Sub-system prototype (TRL6)

D3.1 – Public

HyPowerGT – Demonstrating a hydrogen-powered gas-turbine engine fuelled with up to 100% H2

Version 01 – Date 23/07/2025

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).

Abstract

A fundamental milestone of HypowerGT project is to achieve and demonstrate the DLE H2 combustion technology for the NovaLT16 engine up to TRL6. Design upgrades in the burner technology as well as in the combustion chamber components will be verified by means of a full annular rig test campaign of the NovaLT16 combustion system burning natural gas and hydrogen fuel blends up to 100% H2.

This deliverable D3.1 is intended to provide a description of the test rig, designed for the combustion system full size, full pressure and temperature verification of the NovaLT16 H2 DLE combustor (Task 3.1) and to present the activities performed to design the burner and combustion chamber parts and to setup the combustor instrumented prototype.

Keywords	
Deliverable ID	D3.1
Dissemination level	PUB
Deliverable Type	Report
Submitted date	31/08/2025

AUTHORSHIP/APPROVAL INFORMATION	
AUTHORS Stefano Gori	DATE 01/08/2025
REVIEWED BY Paolo Bruttini	DATE 04/08/2025
VERIFIED BY Egidio Pucci	DATE 04/08/2025
APPROVED BY Management Support Team	DATE 12/08/2025
ENDORSED BY (only if public) Executive Board	DATE 26/08/2025

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).

Table of contents

Abbreviations and Acronyms

CFD	Computational Fluid Dynamics
DLE	Dry Low Emissions
FAR	Full Annular Rig
GA	Grant Agreement
GT	Gas Turbine
TRL	Technology Readiness Level
TRS	Test Requirement Specification

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).

Executive Summary

HyPowerGT aims to moving technological frontiers to enable gas turbines to operate on hydrogen without any kind of dilution to abate the NOx emissions.

The core technology is a novel dry-low emission combustion technology (DLE H2) capable of handling mixtures of natural gas and hydrogen with concentrations up to 100% H2.

The WP3 is the Work Package core for the development of this technology that allow, with two experimental verification steps the demonstrate this technology in full prototype of a Baker Hughes NovaLT™16 gas turbine exploring all the operative range, aimed to guarantee all the KPI of HyPowerGT project, as reported in the Section 1.1. of the Grant Agreement.

To achieve the final objective, Baker Hughes, as the leader of Work Package 3 and its associated tasks, is responsible for the development and validation of the DLE hydrogen combustion system up to TRL7. The first step of the validation involves testing on the FAR prototype, a full-scale (1:1) model of the NovaLT™16 gas turbine combustion system, at the SestaLab facility (https://www.sestalab.com/site/index.php/en/). Following this, the system will be integrated into a full-size NovaLT™16 gas turbine prototype, with the aim of reaching TRL7 through a full-speed, full-load test campaign to be carried out at the Baker Hughes-Nuovo Pignone Tecnologie Srl. testing facility located on its Florence campus (Italy).

In this Deliverable D3.1 “Sub-system prototype (TRL6)” are presented the activities performed to the set-up the FAR prototype in the Baker Hughes-Nuovo Pignone Tecnologie Srl. Laboratory located in the Florence Campus (Italy) and the correlated activities conducted by the Engineering teams of Baker Hughes Baker Hughes-Nuovo Pignone Tecnologie Srl. (combustion eng., testing eng., advance manufacturing eng., gas turbine eng., product safety).

It’s to consider that, on top to the original targets of the HyPowerGT project, with the Executive Board meeting held on Nov 2024, it has been agreed to use part of the additional grant available from the associated partners to develop and test an additional solution of burner (Kit2 or enhanced burner) developed by Baker Hughes.

