Gas-Only Internal Combustion Engines

Project number 652816

H2020 GV-3-2014 Future natural gas powertrains and components for cars and vans

Work Package – WP5
Non-DI CNG lean burn combustion process and on-board gas sensor-concept

The next step beyond the today's gas engine technology

A non-DI CNG lean burn combustion concept based on the transfer of a very efficient combustion process from large stationary diesel engines (concept MAN)

- avoid the major concern for a robust ignition in a lean or diluted CNG mixture
- with a new pre-chamber ignition concept
- improving engine efficiency through λ up to 2 and increased cylinder pressure

WP5 Objectives

<u>Part 1 of WP5</u>:

- *development of a new **combustion process** for CNG-only engines with a **non-DI** layout, with **λ up to 2***
- ***4-cyl** full engine development and **tests** of new combustion process, new **pre-chamber** ignition system and operating strategies*
- ***understanding** of mixing, ignition and combustion **fundamentals**. Definition of limits for lean burn and ignition capability*

<u>Part 2 of WP5</u>:

- *development of an **on-board sensor** concept and module to detect the relevant gas quality parameters, like caloric value and methane number*
- ***test** of sensor module prototype **in test cars** to validate performance*

Main tasks part 1

Mixing, ignition and combustion fundamentals
(ETH, VW, PUT, Ricardo)

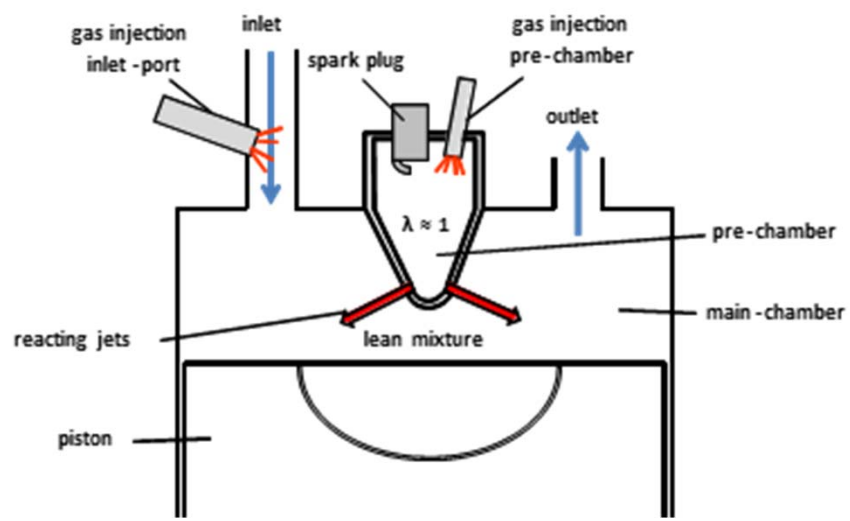
Validation of CFD investigation using 1-cylinder research engine
(PUT, Ricardo, ETH)

Full engine combustion-process development
(Empa, ETH, VW)

Validation
(VW, Empa, ETH)

The principle of pre-chamber ignition

The CNG will be ignited inside a pre-chamber with an “ignition friendly” air-CNG-mixture and thus creates flame coils into the main combustion area. Those flame coils deliver approximately 10 times more energy than a spark plug system and are able to ignite very lean mixtures. The mixture of the pre-chamber can be optimised for ignition, whereas the mixture in the main combustion chamber will be optimised for highest fuel efficiency ($\lambda >> 1$).



Development steps: New Combustion Process

The conversion of a combustion process from a **large stationary** diesel engine **to** a new CNG lean burn combustion concept for **light duty vehicles** requires a totally new approach.

