HIGH HYDROGEN GAS TURBINE RETROFIT SOLUTION TO ELIMINATE CARBON EMISSIONS

15-IGTC21

Gas turbines in a carbon-neutral society

10th International Gas Turbine Conference

11-15October 2021

This work has been partly funded by Dutch hydrogen program within the Top Sector Energy area of the Dutch Ministry of Economic Affairs and Climate Policy.

Contents

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Introduction

The Renewable Gap

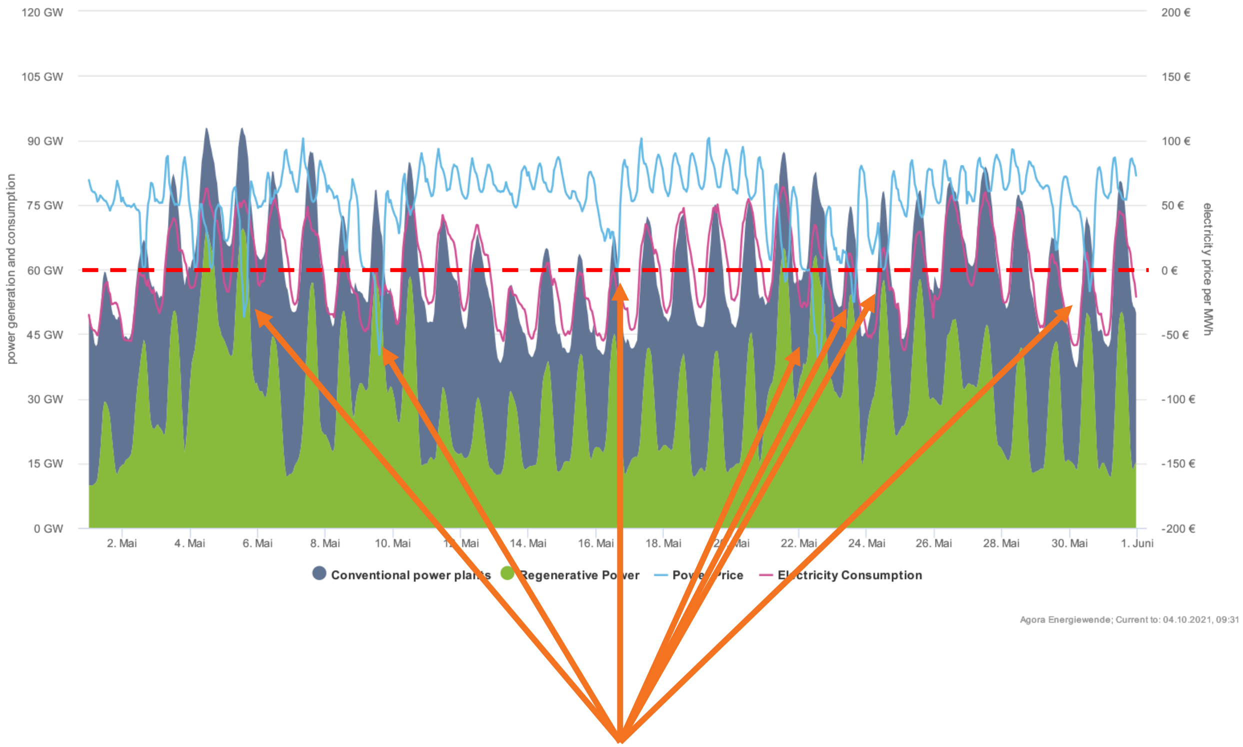
Challenge

- Renewable power generation is highly fluctuating and weather depended
- Variations in renewable generation are ‘in-sync’ leading to higher peaks and lower valleys
- More clean energy results in less grid stability

Solution

- Increase interconnect capacity
- Store energy
- Fast Flexible power generation

Energy production and pricing
May 2021 - Germany



Negative pricing is happening on a daily basis

The energy balancing solution

Gas Turbines

- Flexible fast load coverage
- Extremely low emissions!
- Ability to run on wide range of fuels, including green fuels such as hydrogen
- Large installed base ready to be converted
- Excess renewable energy can be harvested, stored and released in gas turbines

Hydrogen

- Carbon free energy carrier
- Utilizing and building on existing transport infrastructure
- Can be gradually introduced