1. Introduction

This section introduces the activities and the objectives of the sub-system prototype verification test, aimed to demonstrate the successful achievement of the TRL6 for the 100% H2 DLE combustion technology of the NovaLT16 combustion system. In detail, the scope of this activity is to test a full-scale (1:1) prototype of the NovaLT™16 combustion system. This includes the combustion chambers and a set of 39 burners specifically designed and manufactured to meet the unique combustion requirements of this system. All components

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).

will be installed in a special test vessel (representative of the NovaLT16 gas turbine from the compressor discharge chamber up to the turbine first stage nozzle). The set-up also includes:

- A complete auxiliary system for control and safety during operation,
- Standard instrumentation for system control,
- Specialized instrumentation for validating the combustion solution,
- Interfaces with the SestaLab test cell 1 air adduction and hot gas exhaust gas removal

This integrated system is referred to as the Full Annular Rig (FAR). Once assembled, the FAR will be shipped to SestaLab for installation, commissioning and subsequent testing.
The FAR is capable of replicating full-scale operating conditions, including real pressure and temperature at the compressor discharge of the NovaLT™16, as well as the actual throat area of the first-stage high-pressure turbine nozzle.

1.1. Objectives

The main objective of this Deliverable are:

- Finalize the design of the two types of burners (both for Kit 1 and Kit2);
- Production of two complete kits (#39 each + spare) by additive manufacturing + final machining in the Baker Hughes – Nuovo Pignone Tecnologie Srl laboratories;
- Disassembly of the FAR from previous test campaign held in Q3 of 2024;
- Refurbishment of the damaged parts;
- Release of the TRS including details on the special instrumentation and on the test execution;
- Release all the drawings for the mod-machining of the parts;
- Release all the documents to purchase the sensors and measurements chains;
- Purchase of the special instrumentation (sensors);
- Perform mod-machining and install sensors on the burners and the other iters as requested from the TRS;
- Calibration of the sensors (where requested);
- Assembly of all the FAR including the instrumented items;
- Prepare the FAR for the shipment to SestaLab.

1.2. FAR test preparation

During the current reporting period, Task T3.1 focused on preparing the Full Annular Rig (FAR) test campaign at the SestaLab facility in Radicondoli (Siena, Italy). The objective of this campaign is to demonstrate the achievement of Technology Readiness Level 6 (TRL6) for the new H_2 Dry Low Emissions (H2 DLE) combustion system developed for the NovaLT™16 gas turbine.

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).

The task includes:

- Planning and scheduling all operational activities;
- Releasing the complete set of technical documentation required for the procurement of instrumentation, rig assembly, and test execution;
- Manufacturing the dedicated burners using a combination of additive manufacturing and conventional machining;
- Preparing the hardware, including instrumentation of individual components and assembly of all subsystems, leading to the final integration of the FAR ready for shipment.

The Test Requirement Specification (TRS) document for the test campaign with Full Annular Rig at SestaLab has been released in date 19/02/2025 (doc. code: SOE27226).

The document includes following main chapters:

- Modification to the hardware;
- Details of the refurbishment activities;
- Indications for the flow test;
- Instrumentation: selection and positioning;
- Instrumentation list;
- Instrumentation list references;
- Emission measurements;
- Piping & Instrumentation Diagram (P&ID);
- Control logic and test sequences;
- DAQ system and electrical hook-up;
- Certification;
- Indication for the HAZOP;
- Planning for the test campaign.

At the Baker Hughes Florence Laboratory, the disassembly of the Full Annular Rig, previously used in an earlier test campaign, was successfully completed by the end of 2024, in line with the planned schedule. This activity was carried out to enable refurbishment and preparation of the rig for its upcoming use in the HyPowerGT test campaign at the SestaLab facility.

The previously used combustion chamber has been fully refurbished, and a complete new set of instrumentation has been installed. This includes approximately 140 sensors mounted on the combustor, such as thermocouples, pressure taps, dynamic strain gauges, accelerometers, and pressure pulsation sensors.

Due to localized damage of outer liner happened during previous FAR test campaign, a new outer liner has been manufactured and instrumented.

The whole combustion chamber has been then assembled, measured and flow tested for quality checks. External laser scan has been also done for dimensional check of the assembly.

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).