Development tools:

- VECTIS CFD modelling
- RCEM work
- 1-cylinder tests
- 4-cylinder full engine tests

Development steps: New Combustion Process

- Variations of the pre-chamber geometry with 6, 7 or 10, radial or tangential nozzles, and with different volumes.
- Variations of piston bowl geometry
- Variations of the dosing valve (injection duration and timing)
- Variations of compression ratio
- Appropriate control strategy
- All with CFD assistance

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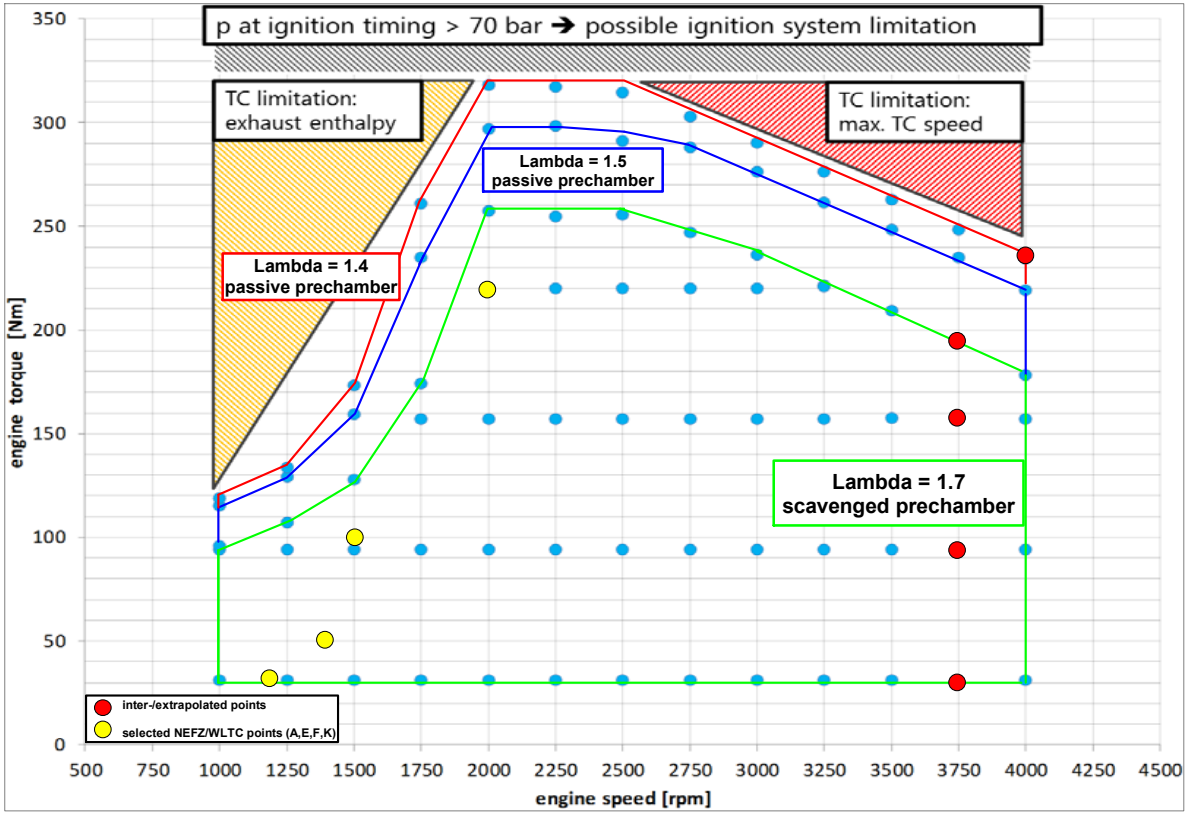
VW, Continental, Empa, ETH Zurich, PUT, Ricardo



Limitations within the GasOn research project:

- Within the GasOn project only a **waste-gate Turbocharger** was available. With a **VTG TC**, the engine power and engine efficiency could increase to a higher level.
- 70 bar at spark timing are a limitation for ignition