Hydrogen specific challenges

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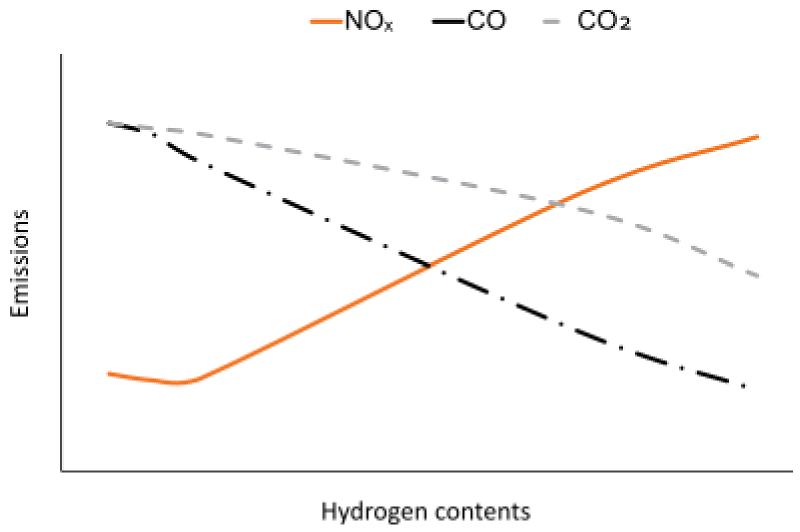
- Fundamental different properties than conventional fuels
- Very high flame speed increases high risk of flashback
  - Upstream propagation of the flame
  - High temperatures and risks for hardware damage
- Very small molecules
  - Can permeate through materials and seals
  - Embrittles certain materials
- Hydrogen is burning with a very high flame temperature
  - High flame temperature increases drastically the NOx emission
  - Conventional combustors running on hydrogen requires post-combustion treatment or water injection

	Methane (natural gas)	Hydrogen
Density (kg/Nm^3)	0.678	0.085
Lower heating value (MJ/kg)	50	120
Lower heating value (MJ/Nm^3)	33.9	10.2
Adiabatic flame temperature (K)	2236	2527
Laminar flame speed (m/s)	0.38	1.70
Lower explosive limit (vol%)	5.0	4.0
Upper explosive limit (vol%)	15.0	75.0



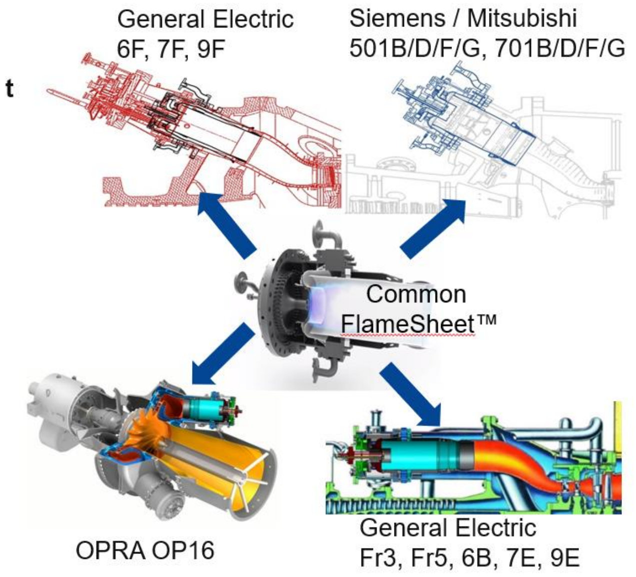
A different fuel with different challenges

Development program approach

Founded a consortium for Hydrogen Retrofits

Objective

- Develop a low emission gas turbine combustor retrofit for fuel flexible operation from 100% Natural Gas to 100% Hydrogen and any mixture thereof
- Flexible fast load balancing capability



4 step plan

1. Atmospheric Test - Completed – This paper!
2. High Pressure Test - First step completed!
3. Engine Demonstration
4. Commercial Operation

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EMMTEC A GETEC GROUP COMPANY
Dow
VATTENFALL
TU Delft
OPRA TURBINES
HYGEAR
DLR
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