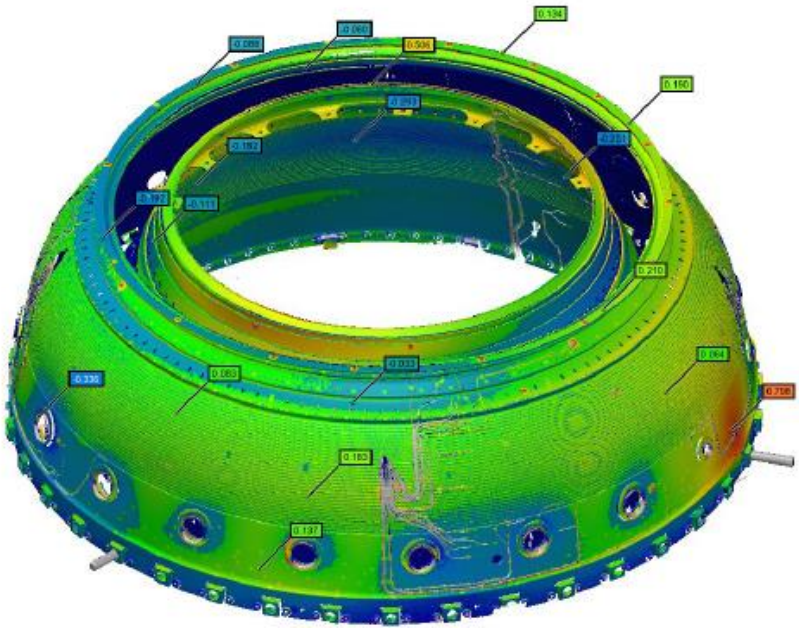

Figure 1-1, H2 DLE combustion chamber laser scan

The FAR (including combustion chamber, vessel and discharge duct) is currently in the final assembly phase and is expected to complete at the end of August 2025 to allow the shipment of the test article (FAR) to SestaLab early September 2025.

For each component involved in the instrumentation process, mod-machining drawings have been released to allow the integration of sensors and the routing of associated cabling. These modifications ensure proper placement, secure installation, and reliable signal transmission throughout the test campaign.

A detailed analysis of flashback events, which was measured by BH during a previous FAR test campaign performed with the same combustor hardware, has been performed by ZHAW University: following the conclusion of such analysis, the test requirement specification has been updated to include additional instrumentation (pressure pulsation probes) within the test article; aim of this new instrumentation is to provide additional insights regarding the flashback phenomena and detection. Scouting for these new sensors is currently ongoing as well as the installation guidelines and will be completed in next weeks.

1.3. Burners kit design & production

Design of first kit of burners has been finalized and the documentation released, allowing to start with the production in additive manufacturing in the AM Center of Baker Hughes located in Florence. During the design enhancement process of the gas injector, the geometry of the premixing chamber has been enhanced to maintain a positive margin against flashback events in all the operating conditions, while targeting at the same time a finer mixing of air and fuel inside burner upstream of the reaction zone inside the combustion chamber to minimize the

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).

thermal NOx production process. Two additional aspects were considered as primary importance during the design enhancement process for the static and dynamic flame stabilization over the whole range of NG/H2 blends:

- Development of a pilot fuel line able to improve flame stability during most challenging operational modes as engine load steps, fast transients or high-rate fuel blend variation;
- Enhanced combustor acoustic design for pressure pulsation and combustion noise abatement.

The production of the prototypal burners has been planned by batch (#4 burners for each printing batch). After the completion of a single batch, burners have been machined and prepared for instrumentation, in agreement to Test Requirements Specification (TRS) document. The production of the kit, comprising 39 burners along with a set of spare parts, has been finalized in February 2025. By the end of July 2025, all burners are fully completed, including machining, flow testing, tuning, and instrumentation: ready for installation on the Full Annular Rig (FAR) for the upcoming test campaign.

A burner kit includes about 200 sensors, mainly thermocouples but also dynamic strain gauges and pressure taps. Additional quality checks done for prototypal pieces have been also done:

- Computed tomography to verify quality of achieved pieces, dimensional checks, cleanness of internal passages;
- External light scan for measuring the external shape and a more accurate dimensional check.

