IDEA2021

Powering the Future: District Energy/CHP/Microgrids

Sept. 27-29 | Austin Convention Center | Austin, Texas

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Hydrogen-Capable Gas Turbines for Carbon Neutral Power Generation

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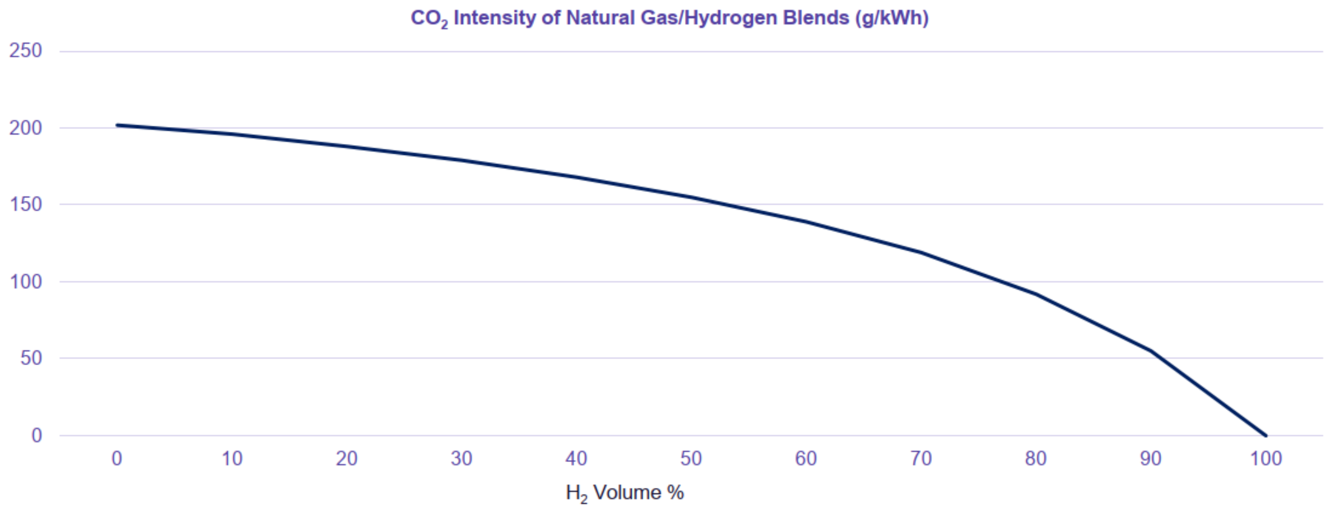
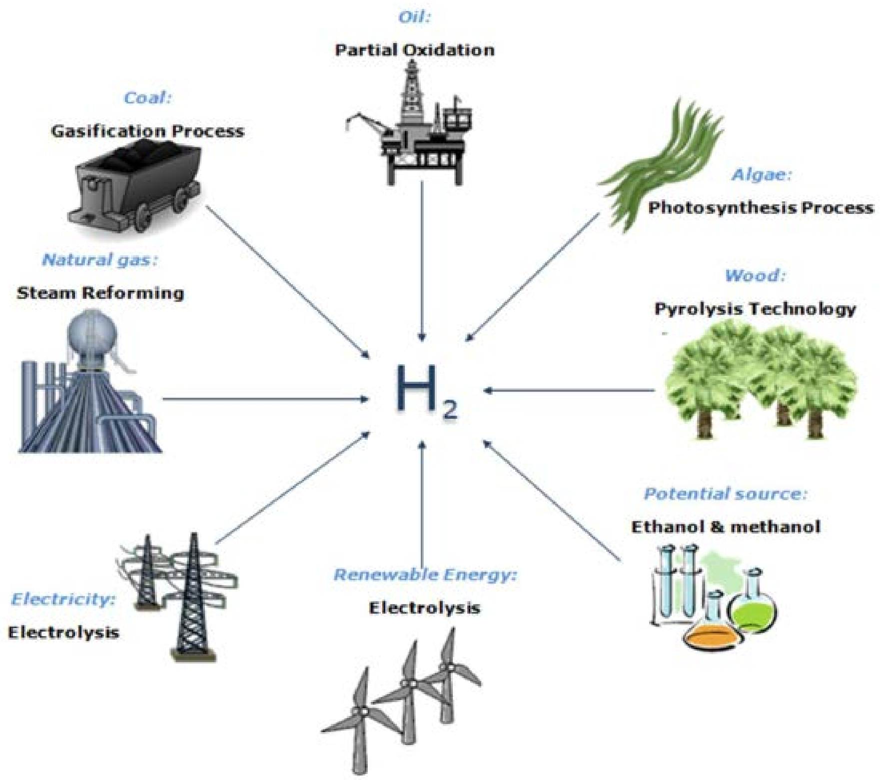
Agenda

