NEWSLETTER

July 2025 | No. 2

FLEX4H2 – Flexibility for Hydrogen

FLEX4H2's goal is to support European ambitious climate targets towards carbon-free fuels. It aims to develop a fuel-flexible combustion system and thus contribute to the EU's pathways towards decarbonisation of the electric power sector.

In this issue

Dear readers,

Our FLEX2H2 project celebrated its second anniversary at the end of 2024, we published our first Newsletter already one year ago, and therefore, we are happy to share with you the important progress we made since last summer.

In September 2024, the project had its first Review Meeting with our EU Project Officer and two external reviewers. We received significant credit for remarkable scientific progress, impeccable project management, and efficient communication & dissemination efforts.

We have a lot to share in this Newsletter; however, it is our technical progress that makes us particularly proud:

The first combustion system development loop set a solid basis for the second one, further boosting the performance of the sequential combustion system. Next to this, small-scale high-pressure experiments at the DLR's optically accessible rig were performed.

At the same time, significant effort was dedicated to the numerical model validation based on the experimental data from full-size testing of the CPSC combustor.

The thermoacoustics team developed experiments with diagnostics, numerical simulations, and low order network models to predict stability margins.

Have a good pre-holiday read and let us know if you have any questions – we are always happy to hear from you.

We wish you a nice summer!

FLEX4H2 team

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Project progress

WP1 (Combustion system development and refinement) & WP4 (Testing and demonstration at TRL6)

Based on the successful outcome of the first development loop (Gen1 could demonstrate the full sequential combustion system to operate from 0 to 100% H2), the second development loop (Gen2) leveraged the acquired experience to further boost the performance of the sequential combustion system.

The new design features

- optimised injectors for faster hydrogen mixing,
- improved mixing sections to reduce hot spots at the burner exit, and
- thermoacoustic damping devices with broad coverage.

All measures are devoted to a broader operating window and higher firing temperatures.

Also, the cooling features of the new prototypes were further revisited and improved to optimise air management and reduce flashback risks, specifically adding effusion air at the burner exit vicinity.

In parallel with the second development loop, small-scale high-pressure experiments were done to validate and improve the numerical models as well as to optimise the operation of the sequential combustion system.

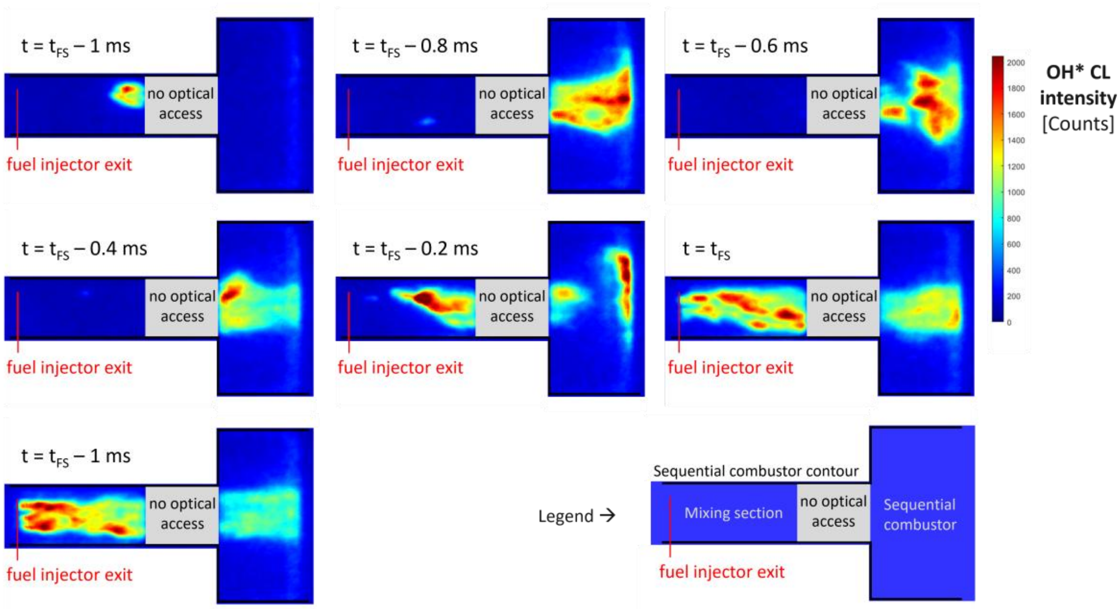
Thanks to the excellent optical access of the DLR high-pressure combustor rig, the combustion phenomena could have been analysed in great detail not only with conventional measurement methods, but also with non-intrusive sophisticated optical diagnostics.