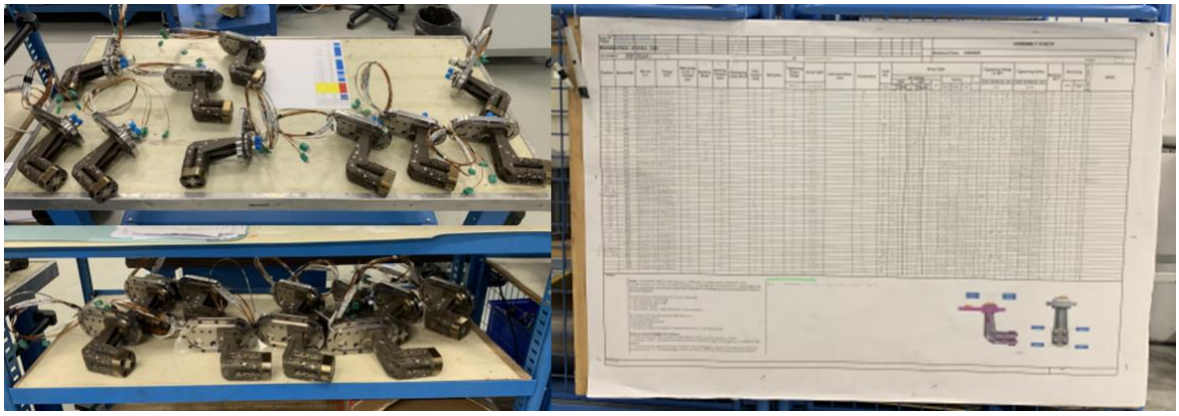

Figure 1-2, Kit 1 instrumented burners during the flow test

It's important to remark that, a fundamental step ahead in the knowledge of core technologies required for H2 DLE combustion has been acquired during SestaLab test of Aug-'24 (part of the BH internal development project, not included in HyPowerGT), reported in Figure 1-3 (flashback margin for 3 burner concepts) and supported by detailed CFD simulations performed by SINTEF, which are part of T2.1 activities.

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).

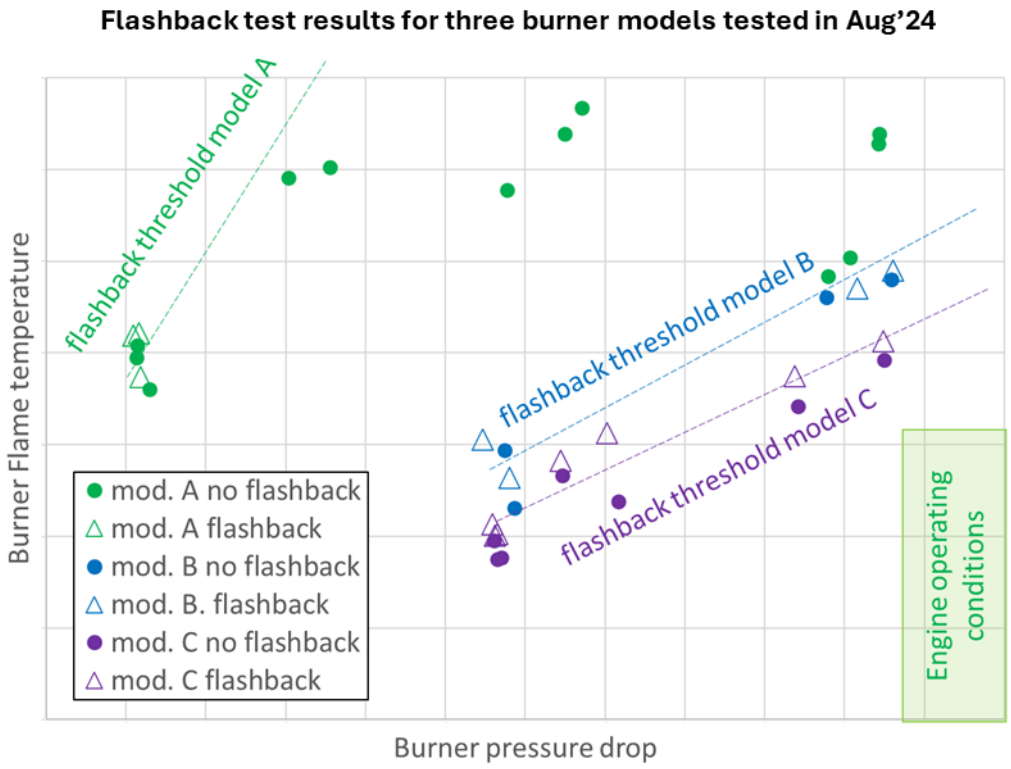

Figure 1-3, Flashback margin for 3 burner concepts, measured as function of combustor delta pressure

An incremental design step is currently under co-developed side by side with the existing plan of activities. Indeed, part of the extra-budget for HyPowerGT project, approved on Nov'24 by the Executive Board, is specifically aimed developing, producing and testing of a second kit (kit II) of instrumented burners (enhanced burner) aimed to:

- enhanced flame stability (NOx reduction);
- enhanced flashback margin operating with 100%H2
- target flame holding proof condition with 100% H2.