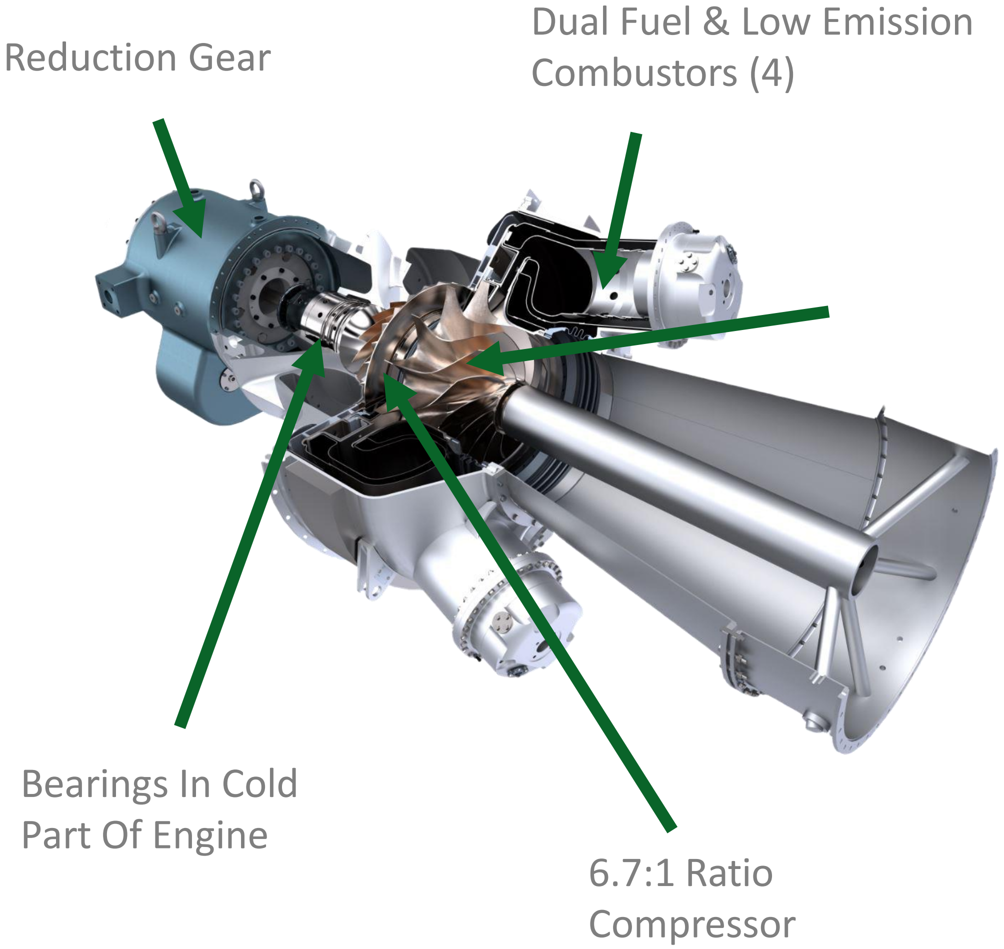
Joint effort between OEM's, End-Users and Academia!

Technology

OPRA OP16 Gas Turbine Engine

The 1.8 MW OP16 gas turbine engine combines the best of simplicity and high performance

OP16 Gas Turbine	
Electric Efficiency	25%
CHP efficiency	~90%
Exhaust Flow	8.7 Kg/s
Exhaust Gas Temp.	570 ºC
Rotor Speed	26,000 rpm



Hydrogen combustion and the FlameSheet™ combustor

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Experience

2004 LECIII including high H2

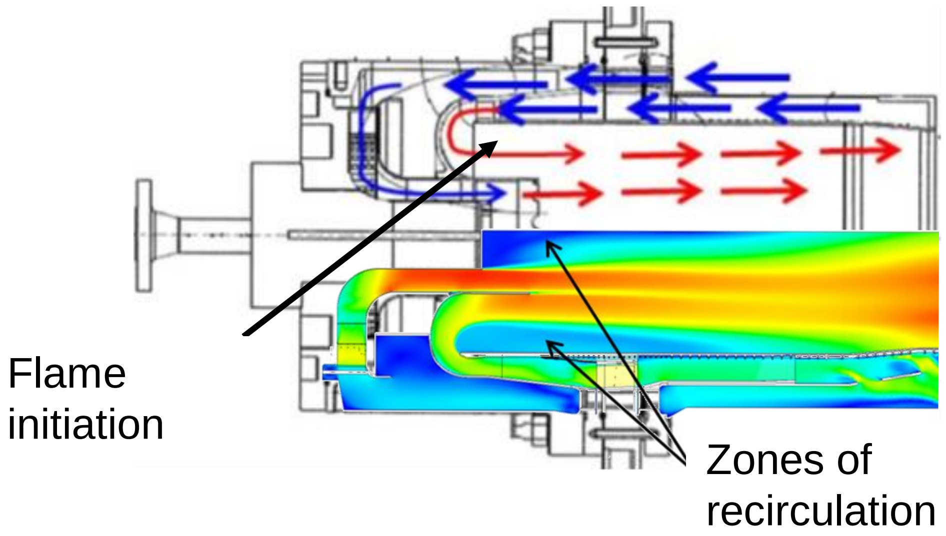
2004 FlameSheet running RFG with H2

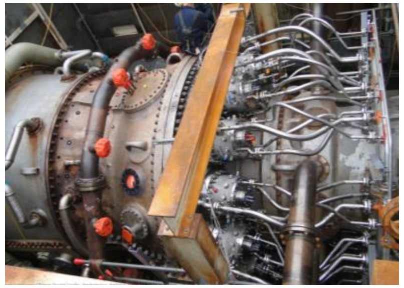
2016 FlameSheet Extended hydrogen operation