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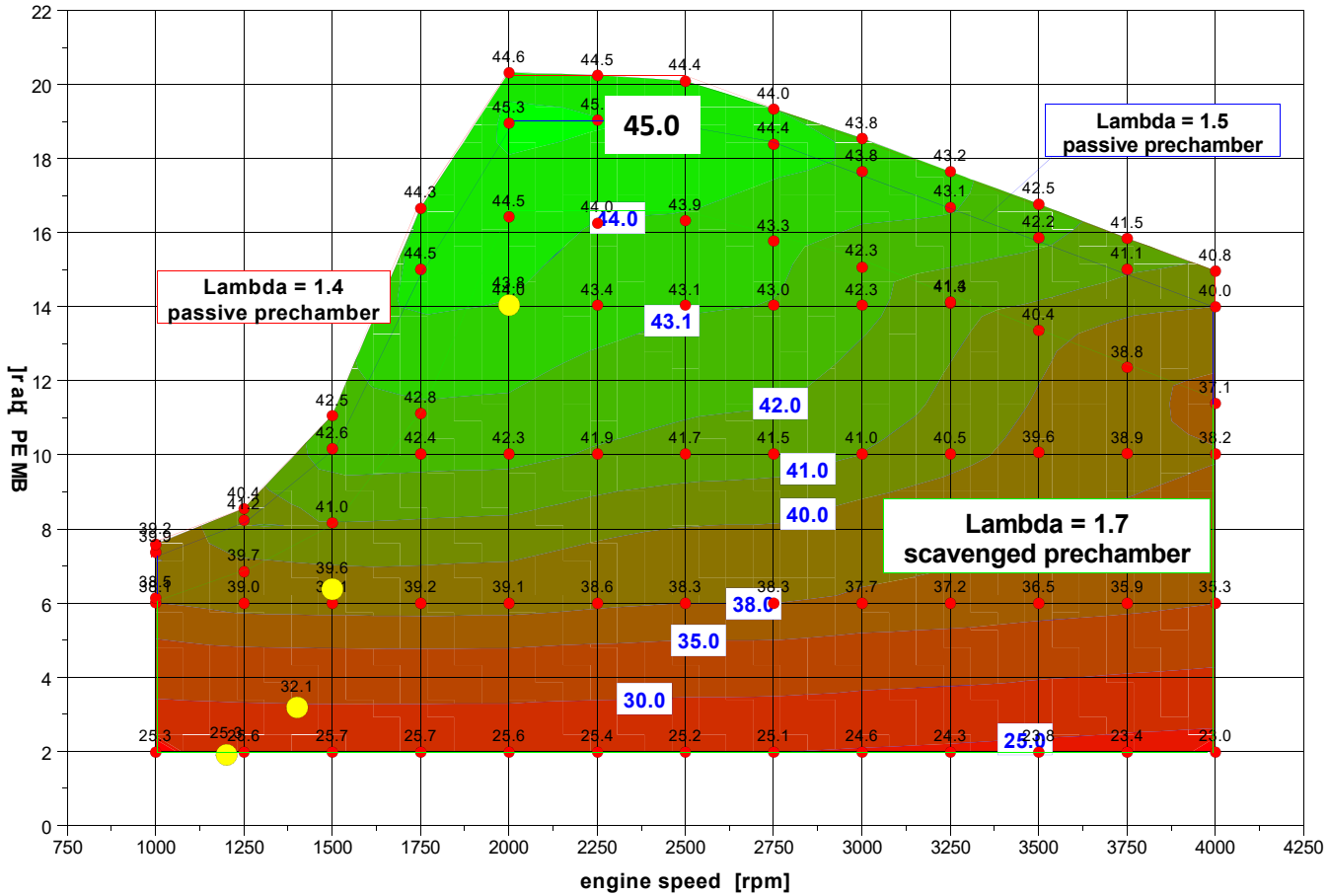
brake engine efficiency [%] / map lambda=1.4/1.5/1.7, GasOn engine w. prechamber PC7, piston: omega rounded
fuel: CNG / catalyst: none / COC = 8°CA a. TDC



Engine operation results:

- The engine is driven mainly between λ=1.4 and λ=1.7 in a very lean and effective engine operation with a brake engine efficiency up to 45%.
- A stable ignition is possible up to λ= 2.2, while the best efficiency has been found up to λ=1.7.
- Even the gas mixture in the "**passive**" pre-chamber, which was pressed from the main ignition chamber into the pre-chamber through compression stroke, ignites at a λ=1.4 to **λ=1.5** without any additional injected CNG dose.
- From **λ=1.6** on, a low dose of CNG must be injected into the now "**scavenged**" pre-chamber.