The kit of enhanced burners will be based on the kit 1 burner architecture with:

- leaner premixing condition, aimed to increase flame holding margin;
- reduced H2 concentration close to walls, aimed to increase flashback margin;
- more homogenous mixture fraction distribution in bulk flow region, aimed to improve thermo-acoustic performances and reduce NOx emissions.

As part of the HyPowerGT project, the design phase for the second burner kit (Kit 2), which incorporates targeted design enhancements, began in January 2025.

In parallel, the production of the first burner kit (kit 1)—representing the initial solution for HyPowerGT—was launched at the beginning of 2025. This kit includes full instrumentation and testing activities and is scheduled for installation on the Full Annular Rig (FAR) for the testing

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).

phase planned in October 2025. As per the first kit, enhanced burners have been produced in the BH AM Center located in Florence; printing process of all 11 batches (39 burners plus some spares) have been completed at the beginning of May 2025. Following the completion of machining activities, the burners underwent flow testing, fuel line calibration, and instrumentation. The full kit is expected to be finalized and ready for installation on the Full Annular Rig (FAR) by end-Sep 2025.

1.4. Propaedeutic single cup test campaign

During February and March 2025, single cup atmospheric reactive tests have been performed at the internal BH facility in Florence (test rig named "*BlueRig*"), as propaedeutic activity to the FAR test campaign. Aim of this single cup test campaign was performing a preliminary evaluation of the performances for the 2 designed burner concepts under atmospheric conditions in terms of flame stability and NOx emissions and also perform a verification of some flashback detection technologies applied to the burners by means of thermocouples and static and dynamic pressure probes.

In Figure 1-4 some results from the BlueRig tests results are reported, as a comparison of flame shapes and NOx performances for different burner architectures for H2 DLN combustion.

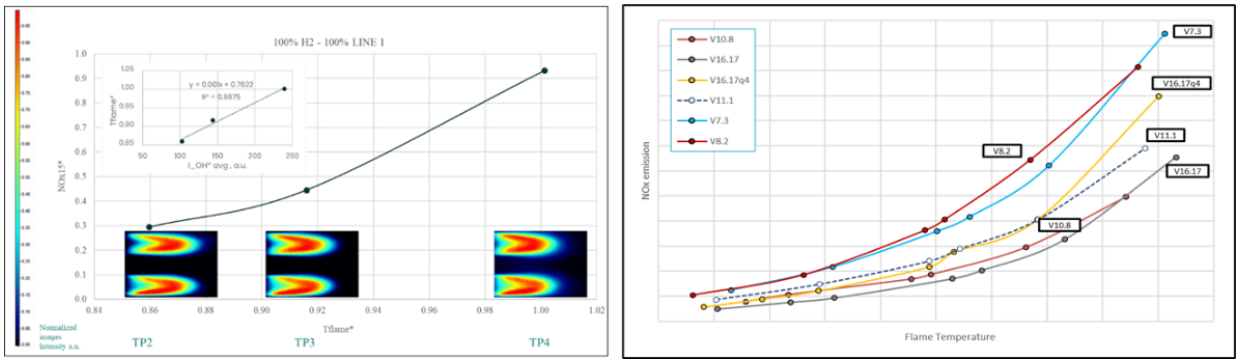

Figure 1-4, BlueRig tests results: flame shape (left) and comparison of NOx performances (right)

1.5. FAR test campaign preparation activities

During the current reporting period, the control narrative for the Full Annular Rig (FAR) test campaign has been completed and reviewed in collaboration with SestaLab personnel. This document outlines all critical aspects of test execution, including:

- Definition of test sequences and phases;
- Control logic and automation strategies;
- Operating procedures and detailed instructions;

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).

- Safety alarms and interlock procedures.

To remark that, the control narrative serves as a key reference to ensure safe, consistent, and effective execution of the HyPowerGT test campaign.

In parallel to above technical aspects, the contract for the FAR test campaign has been finalized with COSVIG (SestaLab Facility Company): contract defines the agreement for the test cell 1 rent, the guaranteed number of test days and running hours, fuel consumption and scheduled supply, energy consumptions, test cell setup and their cost.