1. Why Hydrogen
2. Hydrogen and Gas Turbines
3. Hydrogen Combustion Challenges
4. Solutions
5. Key Enablers to Success

Why Hydrogen?

Hydrogen produces no CO_2 when combusted.

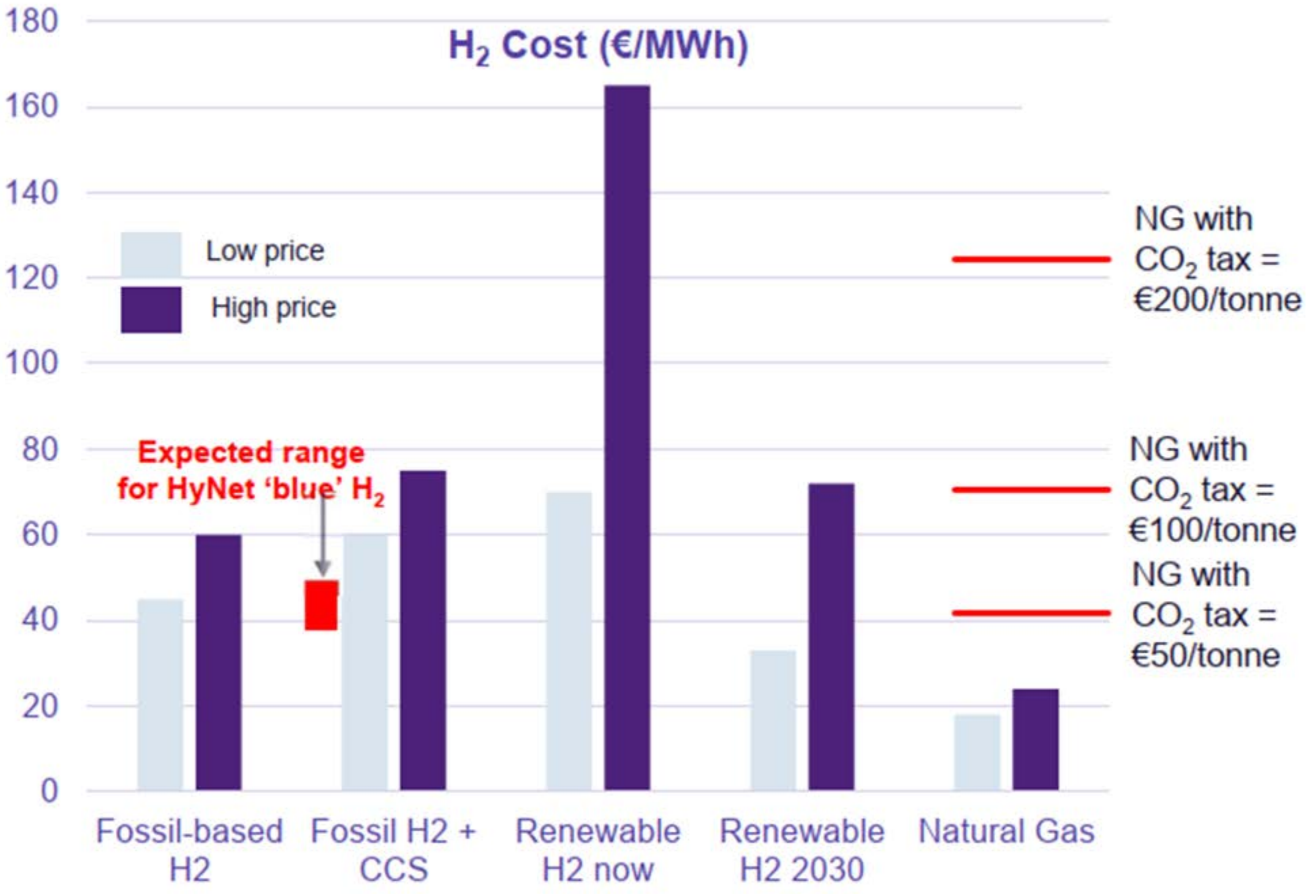




Hydrogen Economy Challenges

Hydrogen is projected to be economically feasible ~ 2030.