In the FLEX4H2 measurement campaign, an extensive variation of the key sequential combustor operating parameters such as inlet temperature, pressure, velocity, and equivalence ratio were performed, focusing on the characterisation of auto-ignition stabilised flames. The position and the shape of the heat release zone (flame zone) were measured with OH^*Chemiluminescence (CL). In order to investigate extremely fast phenomena such as spontaneous ignition and flashback, OH^*-CL High-speed imaging with a recording rate of 5000 Hz (5000 images per second) was applied.

The achieved results show the typical features of a reheat flame. Flame stabilisation in the sequential combustor is almost insensitive to a variation of flame temperature but is very sensitive to a change in combustor inlet temperature, corroborating the overall advantage of sequential combustion for a wide variety of fuels, including hydrogen.

A stable flame was achieved for a wide range of sequential combustor operating conditions. At very high inlet temperatures, flashback and flame stabilisation at the fuel injector have been observed, providing significant input to the future development steps.

The generated results will serve as an excellent database for the validation of the models used in the numerical simulations within the project.



Sequence of OH^*-CL images extracted from the high-speed video illustrating the extremely fast nature of spontaneous ignition ($t = t_{FS}$-1 ms) and flashback. At $t = t_{FS}$ the flame stabilises at the fuel injector exit due to a flashback event.

(FS = Flame Stabilisation)

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Project progress (contd.)

WP2 (Numerical modelling)

Advanced & high-resolution numerical simulations of the combustion process taking place in gas turbines combustors, if proven consistently accurate, can potentially shorten the combustion system development loop, making it significantly less costly. Typically, the introduction of new design features, such as

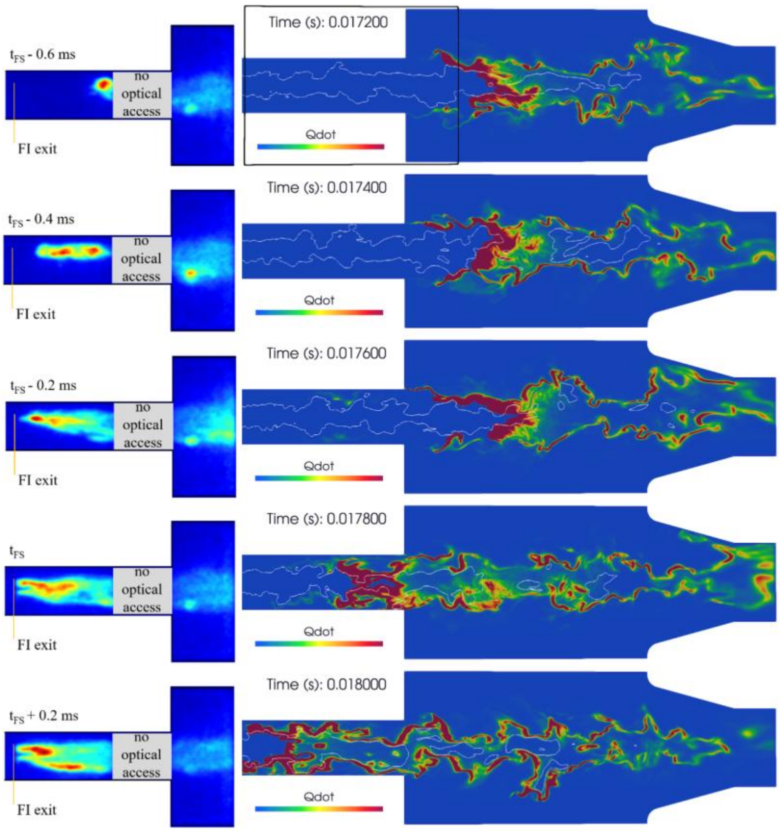
- optimised fuel injectors for faster and more uniform hydrogen mixing with the oxidiser, or
- modifications to the aerodynamics of the flow in the burner to improve flame stabilisation,

are first tested numerically to obtain a preliminary assessment of their performance and expected improvements. However, this reliance on numerical simulations requires the ability of the numerical model to accurately capture trends, at least qualitatively if not quantitatively, in the operation of the combustion system.