2017 Commercial 9E up to 35% H2 (LECIII)

2018 Commercial 7FA up to 5% H2 (Flamesheet™)

2019 Partnership Kick Off





Unique FlameSheet™ features

- Trapped vortex flames less sensitive to flame shifting position
- Flame anchored at point of vortex as defined by geometry and less dependent on fuel constituents
- FlameSheet primary flame stabilization by aerodynamic trapped vortex

Building on past experience! Making the step to 100% H2

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Modelling

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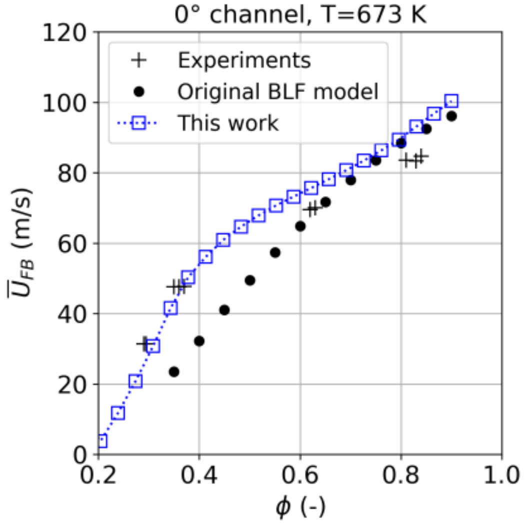
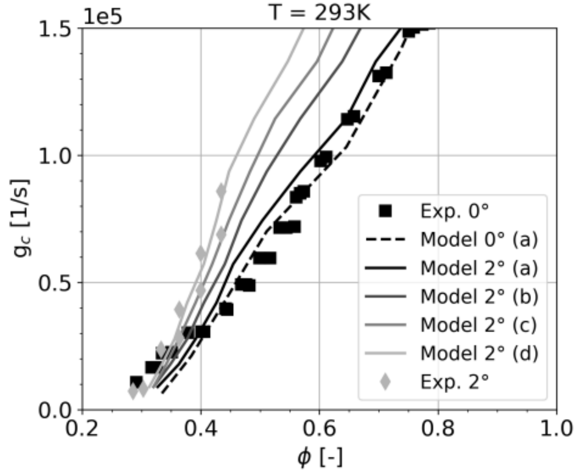
Boundary layer flashback model

Goal: Calculating the potential risk on boundary layer flashback

Based on the observations by Eichler and the model by Hoferichter the TU Delft model:

- Determines the backpressure resulting in boundary layer instability (Stratford)
- Utilizes CFD input on the boundary layer velocity profile
- Calculates local turbulent flame speed (Damköhler)
- Correct for low Lewis number





Capturing turbulence is key

Outlook

- Using the experimental results from the Flamesheet™ combustor
- Effect of low velocity turbulent streaks
- Better understanding of the turbulence and backpressure interactions
- Wall temperature impact

