

Contents of Work Package 3-WP07 New ICE Combustion Concepts

3-WP07: New ICE Combustion Concepts

Coordinator of the WP

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Participants of the WP

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Main Goal of the WP

Development of the new ICE combustion concepts, for renewable liquid and gaseous e-fuels and development of a modular system for determining mechanical losses ICE by motoring

Partial Goals for the Current Period

Develop functional samples + improve optimization tools.

Contents of Work Package 3-WP07 New ICE Combustion Concepts

Official 3-WP07 Deliverables:

- 3-WP07-001: **Advanced ICE with renewable liquid fuels compatibility and high power density**, Gfunk, VI./2026, ŠKODA AUTO 0.5, CTU 0.5
- 3-WP07-002: **Low/zero carbon fuels combustion system**, Gfunk, VI./2025, CTU 0.5; ŠKODA AUTO 0.5
- 3-WP07-003: **Report on Milestones - Advanced combustion concepts and renewable fuels**, O, XII./2025, CTU 1.0
- 3-WP07-004: **Active pre-chamber optimized for multi-fuel operation**, G-funk, VI./2026, VaT 0.5; CTU 0.5
- 3-WP07-005: **Report on Milestones - Active pre-chamber for multi-fuel operation**, O, VI./2026, CTU 1.0
- 3-WP07-006: **Modular system for determining mechanical losses ICE by motoring**, G-funk, VI./2026, TUL FME 0.9 ; Skoda Auto 0.1

Activities in 3-WP07 New ICE Combustion Concepts

3-WP07-001: Advanced ICE with renewable liquid fuels compatibility and high power density , Gfunk, VI./2026, ŠKODA AUTO 0.5, CTU 0.5

Upgrade of a renewable liquid fuels conditioning system
Single cylinder test cell modification for ammonia experiments

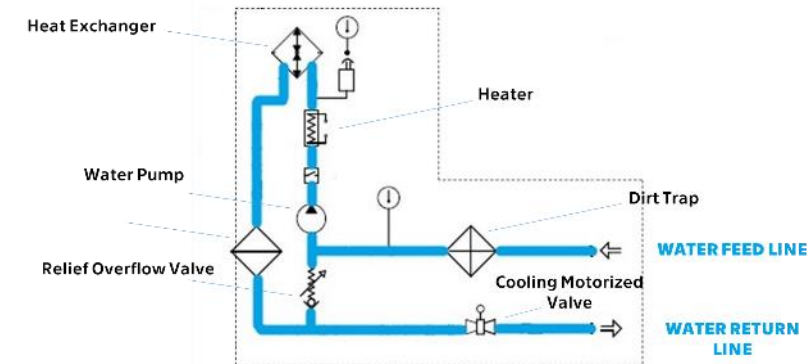
Toxic gas – safety measures (25 – 30ppm save limit, smell around 5ppm)

New types of exhaust emissions NH₃, N₂O – possible detection with FTIR

Gas cylinder – pressure regulator (heated) – flow meter

First step - acquisition of first data with engine without modifications

The Fuel Conditioning System



Fuel pipes isolation



Activities in 3-WP07 New ICE Combustion Concepts

3-WP07-002: Low/zero carbon fuels combustion system, Gfunk, VI./2025, CTU 0.5; ŠKODA AUTO 0.5

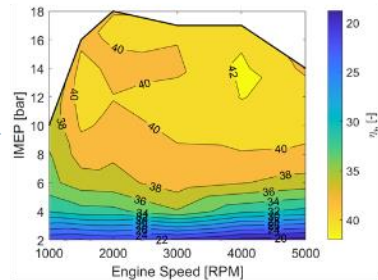
SCE H2 SI combustion full performance map measurement

Virtual MCE + driving cycle simulation = driving cycle fuel consumption and emissions estimation

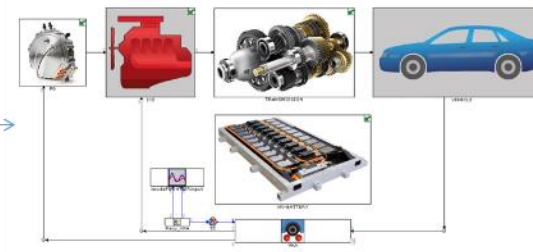
Experimental data



Equivalent 4-cyl engine



Quasi-steady WLTC simulation



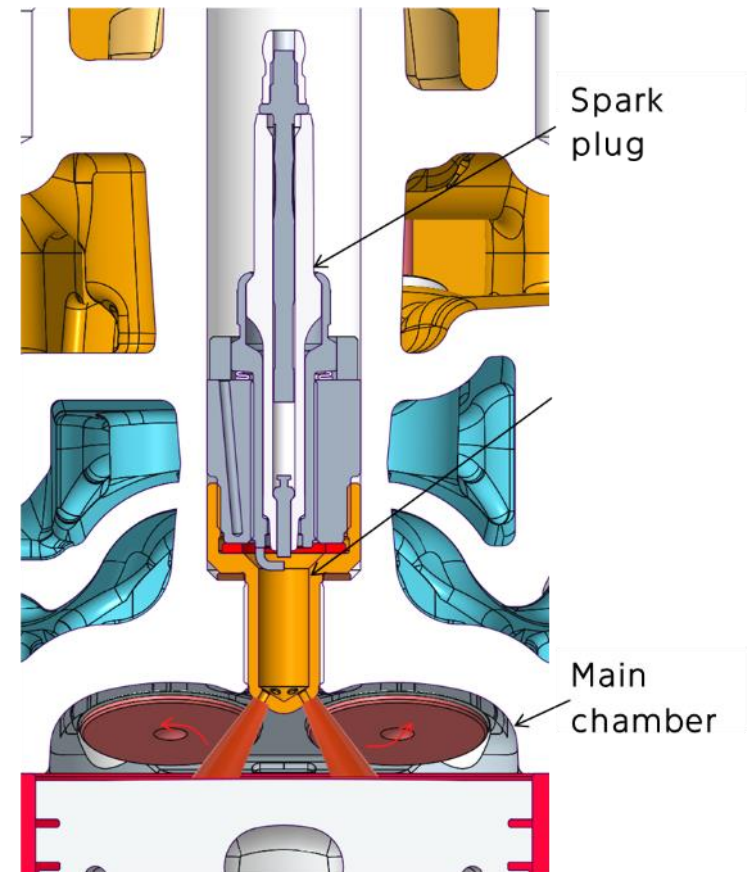
Vehicle class	H2 consumption [kg/100km]	Energy consumption [kWh/100km]	Gasoline equivalent consumption [l/100km]
C segment	1.14	38	4.3
D segment	1.22	40.7	4.6
SUV	1.38	46	5.2
Van	1.68	56	6.4