Accordingly, a significant portion of FLEX4H2's Work Package 2 (WP2) research has been devoted to the validation of the numerical model. These validation efforts have relied, more broadly, on a limited amount of experimental data from full-size testing of the Constant Pressure Sequential Combustor (CPSC) and, more specifically, on dedicated lab-scale experiments with optical access to the flame (WP4).

Thanks to the excellent optical access of the DLR high-pressure combustor rig, the combustion process that controls flame stabilisation at the „reheat“ conditions present in the CPSC could have been analysed in great detail with non-intrusive sophisticated optical diagnostics.

Massively-parallel calculations, exploiting a Large-Eddy Simulation (LES) turbulence model and a Partially-Stirred Reactor (PaSR) turbulent combustion model, were performed on Norway's most powerful supercomputer Betzy. Results from the numerical simulations revealed that the combination of the LES-PaSR models, if used jointly with detailed chemical-reactions kinetics of hydrogen-air combustion, is able to correctly predict the experimentally-observed trends in the flame stabilisation response to changes in oxidant temperature or fuel composition. The figure below illustrates the flame response to an increase in the oxidiser temperature with a very fast transition from a „lifted“ premixed flame stabilised in the combustion chamber to an „attached“ non-premixed flame stabilised at the fuel injector. Moreover, the LES-PaSR results suggest that achieving quantitative agreement between numerical simulations and experiments is significantly more challenging. This requires a very accurate specification of the boundary conditions with an important sensitivity to the temperature and compositional variance of the oxidiser inlet.



Extremely fast transition between flame stabilised in the combustion chamber to flame attached at the fuel injector (from top to bottom). Comparison of high-speed imaging of the reheat hydrogen flame (OH* Chemiluminescence, on the left) with LES-PaSR results (heat release rate, on the right).

The black outline in the top right picture indicates the experimental measurement domain.

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Project progress (contd.)

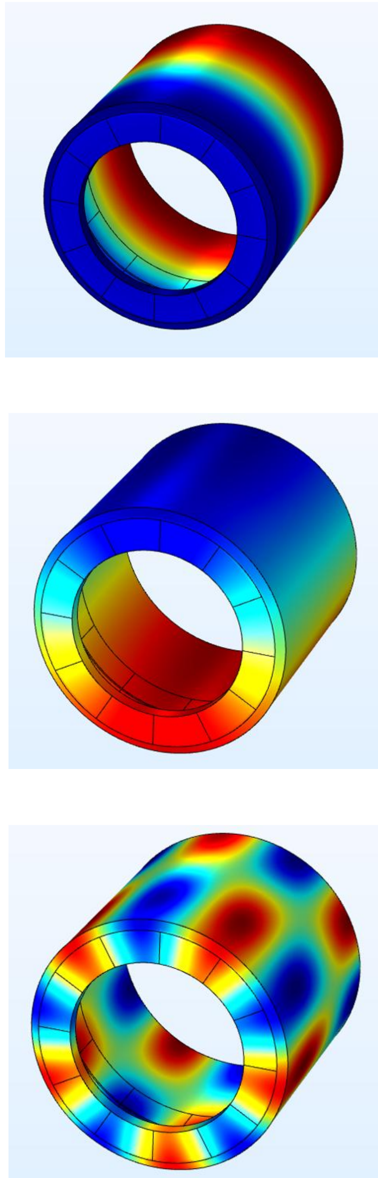
WP3 (Thermoacoustics)

Reliable operation of a gas turbine requires a solid understanding of how combustion dynamics interact with pressure fluctuations. Even minute perturbations in pressure can act as a seed for a rapidly growing instability, forcing the system away from its optimal operating point, causing reduced efficiency, increased emissions, and, in severe cases, mechanical fatigue or structural failure. This phenomenon becomes even more critical when the turbine is designed to burn hydrogen or hydrogen-rich fuels. Hydrogen's high flame speed and broad flammability limits make it inherently more sensitive to velocity and pressure perturbations than traditional hydrocarbon fuels.