Big steps are made due to the combination of experiments and modelling

Experimental setup

Experimental setup – Atmospheric combustor test rig

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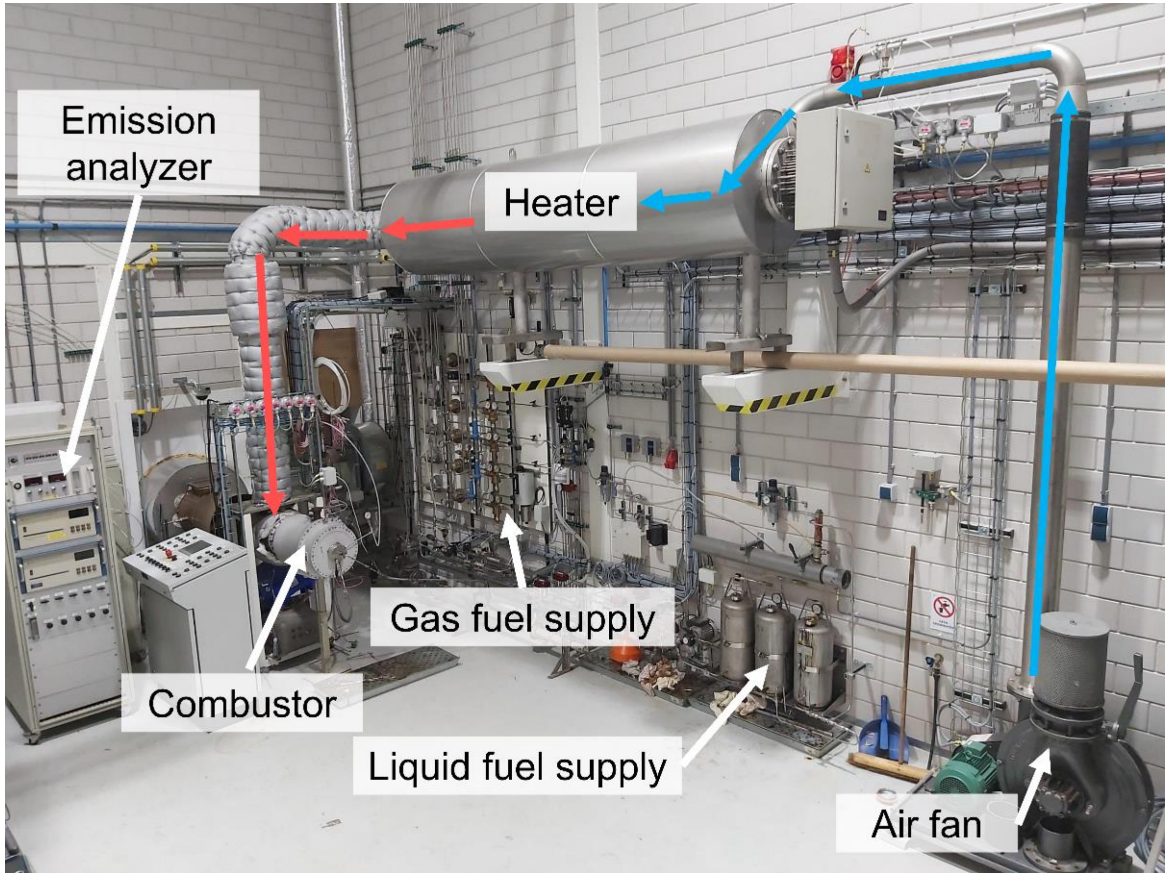
Located at OPRA's premises in Hengelo, the Netherlands

Both liquid and gaseous fuels can be tested

A gas mixing station enables mixing of any type of gaseous fuel

- Methane or propane or natural gas
- Hydrogen
- Carbon monoxide
- Nitrogen
- Carbon dioxide

Full engine temperature condition



Unique facility to aid in combustor development

Experimental setup – Instrumentation

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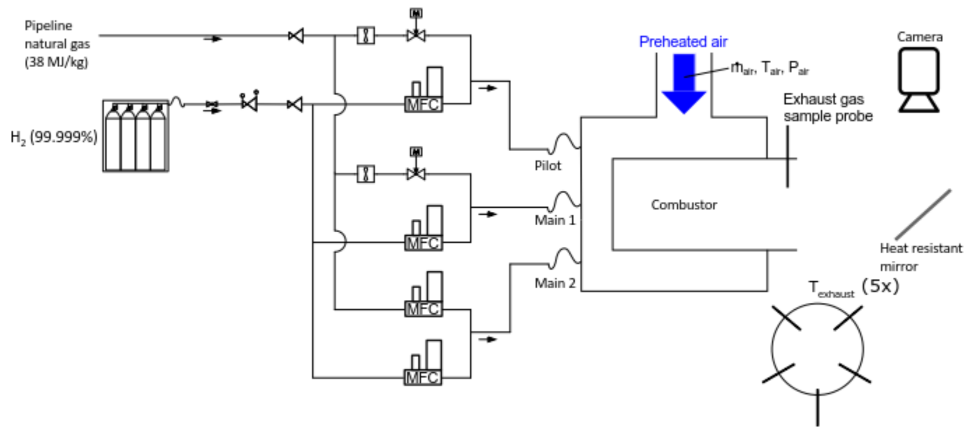
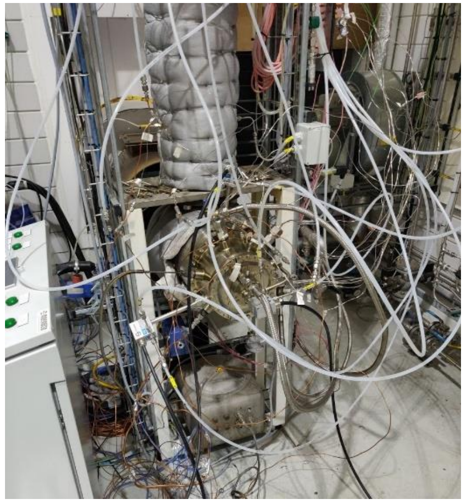