Activities in 3-WP07 New ICE Combustion Concepts

3-WP07-002: Low/zero carbon fuels combustion system

Prechamber

- Two sub-volumes
- Fraction of A/F mixture ignited in Prechamber
 - $\Delta p \Rightarrow$ jets protruding to cylinder
 - Rapid combustion
- Low Temperature Combustion?
 - Lowering through dilution
 - Lean limit of SP
 - Fuel scavenging
- **H2??**

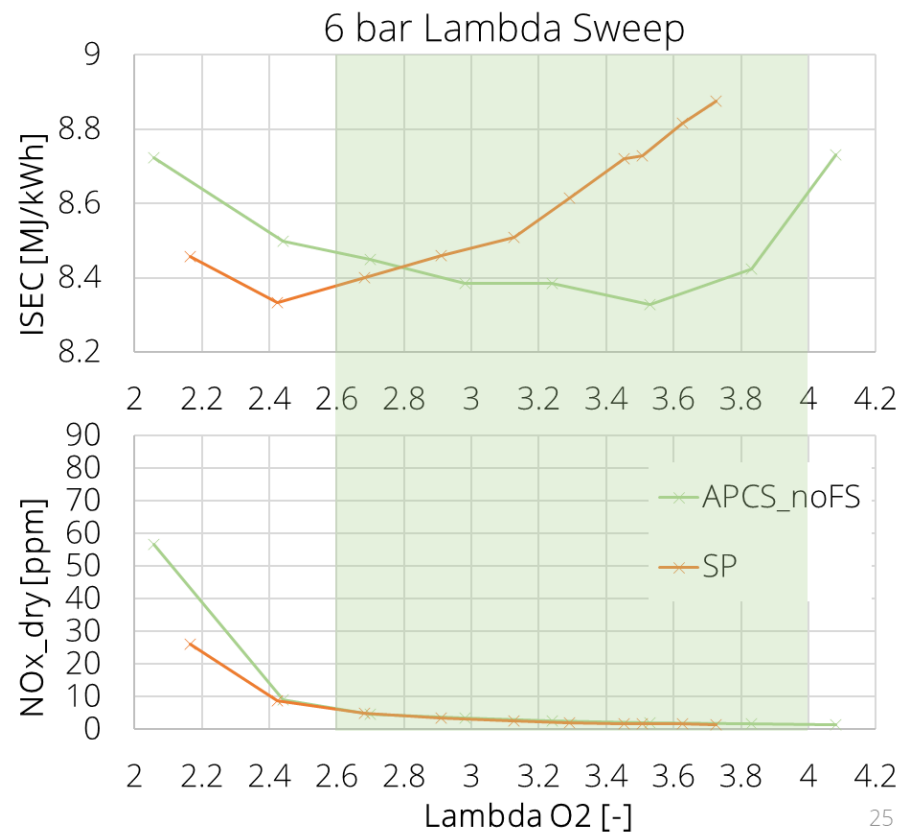


Activities in 3-WP07 New ICE Combustion Concepts

3-WP07-002: Low/zero carbon fuels combustion system

Application of pre-chamber to accelerate LTC and efficiency enhancement

- $\lambda > 2.4 \Rightarrow \text{NO}_x \text{ [ppm]} < 10$
- SP
 - best ISEC @ $\lambda = 2.4$
 - \Rightarrow Single *best* operation point @ $\lambda = 2.4$
- APCS
 - Good ISEC upto $\lambda = 3.8$
 - \Rightarrow wider operation range $\lambda = 2.4 - 3.8$