In the following picture, taken within the Baker Hughes-Nuovo Pignone Tecnologie Srl Laboratories (Florence campus-Italy) it is reported the status of the FAR on Jul 29th, 2025. The FAR prototype assembly is 90% completed. Next step is to install the burners and then the prototype will be positioned on a dedicated trolley to be ready to be shipped to SestaLab early September 2025.

Figure 1-5, FAR assembled in the BH Florence shop, ready for shipment to SestaLab

In below table a list of main released drawings for 2025 FAR test campaign.

SEO0370300	Kit#1 burner assembly
SOE35197	Kit#1 burner instrumentation
SOE35207	Kit#2 burner instrumentation

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).

SEO0370100	Test article assembly
SEO0370700	Test article instrumentation assembly
SE-4823755	Combustion chamber instrumentation drawing assy
SE-4830403	Inner liner instrumentation drawing
SE-4830474	Outer liner instrumentation drawing
SE-4828682	Domeplate instrumentation drawing
SE-4828958	Inner baffle instrumentation drawing
SE 4828732	Outer baffle instrumentation drawing

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).

2. Conclusions and Recommendations

The plan of activity for the FAR test campaign originally defined for the task 3.1 of HyPowerGT project has been successfully respected during the execution phase.

The full annular rig, equipped with the prototypal H2 DLE combustor will be shipped to SestaLab cell 1 within early September 2025, allowing to start with the installation and commission and then start with the first firing day from mid October 2025.

An additional scope of work has been added in November 2024, leveraging the opportunity of such relevant test campaign to introduce enhancing concepts in the burner architecture and verifying it by means of a second kit of burner which will be tested after the completion of the first kit testing phase. The design phase for the kit of burners has been supported by SINTEF and ZHAW.

The current plan status is matching the target to release deliverables D3.2 and D3.3 (related to the test results of TRL6 test campaign) at M24, as per baseline schedule.

2.1. Summary of main findings

This period of preparation of FAR test campaign for the H2 DLE technology verification has allowed to define two different solutions of burners able to manage blending of H2 in CH4 from 0 to 100%. These solutions have been defined based on Baker Hughes experiences, analytical development process, dedicated tests on single burner in atmospheric condition (at Baker Hughes rig located in Florence) and dedicated pre-test on the same FAR performed on August 2024 (not included in HyPowerGT project).

It's important to highlight that, within the current reporting period, significant progress has been made through collaborations with project partners. The results of the DNS analysis conducted under WP2.1, combined with high-fidelity LES simulations provided by SINTEF, have offered valuable insights into the flashback phenomenon.

Additionally, the extended collaboration with ZHAW under WP2.2 has further enhanced the understanding of flashback detection mechanisms. These findings will be validated during the upcoming FAR test campaign, alongside standard detection techniques.

2.2. Next steps

Within the end of August 2025, the FAR will be completed and will be shipped to SestaLab (around 100 km far from Baker Hughe-Nuovo Pignone Tecnologie Srl Florence (IT) campus).

Then the installation and commissioning of the FAR in the SestaLab testing cell will start and then the leakage and aero test will be performed. This phase will be completed with the Red

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).

Flag Review, an official milestone before the fire-up of the test in which will be reviewed the checklist of the test including the safety aspect.

The test is planned to start in the second half of October 2025. The test campaign consists in 8 days of test (non-continuous days to allow to analyze data, check-recover instrumentation and change hardware configuration).

Test campaign is expected to be completed within December 2025.

Best configuration among the 2 different burner concepts will be selected and the combustor tuned accordingly to finally demonstrate the achievement of TRL 6 for the H2 DLE combustion technology, accordingly to the KPI reported in the Section 1.1 of the GA. Such combustor technology will be then used for the test campaign at TRL7 using a complete NovaLT^{TM}16 Gas Turbine as system (Task 3.2).

Clean Hydrogen Partnership
Co-funded by the European Union
Project funded by
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

The HyPowerGT project is supported by the Clean Hydrogen Partnership and its members (GA 101136656) and the Swiss Federal Department of Economic Affairs, Education and Research, State Secretariat for Education, Research and Innovation (SERI).