Instrumented set-up and combustor

Movable emission probe

- Air and fuel flow meters
- Line, point and moveable emission probes
- Thermocouples
- Dynamics monitoring and local pressure measurement
- Visual access to the flame by 4K @ 50 Hz camera

Experimental setup

Development targets

- 100% NG to 100% H_2 operation
- Sub 9 ppm emissions
- Wide operating range

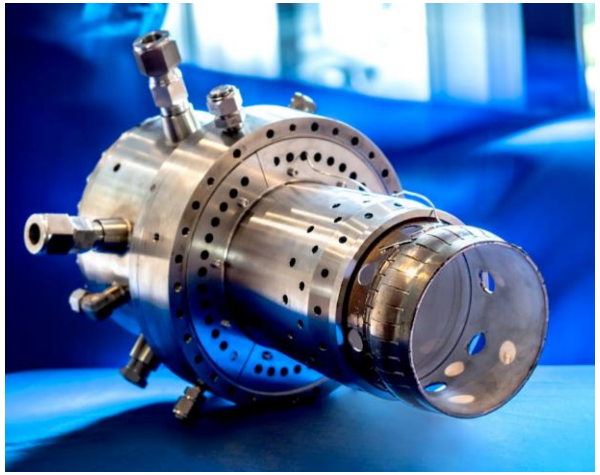
Specific technical targets:

- Prevent Flashback
  - Focus on optimal fuel air ratios → specifically in the boundary layer
- Prevent flame holding to prevent local overheating
- Fuel flexibility
  - Proper mixing for all fuel mixes → low emissions

Hardware setup

- Baseline design based on scaling of commercial hardware
- A wide range of main flow and pilot flow path hardware specifically aimed at preventing flashback
- Very flexible setup allowing for easy swapping of parts and subassemblies

11 builds different builds
21 test days



Results

Results – Initial design

Step 1 – Cold flow validation

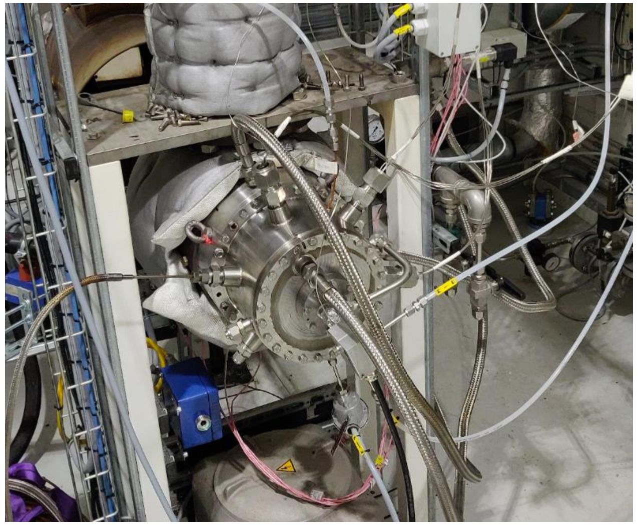
Validate the constant velocity scaling approach

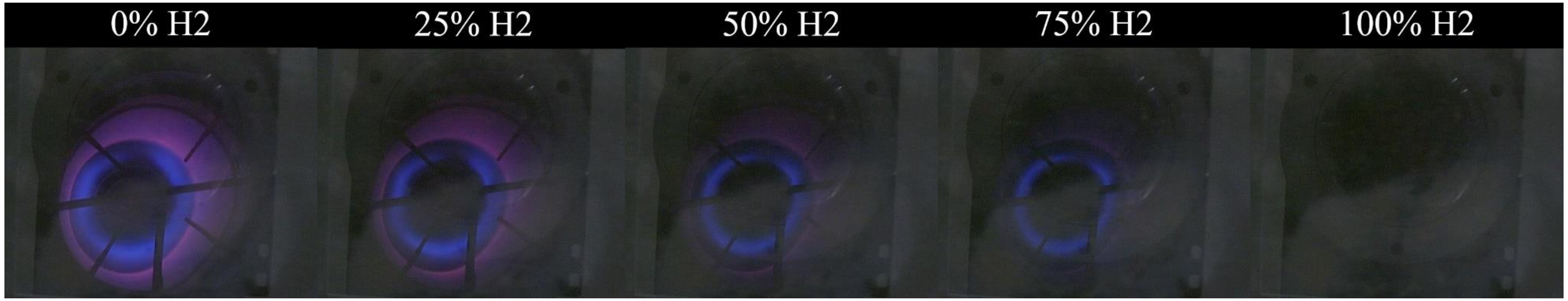
Fully characterize all flow splits

Step 2 – Establish the baseline

Demonstrating that 100% H2 is already possible at part-load!