Within thermoacoustics, one typically uses a combination of experimental diagnostics, numerical simulations, and low order network models (LOM) to predict stability margins. Over the last year, various LOMs have been proposed, adjusted, and tested with the goal of reproducing experimentally gathered data. They were composed of many subsystems described with a finite-element-method (FEM) approach resulting in a large degree of fitting parameters for the concatenated system. The obtained results were only partly satisfactorily and hence a new modelling approach has been chosen which puts a heavier reliance on the measured data rather.

By using different operating modes of the GT36 and its partial system, i.e., the "first-stage-only" (FSO) and "full-can-setup" (FCS) operating modes, the LOM can make use of different system boundaries, where FSO only includes the initial first stage flame and FCS both flames of the GT36's CPSC architecture.

With these system boundaries, a subsystem can be represented purely by its experimental data. In this case, the LOM's FSO subsystem can be represented just by its upstream-faced reflection coefficient at downstream location, i.e., how much of an upstream-travelling pressure wave is reflected downstream at the exit of the FSO. After validating this model's behaviour against the FCS's experimental data, the LOM can then be used to extract information regarding its stability, e.g., unstable eigenfrequencies, eigenmodes and their growth rates, a topic for FLEX4H2's next newsletter.



Visualisation of selected pressure mode shapes of one of the combustor's elements, calculated through FEM. Combination of multiple elements' mode shapes in a LOM can predict the thermoacoustic behaviour of the complete system.

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Interview with FLEX4H2 partner: Advancing hydrogen combustion for turbomachinery – Peter Griebel (German Aerospace Centre – DLR)

DLR recently finished the high-pressure scaled burner test campaign. What is the project role of DLR and what exactly was investigated in your test bench?

Peter Griebel, DLR

DLR has a long tradition in the development of hydrogen combustion. Due to the participation in EU funded projects like ENCAP and H2-IGCC, we were able to build a strong expertise in investigating hydrogen combustion phenomena at gas turbine (GT) relevant operating conditions with sophisticated laser diagnostics. In addition, DLR has been working closely with Ansaldo Energia, previously ALSTOM Power, since 2007 to support the development of sequential combustion technology (e.g. FUEL FLEX, H2-SEV projects).

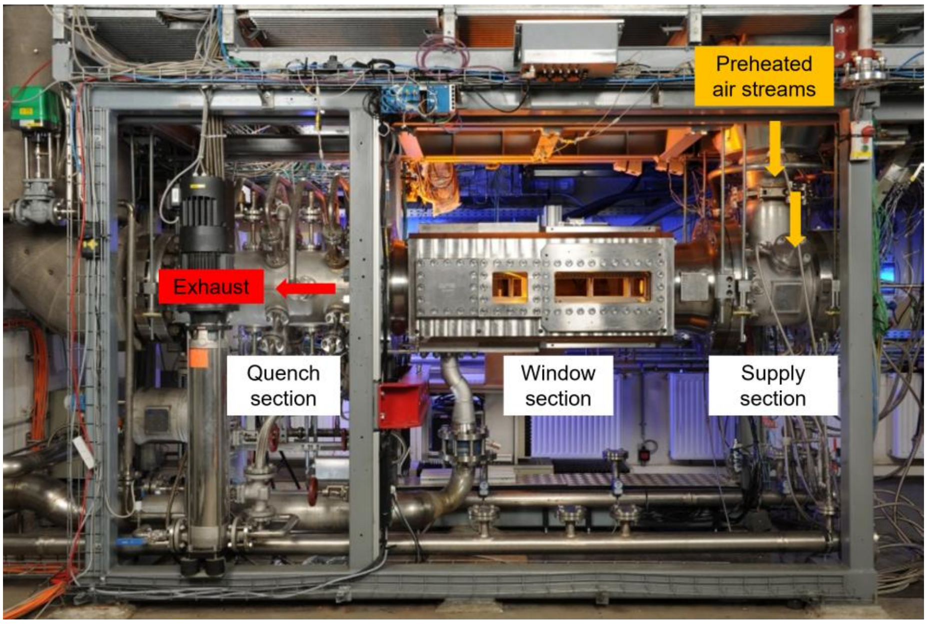
In FLEX4H2, DLR is performing high-pressure tests of a simplified sequential combustor geometry at GT relevant operating conditions in an optically accessible rig, providing experimental data for both numerical modelling validation and the optimisation of the engine operation concept. In the recently finished measurement campaign, spontaneous ignition and flashback behaviour have been studied at a wide range of sequential combustor operating conditions in our test bench HBK-S.