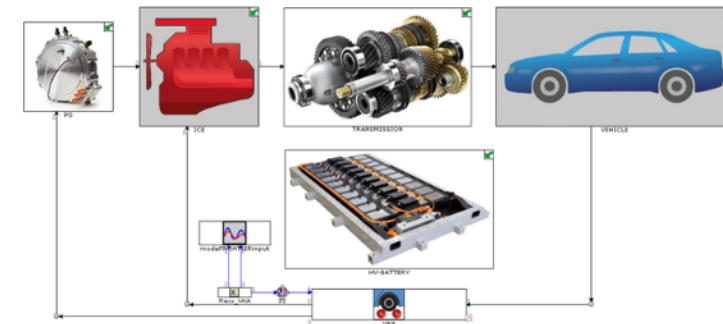


Activities in 3-WP07: New ICE Combustion Concepts

3-WP07-002: Low/zero carbon fuels combustion system

Drive cycle simulation

- Rerunning drive cycle simulation from [1] with **new maps**



- Fuel consumption improvement for a C-Segment vehicle

	H2 consumption [kg/km]	Relative improvement
C segment	1.12	1%

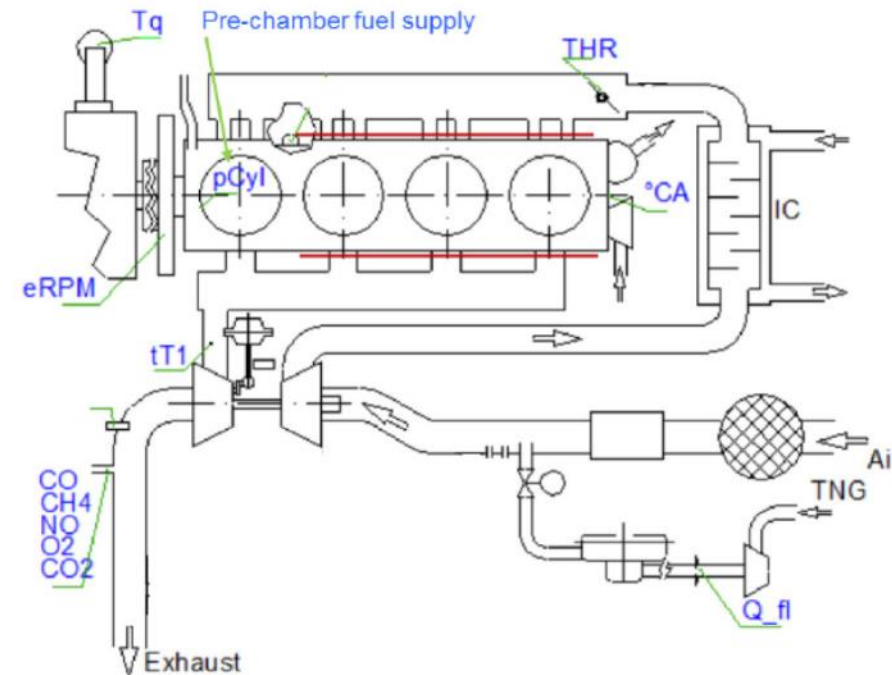
- Low loads ~20% of cycle but only 11% of fuel consumption

Activities in 3-WP07: : New ICE Combustion Concepts

3-WP07-004+005: Active pre-chamber optimized for multi-fuel operation:

- Test engine:
 - 4-cylinder 4-stroke natural gas engine
 - engine was converted to a single-cylinder configuration

Engine Parameter	Unit	Value
Bore	mm	102
Stroke	mm	120
Compression Ratio	-	12
Number of Valves per cylinder	-	4
Fuel		Methane
Fuel Injection		PFI + pre-chamber

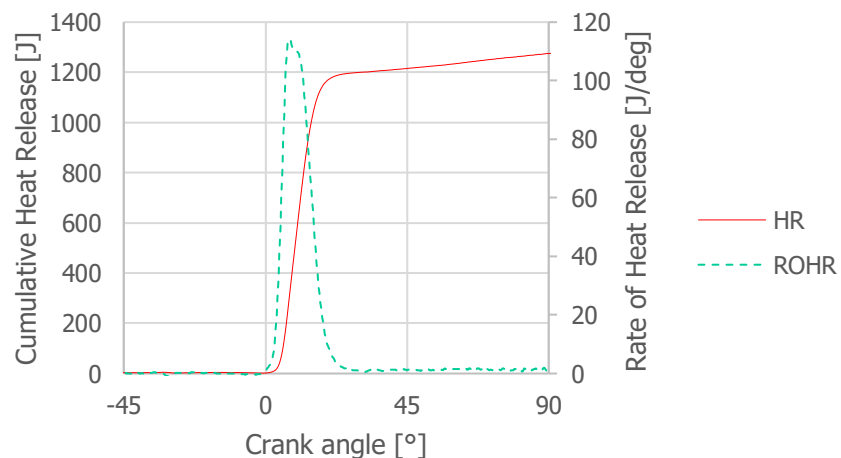


Activities in 3-WP07: : New ICE Combustion Concepts

3-WP07-004: Active pre-chamber optimized for multi-fuel operation

- Functional sample
 - pre-chamber with fully variable fuel flow and air flow
 - modular design enables replacement of bottom part (volume and design of connecting channels can be changed)
 - last version operates without bigger issues