Limited by boundary layer flashback



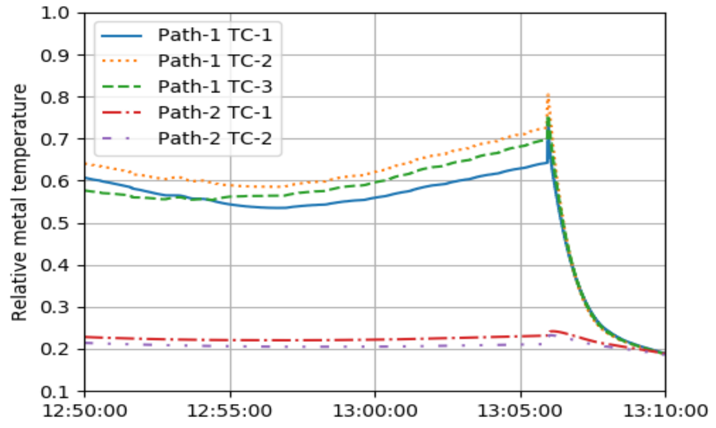


Our baseline already showed great promise! 100% H2 at part-load!

Results – Further design exploration

Optimization using

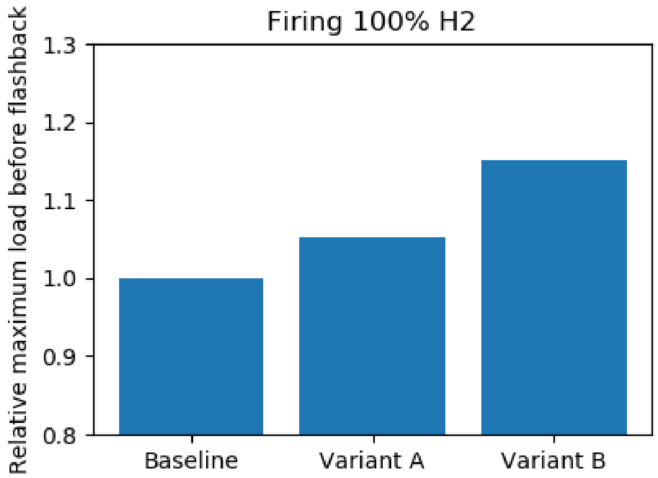
- CFD
- Boundary flashback model
- Flashback thermocouples along multiple paths



Design exploration

- 2 different liners
- 3 different main gas injectors
- 2 different pilot injectors
- 2 different combustor head ends

Injector impact example



The novel variant B
Shows no flashback
at all!

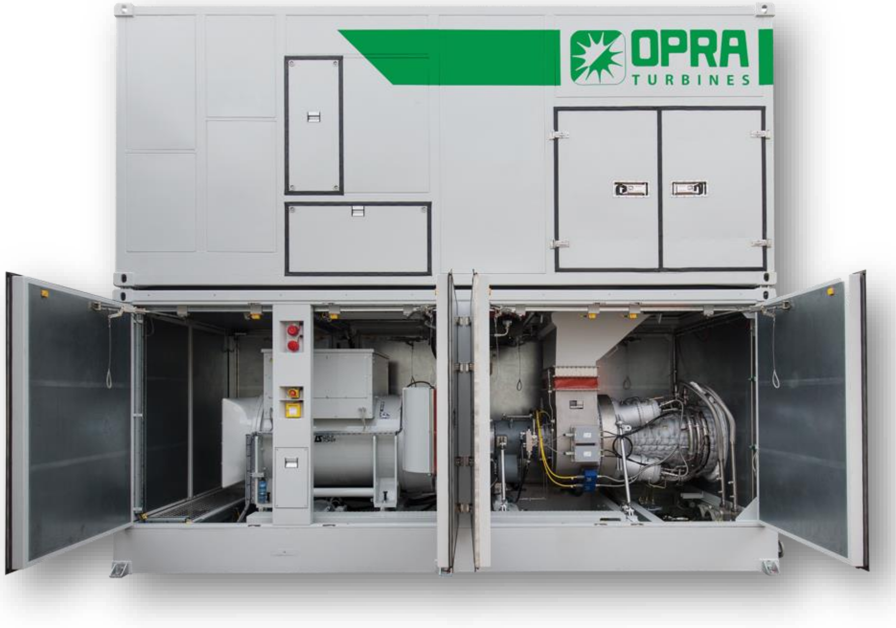
Promising results!