What are the key findings of the performed test?

In the FLEX4H2 measurement campaign, an extensive variation of the key sequential combustor operating parameters such as inlet temperature, pressure, velocity, and equivalence ratio were performed, focusing on the characterisation of auto-ignition stabilised flames. The position and the shape of the heat release zone (flame zone) were measured with OH^* Chemiluminescence (CL). In order to investigate extremely fast phenomena like spontaneous ignition and flashback, OH^*-CL high-speed imaging with a recording rate of 5000 Hz (5000 images per second) was applied.

The key findings are the following:

- A stable flame was achieved for a wide range of sequential combustor operating conditions.
- At very high inlet temperatures, flashback and flame stabilisation at the fuel injector have been observed.
- Significant input was provided to help the definition of the engine operating concept.
- The generated results will serve as an excellent data basis for the validation of the models used in the numerical simulations within the project.



Optically accessible high-pressure combustor rig (HBK-S) at the DLR institute of Combustion Technology

Continue reading the interview

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FLEX4H2 in the media

Our project appeared twice in the Gas Turbine World

The second article (published in October 2024) is a follow up of our first article from October 2023. It is entitled "*Ansaldo tests 100% hydrogen fuel using sequential combustion*" and provides an update on further development and testing of the modified design to safely operate on up to 100% hydrogen.

Read both articles here → Read more

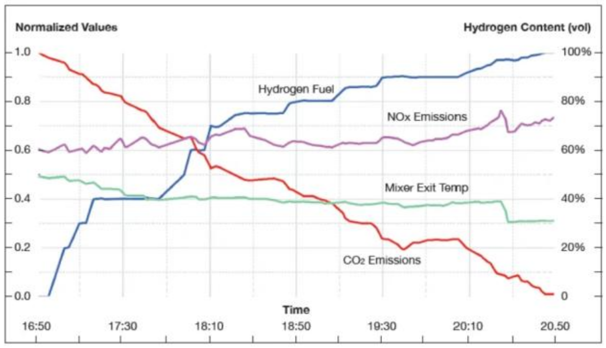
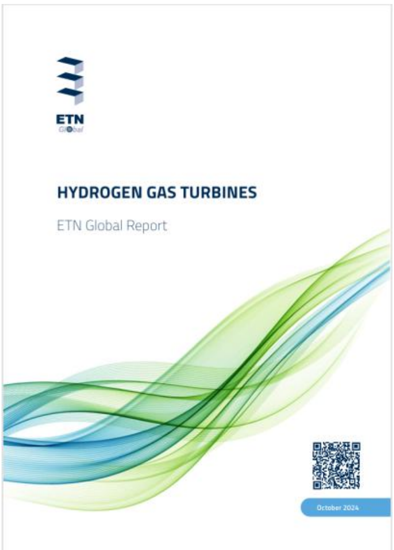


Figure 11. Overview of GT36 single can test run at full pressure conditions. The hydrogen fuel content (blue line and right Y-axis) was raised from zero to 100% over a 4-hour test period resulting in reduction of CO2 emissions to zero (red line). This was achieved through MET (green line) adjustments to compensate for high H2 reactivity. The NOx emissions (purple line) kept within project limits throughout via adaptation of the exit temperature. All measurement values, except H2 concentration, are "normalized" and show changes only.



FLEX4H2 in the ETN Global Hydrogen Gas Turbines Report (2024 edition)

This report was part of the activities undertaken by ETN Global's Hydrogen and other alternative fuel Working Group. Ansaldo Energia, who was one of the main contributors, has a dedicated page featuring the FLEX4H2 project.