$\lambda = 1,61$, $\alpha_{50} = 10^\circ$ aTDC, IMEP = 5,4 bar, 1200 rpm

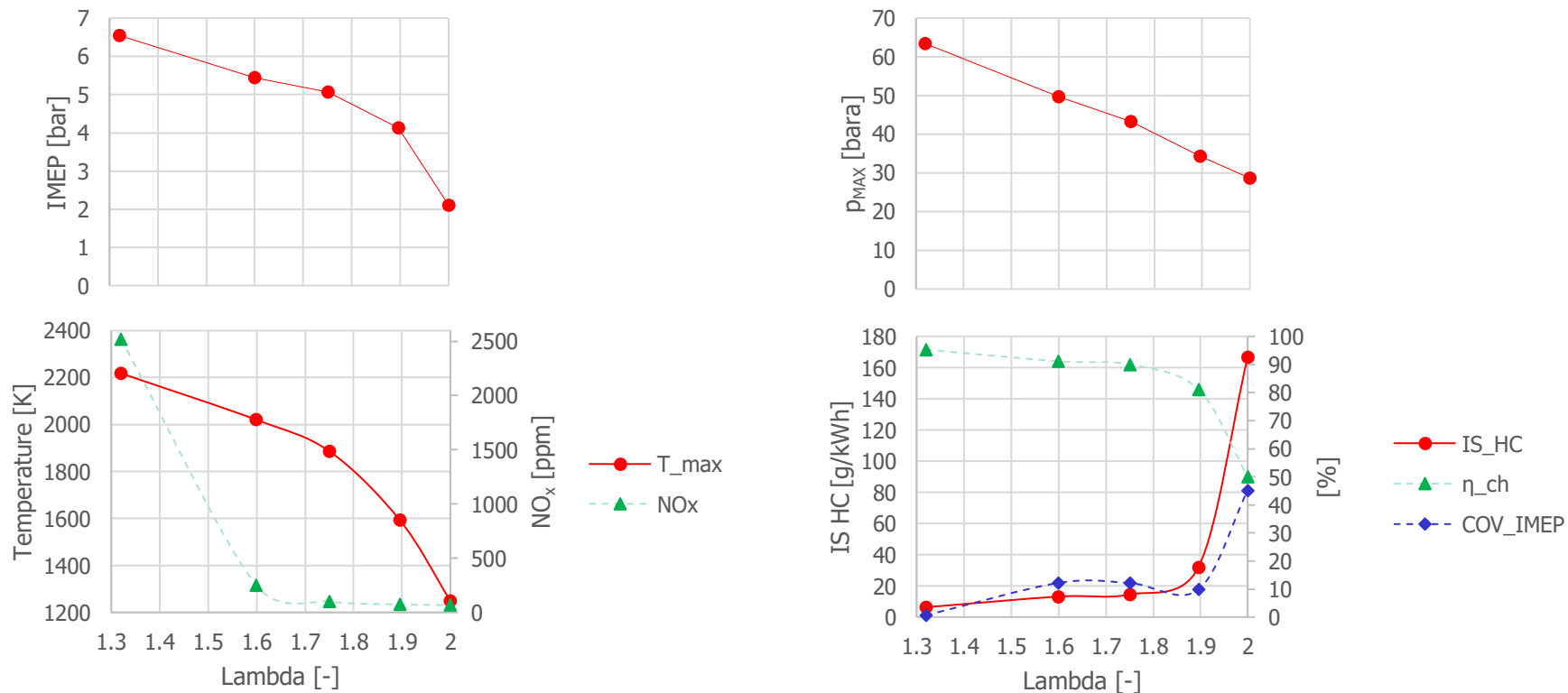


Activities in 3-WP07: : New ICE Combustion Concepts

3-WP07-004: Active pre-chamber optimized for multi-fuel operation

- Measured data

$\alpha_{50} = 0 - 12^\circ$ aTDC, 1200 rpm

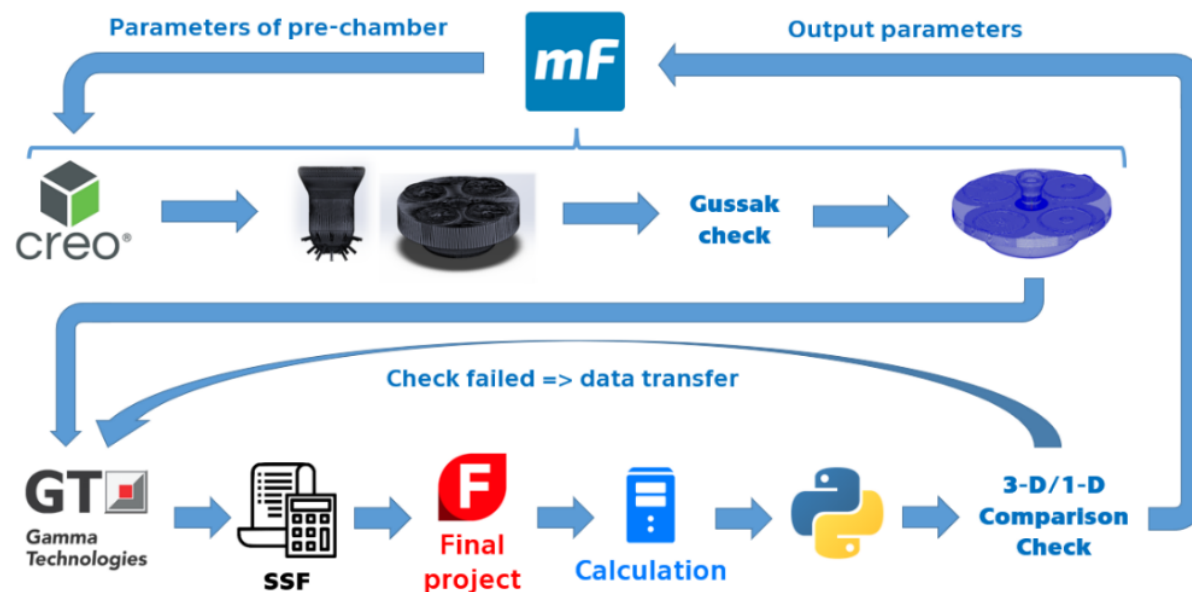


Activities in 3-WP07: New ICE Combustion Concepts

3-WP07-005: Report on Milestones - Active pre-chamber for multi-fuel operation

3-D CFD optimization tool:

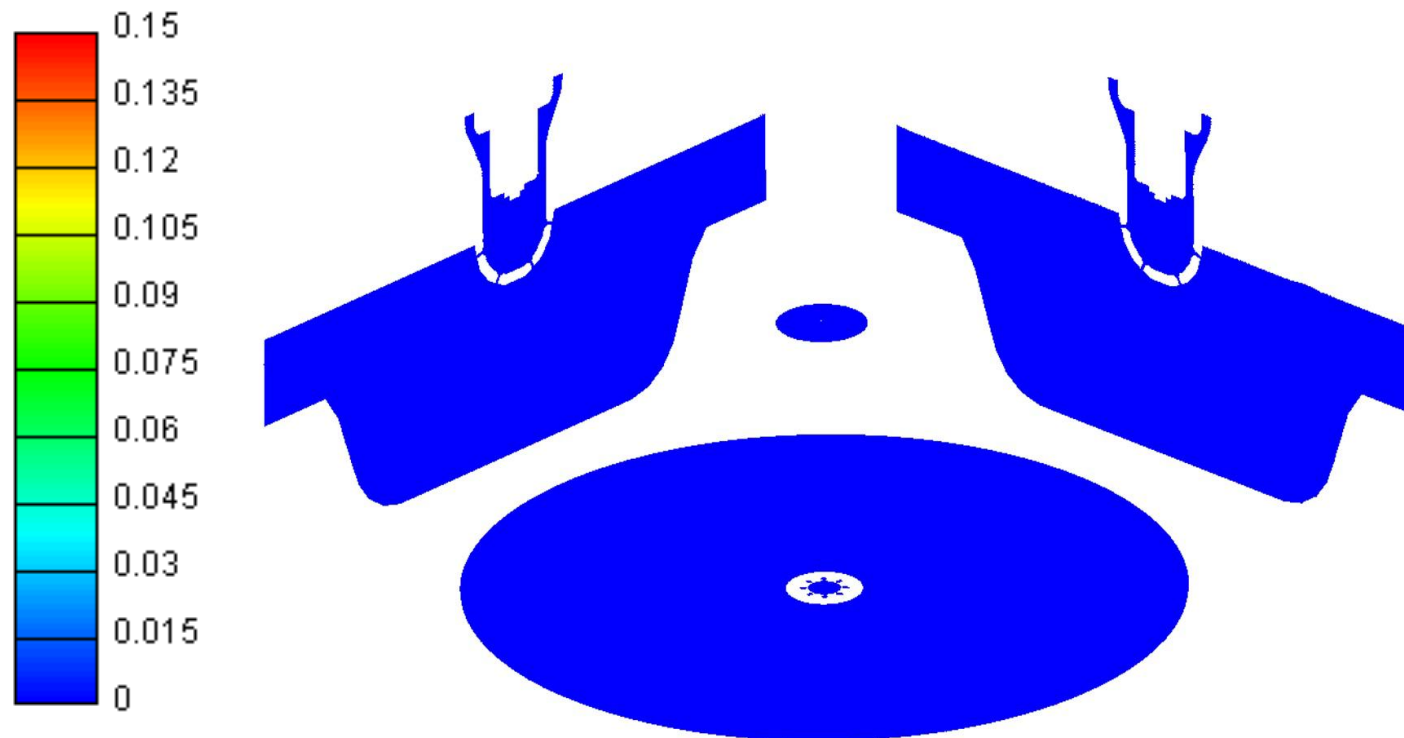
- combines 1-D and 3-D CFD approach
- tool enables:
 - automatic model calibration
 - optimization of pre-chamber geometric parameters (size/amount of connecting channels, fuel injector position/direction, spark plug position etc.) and simulation setup (ignition timing, air/fuel inlet pressure etc.)



Activities in 3-WP07: New ICE Combustion Concepts

3-WP07-005: Report on Milestones - Active pre-chamber for multi-fuel operation

Results: 3-D CFD optimization



CO₂ mass fraction

Fulfillment of goals and deliverables of 3-WP07: New ICE Combustion Concepts

Current State of Deliverables and Fulfillment of Goals


- 3-WP07-001: Advanced ICE with renewable liquid fuels compatibility and high power density
 - Renewable liquid fuels conditioning system
 - Single cylinder test cell modification for ammonia experiments
- 3-WP07-002: Low/zero carbon fuels combustion system
 - Next steps – EGR dilution study H2 combustion
 - Preparation for MCE experiments – laboratory H2 infrastructure upgrade in progress
- 3-WP07-003 | Report on Milestones - Advanced combustion concepts and renewable fuels,
 - published one journal paper and two conference papers
- 3-WP07-004 | Active pre-chamber optimized for multi-fuel operation
 - A functional sample of 'manually' optimized variant (previous NCK) was produced and tested.
 - The results are promising:
 - Engine equipped with pre-chamber operates without bigger issues.
 - Combustion was significantly accelerated.
 - Flammability limits were considerably extended.
- 3-WP07-005 | Report on Milestones - Active pre-chamber for multi-fuel operation
 - The 3-D CFD optimization tool has been developed into a usable version.

Activities in 3-WP07 in progress & no major delays:


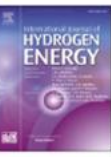
Fulfillment of goals and deliverables of 3-WP07: New ICE Combustion Concepts

Results dissemination:

- Rudolf, J., Vitek, O. 3-D CFD OPTIMIZATION OF PRE-CHAMBER IGNITION SYSTEM. 54th international scientific conference of Czech and Slovak universities and institutions focused on research and teaching methods related to ICEs, alternative powertrains and transport. Hustopeče, VUT v Brně, 2023. ISBN 978-80-214-6164-2.
- Kyjovský, Š., Vávra, J., Bortel, I., Toman, R., 2023, Drive cycle simulation of light duty mild hybrid vehicles powered by hydrogen engine, International Journal of Hydrogen Energy, <https://doi.org/10.1016/j.ijhydene.2023.01.137>.
- Kyjovský Š., Vávra, J., Driving cycle simulation of hybrid passenger cars powered with hydrogen engine, ISBN 978-80-907264-5-1 Hydrogen Days 2023 Book of Abstracts, Prague 2023.
- Kyjovský, Š., Vávra, J., EFFECT OF PRECHAMBER ON LOW LOAD EFFICIENCY OF HYDROGEN COMBUSTION ENGINE, 54th International Scientific Conference of Czech and Slovak Universities and Institutions Focused on Research and Teaching Methods Related to Internal Combustion Engines, Alternative Powertrains, and Transport September 6th–8th, 2023, Hustopeče, Czech Republic.



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Drive cycle simulation of light duty mild hybrid vehicles powered by hydrogen engine

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HIGHLIGHTS

- Experimental H₂ engine data used for drive cycle simulation of mild hybrid vehicles.
- Peak power 80 kW @ 4000 RPM was achieved with 1.5l turbocharged hydrogen engine.
- Peak efficiency (BTE) of 42% is obtained, with 38% in most of the engine map.
- Very low NO_x emissions of 0.1 g/kWh were observed in most of the operating range.
- Drive cycle simulation consumption of 1.1kgH₂/100 km and 0.02gNO_x/km in WLTC.