- Production Volumes
- Transportation of Hydrogen
- Cost
- Timescales
- Water
- Legislation



Source: EU Hydrogen Strategy

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State of the Art
The mission is to burn 100% hydrogen

Gas turbine model		Power Output[1]	H_2 capabilities in vol. %	CO_2 reduction[2)] [%]
50Hz	SGT5-9000HL	595 MW	50	23%
50Hz	SGT5-8000H	450 MW	30	11%
50Hz	SGT5-4000F	329 MW	30	11%
50Hz	SGT5-2000E	187 MW	30	11%
60Hz	SGT6-9000HL	440 MW	50	23%
60Hz	SGT6-8000H	310 MW	30	11%
60Hz	SGT6-5000F	215 to 260 MW	30	11%
60Hz	SGT6-2000E	117 MW	30	11%
50Hz or 60Hz	SGT-800	48 to 62 MW	75	47%
50Hz or 60Hz	SGT-750	40/34 to 41 MW	40	17%
50Hz or 60Hz	SGT-700	33/34 MW	75	47%
50Hz or 60Hz	SGT-A35	27 to 37/28 to 38 MW	15 / 100	5 / 100%
50Hz or 60Hz	SGT-600	24/25 MW	75	47%
50Hz or 60Hz	SGT-400	10 to 14/11 to 15 MW	10 / 65	3 / 36%
50Hz or 60Hz	SGT-300	8/8 to 9 MW	30	11%
50Hz or 60Hz	SGT-100	5/6 MW	30 / 65	11 / 36%
50Hz or 60Hz	SGT-A05	4 to 6 MW	30	11%

