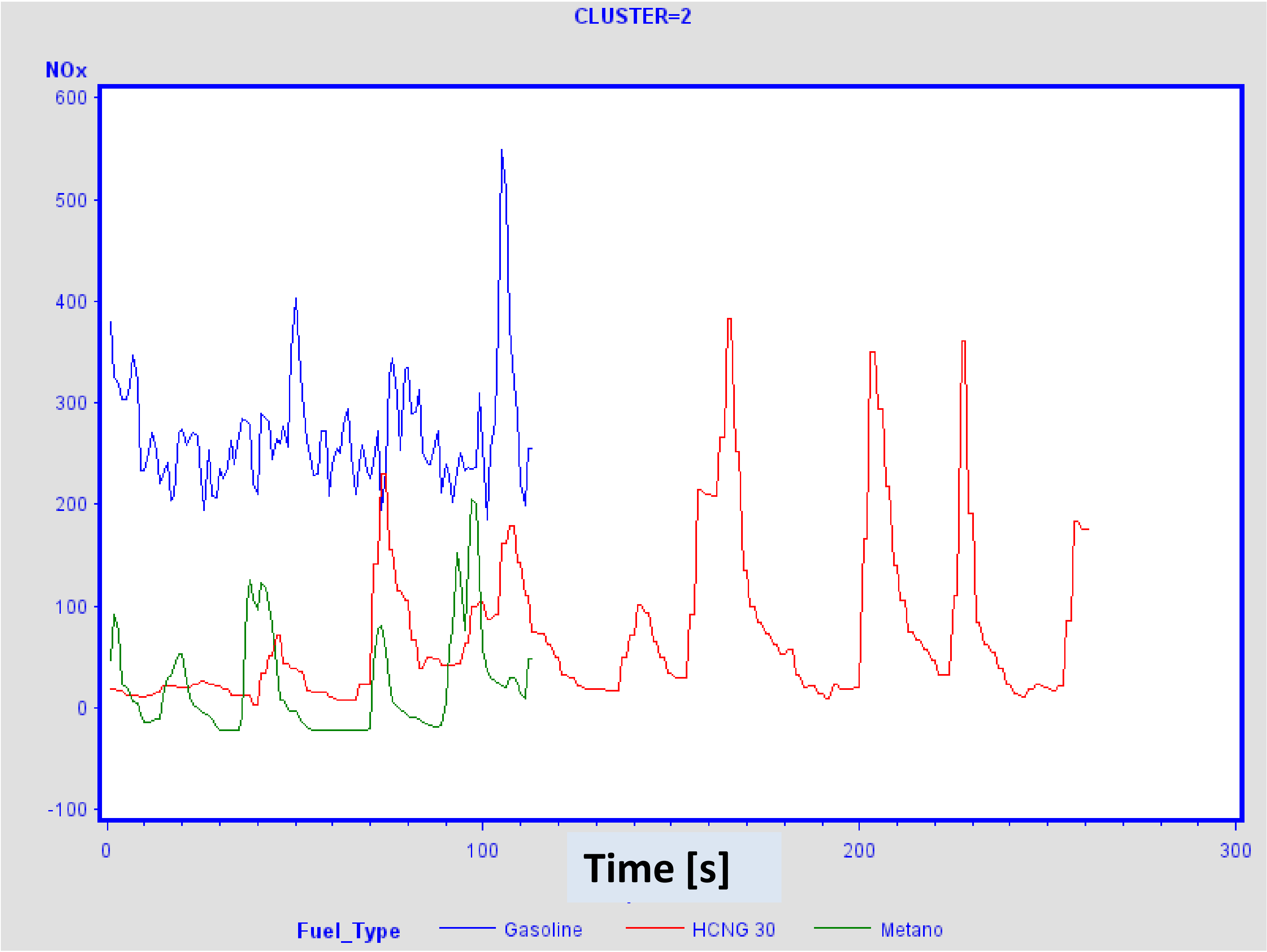
CO_2 emissions in ppm



CO emissions in ppm



NOx emissions in ppm



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Real–life cases of HCNG uses

Arizona

•U.S. Department of Energy Advanced Vehicle Testing Activity (AVTA), Electric Transportation Applications (ETA), Arizona Public Service (APS)

Hydrogen pilot plant:

•Hydrogen production by means of PEM electrolyzer

•Dispensing different HCNG blends with hydrogen ranging from 0% to 100%.

[4]

Sweden

Malmö Hydrogen and CNG/Hydrogen filling station and Hythane bus project

[4] Francfort, J. & Karner, D. (2006). Hydrogen ice vehicle testing activities, SAE paper (2006-01-0433).

Real–life cases of HCNG uses

Italy

ENI Multienergy stations

- Renewable energies for hydrogen production
- Mixer
- Dispenser

ENI Multienergy stations:

1. Milano
2. Collesalvetti (Livorno)
3. Francoforte
4. Mantova

Real–life cases of HCNG uses

Italy

Regione Emilia Romagna and the ENEA

My-Gas
Regione Lombardia, Fiat Research Center, Sapio, CNR-Istituto Motori and Seconda Universitá

[4] Genovese, A., Contrisciani, N., Ortenzi, F. & Cazzola, V. (2011). On road experimental tests of hydrogen natural gas blends on transit buses, Int. J. of Hydrogen Energy 36: 1775–1783.

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Conclusions: Combustion analysis

- Combustion speed increases with hydrogen addition
- Reduction of combustion duration between 2% and 7% for HCNG15 and between 9% and 21% for HCNG30
- The cycle-by-cycle variation decreases, mainly at low loads, with a maximum reduction in COV_{imep} of 18% for HCNG15 and 55% for HCNG30

Conclusions: fuel consumption

- CO_2 emission reduced using HCNG blends. Reduction between 3% and 6% for HCNG15 while between 13% and 16% for HCNG30
- Negligible effect on fuel consumption for HCNG15 while remarkable reductions between 3% and 7% for HCNG30

Conclusions: exhaust emissions

Emissions do not show a common trend:

- CO emissions showed a reduction
- NOx emissions increased, in particular with HCNG30
- HC emissions were similar for the tested fuels

NOx emissions with HCNG30 were reduced adjusting injection calibration

Thank you!

Data reduction

Stoichiometric air-fuel ratio **(1)** $$AFR_{stoich} = \left(\frac{m_a}{m_c}\right)_{stoich}$$

Air-fuel ratio **(2)** $$AFR = \left(\frac{m_a}{m_c}\right)$$

Relative air-fuel ratio **(3)** $$\lambda = \frac{AFR}{AFR_{stoich}}$$

Equivalence ratio **(4)** $$\phi = \frac{1}{\lambda}$$

Indicated mean effective pressure **(5)** $$imep = \frac{1}{V_d} \oint pdV$$

Coefficient of variation imep **(6)** $$\mathrm{COV}_{\mathrm{imep}} = \frac{\sigma_{\mathrm{imep}}}{\mathrm{imep}_{\mathrm{avg}}}$$