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ABSTRACT

In the ongoing efforts to reduce CO₂ and pollutant emissions, hydrogen combustion engine can provide immediately available mature technology for carbon-free transportation. Hydrogen combustion does not produce on-site CO₂ emissions, the principal pollutant is NO_x (which can be minimized using appropriate combustion control and aftertreatment), and the available ICE technology can be readily modified to accommodate for hydrogen use. The paper provides a prediction of the performance of a hydrogen combustion engine in passenger vehicles, aiming at extending or updating the available research with the current powertrain trends, namely downsizing, turbocharging, and hybridization. Data gathered from a single-cylinder engine fueled by a lean hydrogen mixture are used as input into a mild hybrid vehicle model, which is used for quasi-static drive cycle simulations. The results show NO_x emission around the EURO VI limit without the use of any after-treatment and fuel consumption as low as 1.1 kgH₂/100 km in WLTC.
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Fulfillment of goals and deliverables of 3-WP07: New ICE Combustion Concepts

List of Due Deliverables and Their Added Value

- **3-WP07-001 ... 005** – deeper inside into pre-chamber combustion process and its application to automotive SI ICEs, close cooperation with industrial partners (ŠKODA AUTO a.s., VarioTec).

Assessment of the Contribution of Deliverables

- Unconventional combustion modes – 3-WP07-01, 02.
- Automated design & optimization – 3-WP05, 4-WP02.
- Complex 3-D CFD simulations (including coupled ones with 0-D/1-D CFD codes) – 3-WP05.

Activities in 3-WP07: New ICE Combustion Concepts

3-WP07-006: Modular system for determining mechanical losses ICE by motoring

The modular installation:

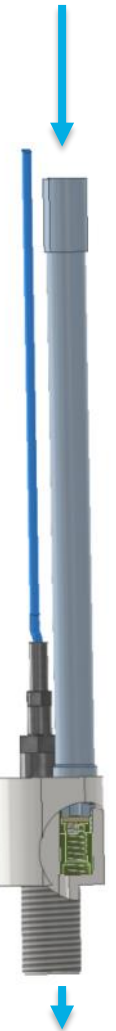
- identify mechanical losses ICE by motoring with the working pressure in-cylinder and engine operation temperature as in real operation with combustion
- universal use in engine test benches with a pallet system
- circuit heating/cooling of the engine operating fluids (lubricating oil, cooling fluid) to ensure that the temperatures agree with the real operation.
- circuit supply of compressed air to self-acting one-way valves in multifunction screws with control of the working pressure in-cylinder as in real engine operation

Methods:

- combination of experiments and simulations

Results:

- faster verification of the power unit's properties during the development process
- cost savings for the industrial partner
- more accurate method in terms of actual engine load than the current commonly used methods

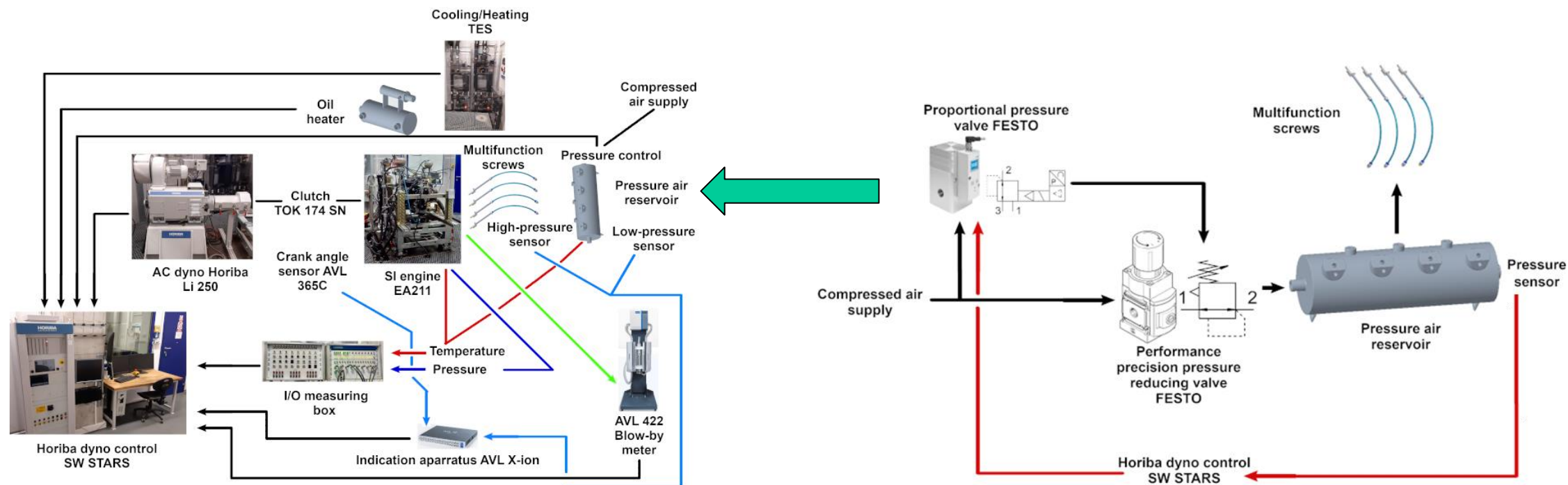


Activities in 3-WP07: New ICE Combustion Concepts

3-WP07-006: Modular system for determining mechanical losses ICE by motoring

Experiment

- Complete diagram of the experiment with the modular system for determining mechanical losses ICE by motoring and pressure circuit including all components.