DLE burner WLE burner Diffusion burner with unabated NOx emissions

Heavy-duty gas turbines Industrial gas turbines Aeroderivative gas turbines

1 ISO, Base Load, Natural Gas; Version 5.2, June 2021 2) Compared with 100% natural gas operation

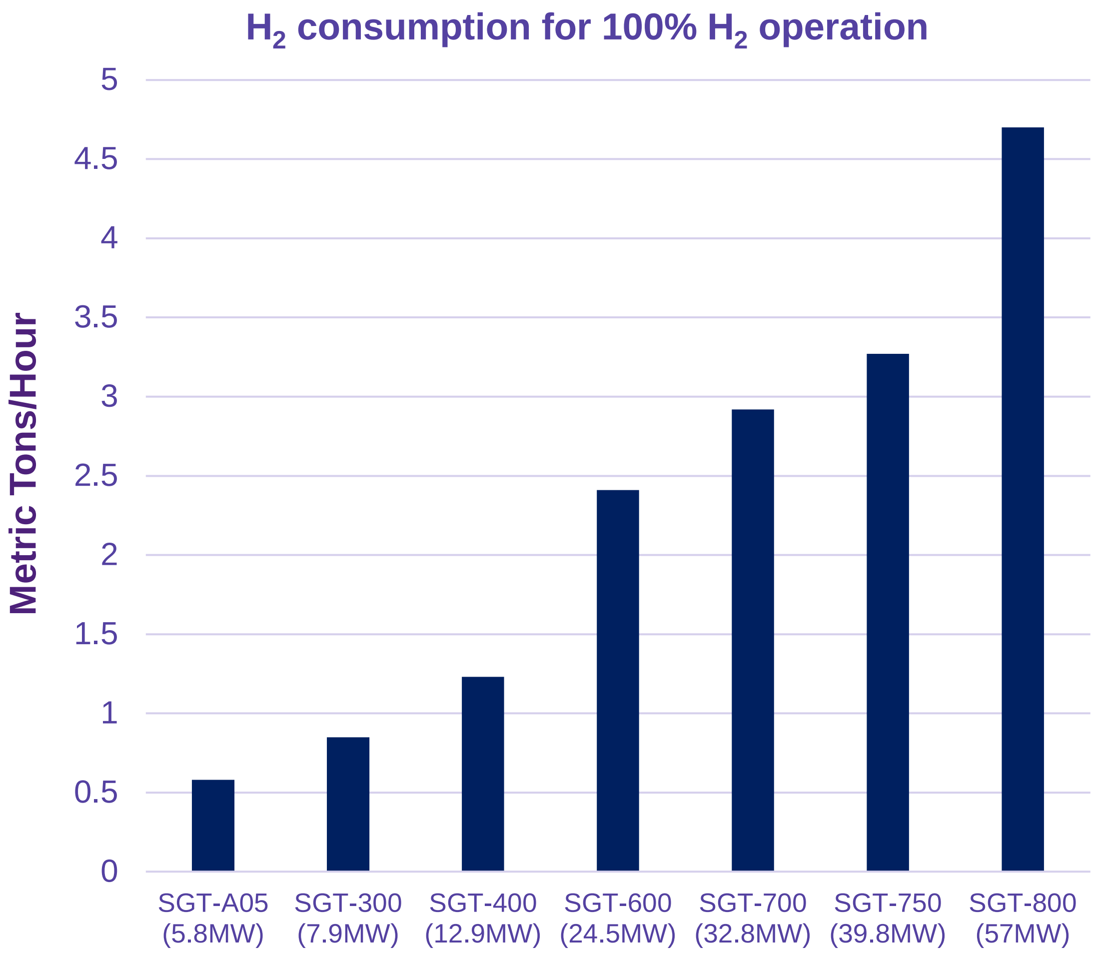
Values shown are indicative for new unit applications and depend on local conditions and requirements. Capability to operate on 100% natural gas is maintained (full fuel flexibility). Some operating restrictions/special hardware and package modifications may apply.

Higher H_2 contents to be discussed on a project specific basis

Benefits of Small Flex-Fuel Gas Turbines in the Hydrogen Economy

- In order to reach a 50% reduction in CO_2 emissions by mass, approximately **80 vol% hydrogen fuel** content is needed

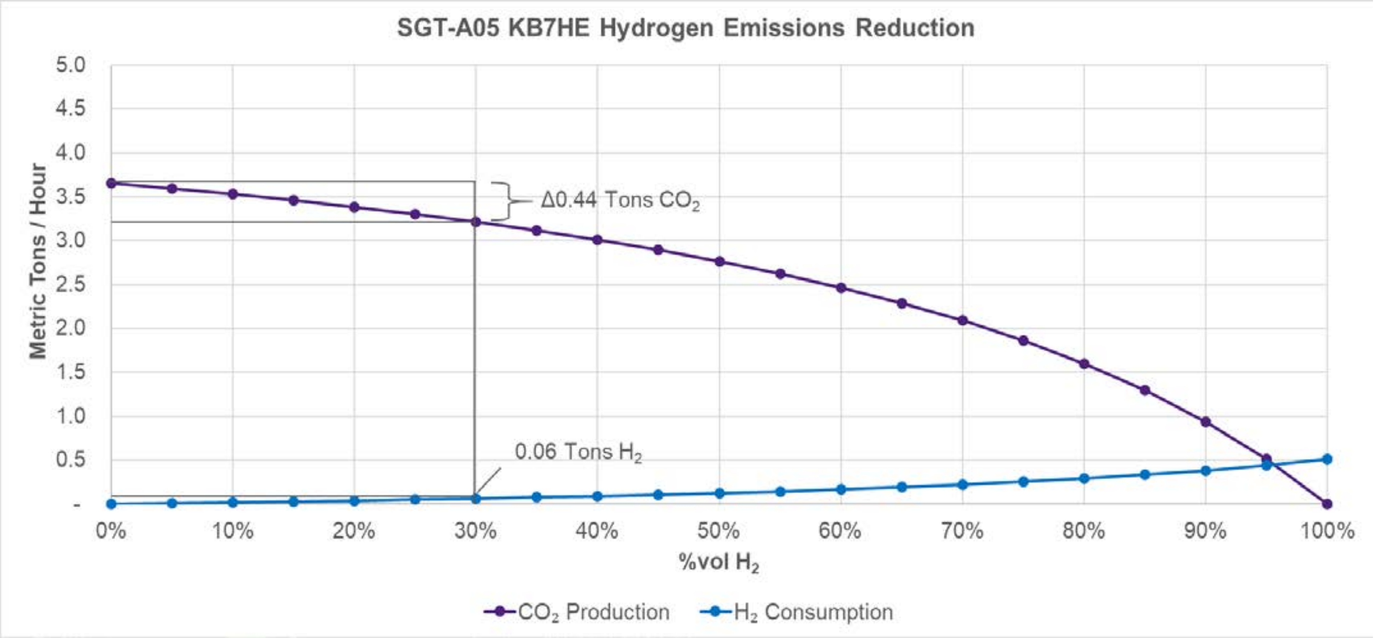
- The amount of hydrogen required to operate large gas turbines at this level of **hydrogen fuel mixture is not economically viable today**