Conclusions & Outlook

Conclusion & Outlook

Conclusions

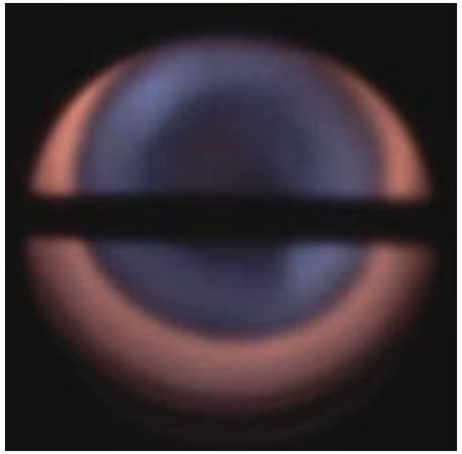
- An improved boundary layer flashback model has been created
- An upgraded version of the Flamesheet™ combustor suitable for the OP16 gas turbine was developed and tested
- Several geometrical adjustments were evaluated to map flashback margins and emission
- Successfully tested in atmospheric conditions from 100% natural gas to 100% H2 without flashback
- Subsequent works will build upon the lessons learned to optimize the combustion system for sub 9 ppm NOx emissions



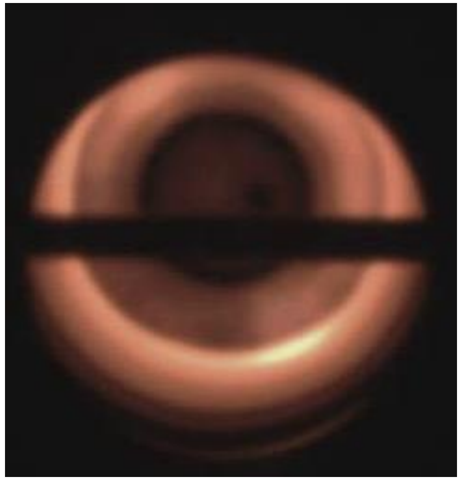
Outlook

- Initial High pressure testing has been completed earlier this year!
- Secondary testing will be performed on the short term followed by an engine demonstrator.

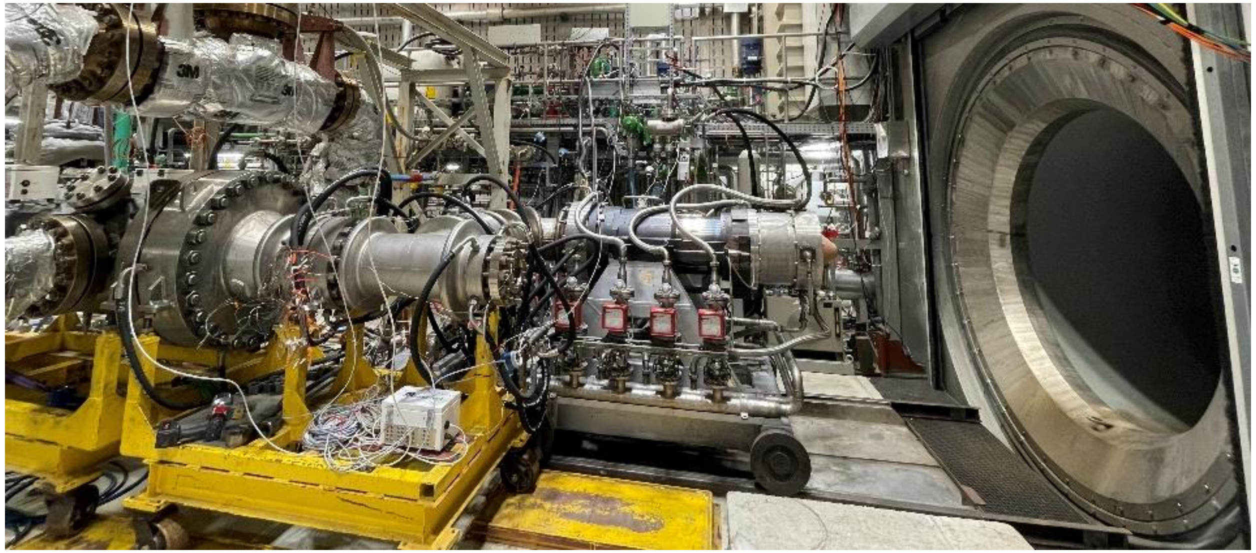
High pressure testing teaser



100% Natural gas



100% Hydrogen



Initial results are very promising with <10ppm NOx

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