- Furthermore, as a part of the computational methodology development, **a novel computational multi-scale plasma spark model and a novel wall-flame interaction model** have been developed and validated.
- These models have been **incorporated into VECTIS** CFD package developed by Ricardo Software and have been **made available** to project partners, existing and prospective Ricardo customers.
- The scope of applicability of the models is **not limited to CNG applications** and they can be used to enhance the accuracy for other combustion systems development within automotive and wider industrial applications.

WP5 Final Results Part 1:

- *Highest reached engine efficiency **45%***
- *A stable ignition is possible up to **λ = 2.2***
- *Limitation for ignition capability is **70 bar** at firing point*
- *New CFD models, elaborated in GasOn, incorporated into **VECTIS***

Main tasks part 2

single sensor build up - principle testing
(Continental, VW)

single sensor calibration / dynamic stability validation / sensor module integration
(Continental)

gas blend testing / sensor principle correlation / proof of concept
(Continental / VW)

The development of a on-board gas quality sensor

The motivation to develop a special gas quality sensor is based on the massive worldwide **variation in gas quality (e.g. >40% in caloric value)** which leads to an inaccurate engine map to cover the broad spectrum of caloric value.
A reliable, stable and fast sensor signal is one of the enablers for mono-fuel efficient CNG driving.

To cover the worldwide variations of CNG, the target values for characterisation are the **Methane Number** and the **Lower Caloric Value**.

Criteria	Target Accuracy
Lower Caloric Value (MJ/m3)	2-4%
Methane Number	+/- 3%

Development steps: On-Board Gas Quality Sensor

A gas quality sensor, providing both methane number and caloric value requires a different and new approach.

- The measurement of the **methane number** allows adjusting the ignition timing to operate the engine close to the **knock line**.
- With the **caloric value** it is additionally possible to optimise **injection strategy** and boost pressure.

Development steps: On-Board Gas Quality Sensor

The development starts with available sensor prototypes, an **ultrasonic** sensor, a **thermal** sensor and an **optical** sensor.

The ultrasonic (sound) sensor showed in first tests an influence of less than 1%.
The high effort on mechanical integration, the size and component price did not justify the additional small benefit, so it was decided not to use the acoustic sensor in the future.

For both sensor modules (optical module and thermal module) it was possible to do a **full calibration** over the desired **temperature** range, **pressure** and **gas composition**.

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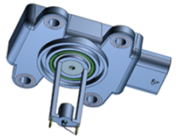
Gas Quality relevant properties									
		 Optical Modul				Thermal Module			
Criteria	**Target Accuracy**	**Sample Output**	**Theoretical Accuracy**	**Results Testbench**	**Results Car Testing**	**Sample Output**	**Theoretical Accuracy**	**Results Testbench**	**Results Car Testing**
Lower Caloric Value (MJ/m3)	2-4%	yes	< 5%	+/- 4%	+/- 4%	yes	< +/- 5%	< +/- 10%	< +/- 10%
Methane Number	+/- 3%	no	with gas composition values deducible through algorithm			yes	< +/- 15%	< +/- 15%	< +/- 20%
Air Fuel Ratio	2- 4%	yes	—	+/- 6%	+/- 6%	no	< 6%	—	—

The optical sensor will be **the solution** for further development and series production. It was possible to **predict gas components**, like Butane, Carbon Dioxide, Nitrogen and to calculate the Wobbe Index.

This on-board optical gas sensor will help also to increase the engine efficiency of **all CNG light duty vehicles**, through the possibility to set ignition timing for all gas qualities to maximum efficiency.

WP5 Final Result Part 2:

- Optical sensor module offers promising perspectives
- *Gas quality sensor enables a **predictive** engine control parameters optimisation*

Conclusion WP5

Pre-chamber ignition system allows very lean engine operation	√
Main engine operation in a very lean range of λ = 1.4 – 1.7	√
Engine efficiency up to 45% (with a 2.0L engine)	√
New CFD models incorporated into VECTIS	√
New gas quality sensor ready for further development	√

Thank You !