Benefits of Hydrogen Capable Gas Turbines

Net-zero Carbon emissions

- 30% vol H_2 is 1.5 tons total Hydrogen per day for a small 6 MW gas turbine
- 1.5 tons H_2 per day reduces CO_2 emissions 12%



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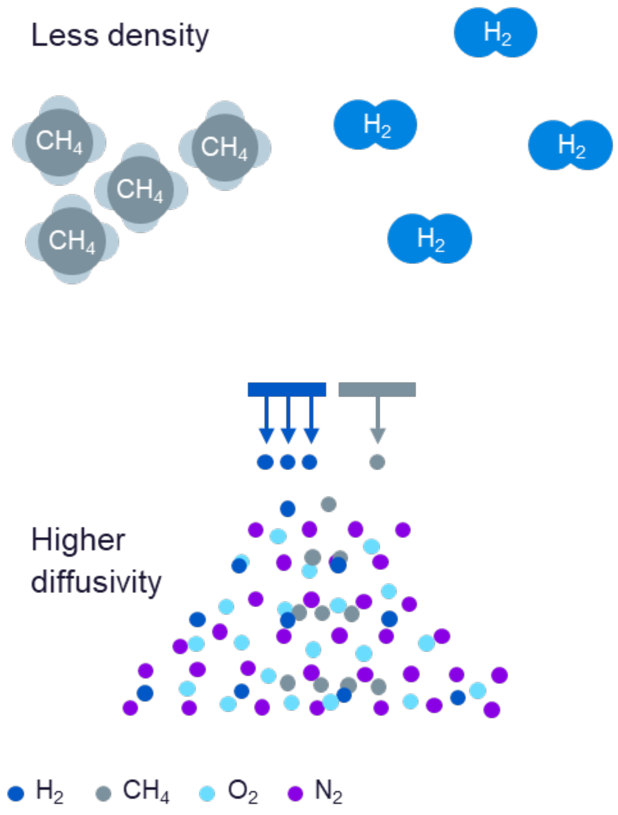
Hydrogen Combustion Challenges

Differences of hydrogen and natural gas as a fuel in gas turbines

Physics of hydrogen

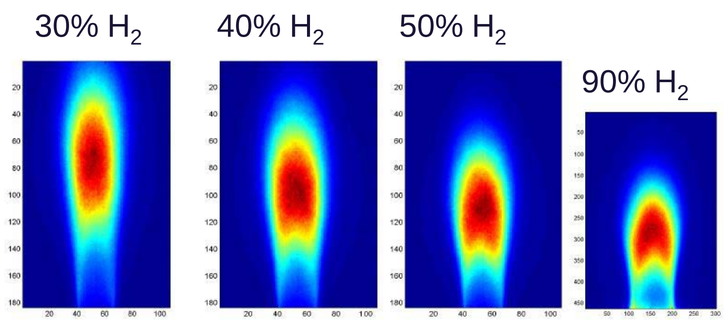


H_2 Impact on Package

- High volumetric fuel flow for the same energy content
- 3x higher flow velocity than CH_4
- Jet momentum (mixing) affected
- 10x higher flame speed