Download the whole report here → Read more

Our scientific papers

Numerical Investigation of Reheat Hydrogen Flames in the Sequential-combustion Stage of a Heavy-duty Gas Turbine

- With authors from SINTEF Energy Research and Ansaldo Energia
- Presented at ASME Turbo Expo in June 2024 (London, UK)

Development and validation of a framework to predict the linear stability of transverse thermoacoustic modes of a reheat combustor

- Authored by ZHAW
- Published in the Combustion and Flame journal in May 2025

LES of Hydrogen-Fuelled Combustion in the First Stage of the Ansaldo Energia GT36 Constant Pressure Sequential Combustion System

- With authors from CERFACS and Ansaldo Energia
- Presented at ASME Turbo Expo in June 2025 (Memphis, US)

Linear Stability Analysis of Transversal Thermoacoustic Modes in Reheat Combustors

- With authors from ZHAW and Ansaldo Energia
- Presented at ASME Turbo Expo in June 2025 (Memphis, US)

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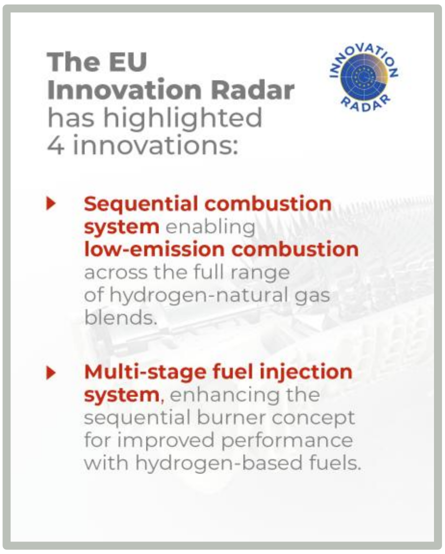
FLEX4H2's major achievement – Key Innovator

As a part of the EU Innovation Radar, our coordinator Ansaldo Energia received a prestigious recognition from the EU for its contribution to sustainable development. Specifically, this recognition refers to 4 innovations:

- Sequential combustion system enabling low-emission combustion across the full range of hydrogen-natural gas blends
- Multi-stage fuel injection system, enhancing the sequential burner concept for improved performance with hydrogen-based fuels
- Integration of instrumentation into the additive manufacturing process for precise hydrogen burner characterisation
- Advanced cooling features in the burner mixing section to prevent hydrogen boundary layer flashback

Read more about our innovations → Read more



FLEX4H2 on the stage

- ETN Global's October Workshop (8-10 October 2024, Stuttgart, DE) – project expo
- ETN Global's AGM & Workshop (25-27 March 2025, Bergen, NO) – panel session on EU-funded projects, project expo
- Workshop between the Clean Hydrogen Partnership and the New Energy and Industrial Technology Development Organisation – NEDO (26 March 2025, Kobe, JP) – workshop participation (Ansaldo Energia, SINTEF)
- vgbe Gas Turbines 2025 (4-5 June 2025, Wesel, DE) – project presentation "FLEX4H2 – 100% hydrogen with sequential combustion"
- ASME Turbo Expo 2025 (16-20 June 2025, Memphis, US) – presentation of two project papers, sessions chairing, panel participation, and expo in the ETN Global booth

FLEX4H2 project partners in the ETN booth at the ASME Turbo Expo. From left to right: Simon Heinzmann (ZHAW), Christian Fleing (DLR), Douglas Pennel (Ansaldo Energia), Oliver Paschereit (not a project partner), Andrea Ciani (Ansaldo Energia), Aldo Schioppa (CERFACS), Luis Tay Wo Chong (Ansaldo Energia), Giuseppe Tilocca (ETN Global)

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Communication highlights & updates

- Project website 🌏: www.flex4h2.eu
- Updated leaflet, poster, roll-up, and the public presentation are available online 🪧
- All the scientific papers, articles, as well as public documentation are saved in the Zenodo repository 📁
- FLEX4H2 project video is on our YouTube channel 🎞️
- Follow us on LinkedIn

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