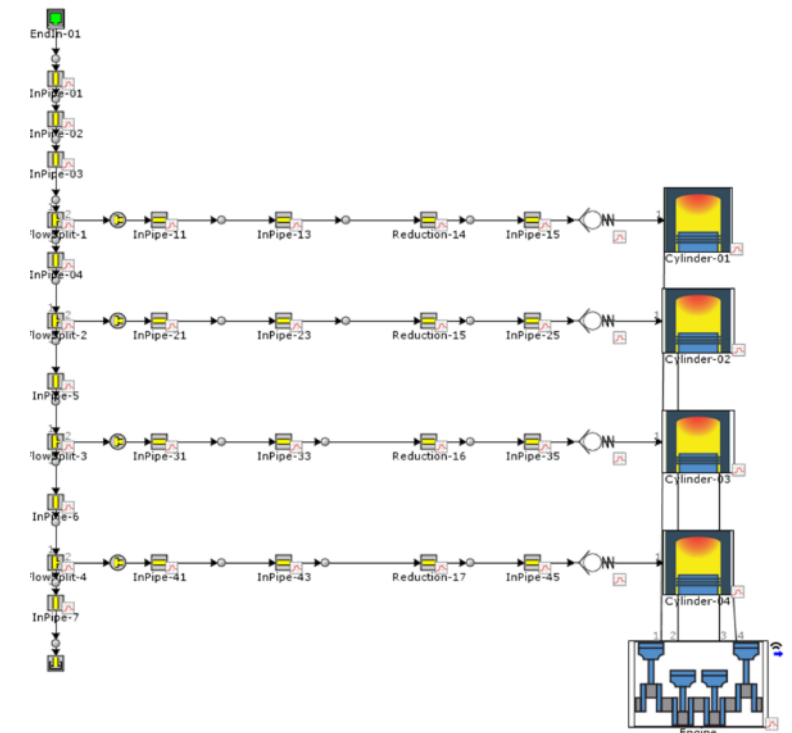
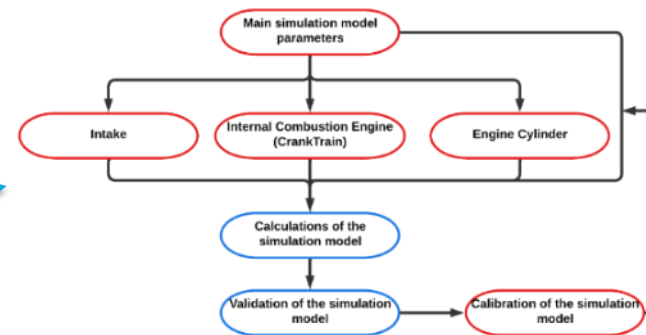
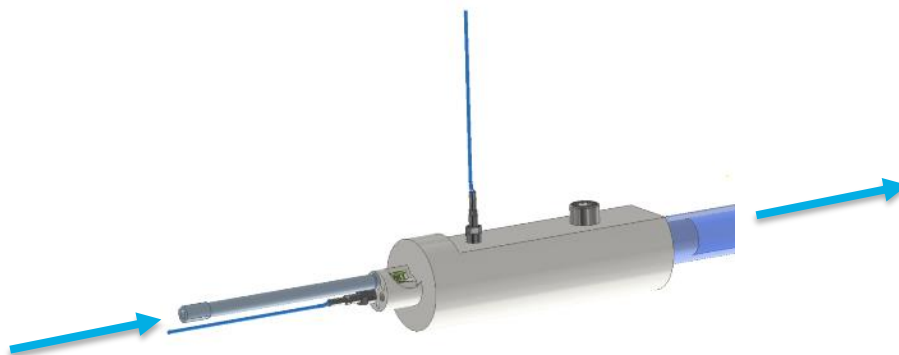


Activities in 3-WP07: New ICE Combustion Concepts

3-WP07-006: Modular system for determining mechanical losses ICE by motoring

Simulation

- creating a complete mathematical model of the SI engine in GT-Suite software for determining mechanical losses by ICE motoring
- calibration and validation of the simulation model by experimental data (indication in cylinders and intake, torque, blow-by, temperatures and pressures), 3D CAD data and construction parameters of the engine.



Activities in 3-WP07: New ICE Combustion Concepts

List of Due Deliverables and Their Added Value

- **3-WP07-006** - deeper inside into identifying mechanical losses of future automotive applications. Close cooperation with industrial partner (Skoda Auto) – both funded R&D projects and commercial ones.

Assessment of the Contribution of Deliverables

- Simulation of ICE - (4-WP08-003)

Activities in 3-WP07: New ICE Combustion Concepts

Current State of Deliverables and Fulfillment of Goals

- 3-WP07-006 | Modular system for determining mechanical losses ICE by motoring. G-funk, VI./2026, TUL FME 0,9; Skoda Auto 0,1 – **in progress & no major delays:**
 - Design work, selecting and purchasing suitable components for the pneumatic/heating/cooling circuit, and production work are in progress.
 - System setup/programming in the test cell is in progress.
 - A simulation model is being prepared and will be verified by experiment.

Current contribution of 3-WP07: New ICE Combustion Concepts

Assessment of the Formal/Administrative Goals of the Work Package

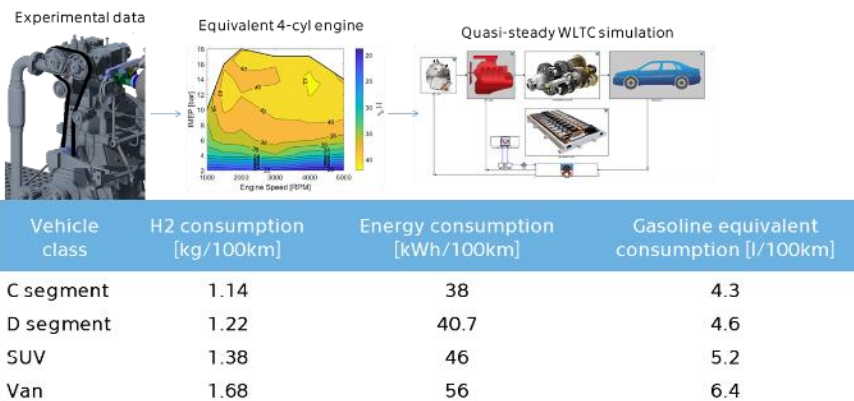
All formal and administrative requirements are expected to be fulfilled.