Hydrogen Flame

Flame location closer to the burner increases risk of flashback

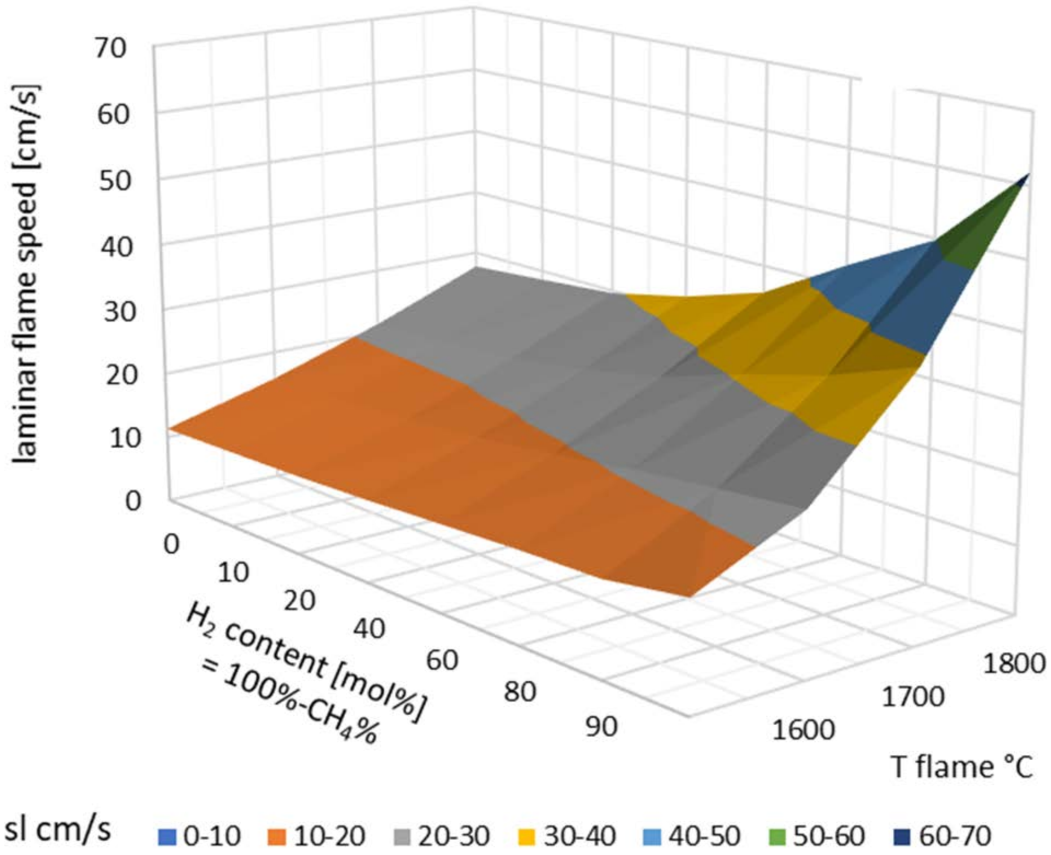


100% H_2 Combustion Kinetics

H_2 Impact on Combustion

- Increase of laminar flame speed with hydrogen %
- Increase of laminar flame speed with flame temperature
- Progressive increase of Flame speed with hydrogen