Acknowledgment

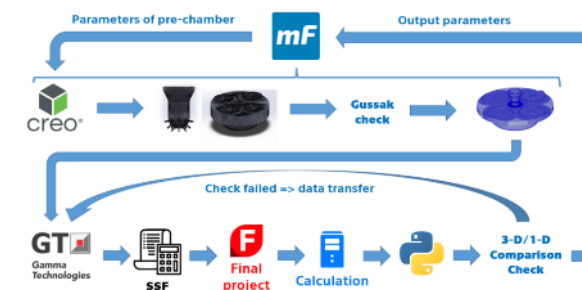
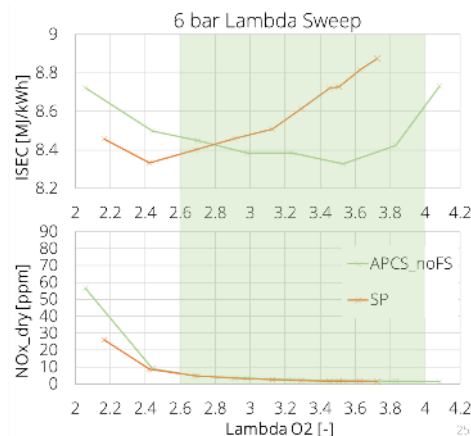
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Results of 3-WP07: New ICE Combustion Concepts – achieved 2023

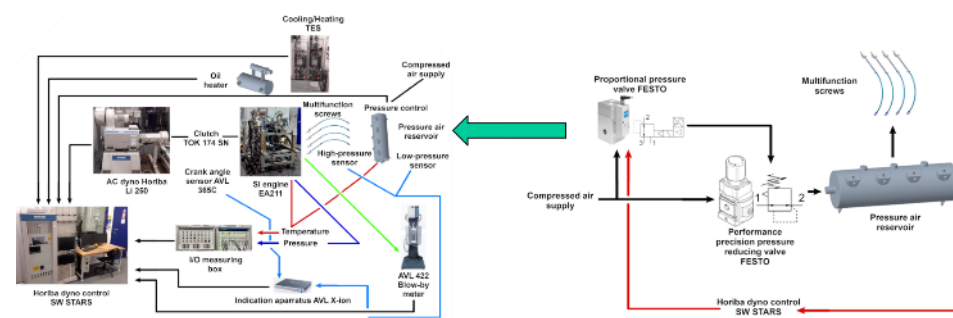
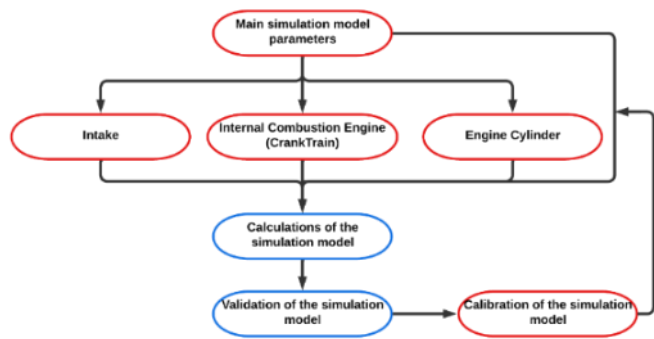
3-WP07-002: Low/zero carbon fuels combustion system



3-WP07-004 - 005 Active pre-chamber optimized for multi-fuel operation

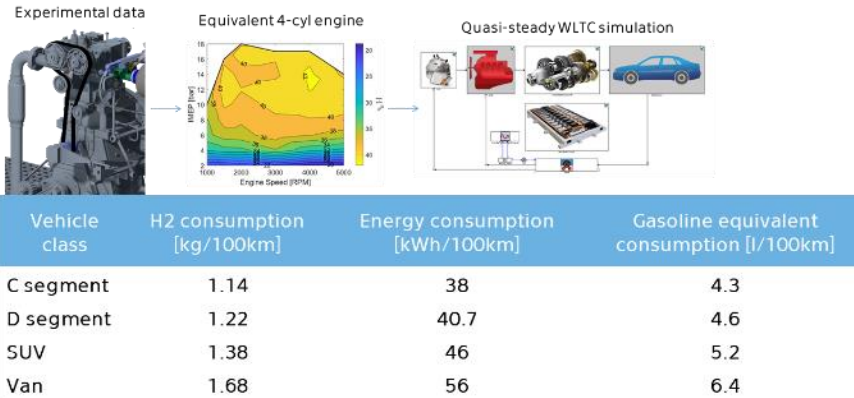


3-WP07-006: Modular system for determining mechanical losses ICE by motoring - simulations and experiments

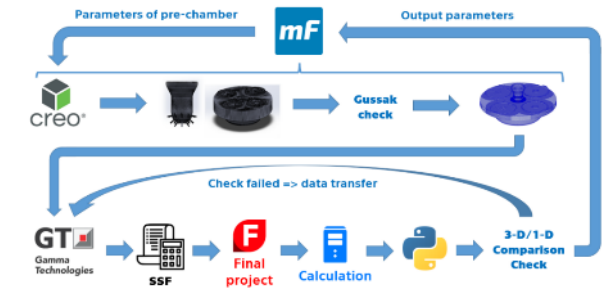
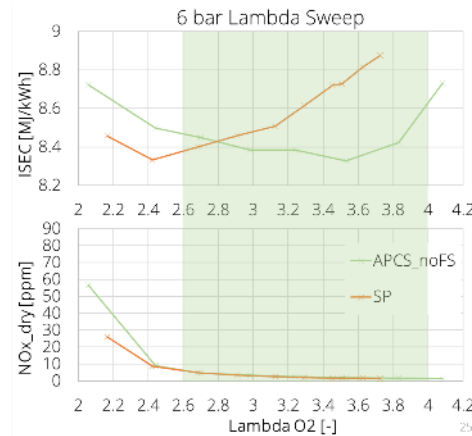


Results of 3-WP07: New ICE Combustion Concepts - achieved 2023-2025

3-WP07-002: Low/zero carbon fuels combustion system



3-WP07-004 - 005 Active pre-chamber optimized for multi-fuel operation



3-WP07-006: Modular system for determining mechanical losses ICE by motoring - simulations and experiments