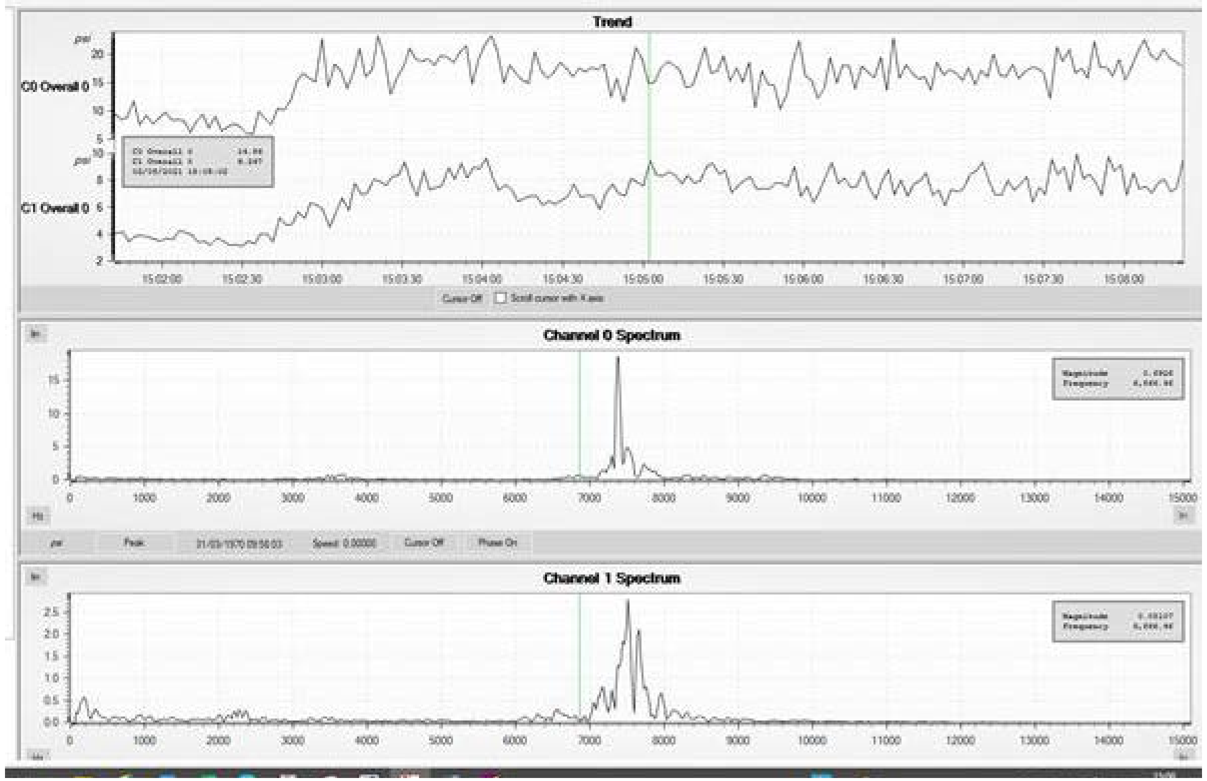
High engineering effort is expected to enable combustion systems for 100% Hydrogen.



The Combustion Dynamics Challenge

- The shorter Flame can change the combustion noise signature
- Generally, higher energy density promotes combustion dynamics
- Higher flow speeds into the combustor to combat flashback also raise the probability of high frequency dynamics (screech)

Rig testing of combustor sectors, or full-scale combustors alone cannot reproduce the acoustic environment of the gas turbine

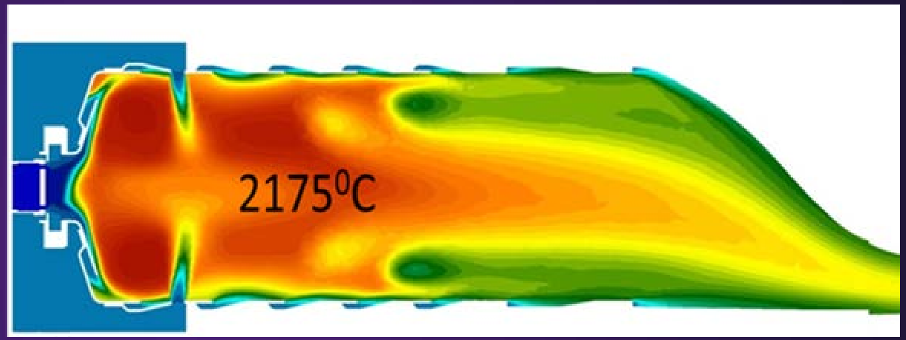


Gas Turbine Combustion Technology
Diffusion Flame Combustors (non-DLE)

Photo courtesy Luc Viatour

Advantages and disadvantages of non-DLE systems:

- Robust systems (100% H_2 on some Siemens Energy Platforms)
- High flame temperatures yield high NOx
- Water injection rates typical for NOx abatement



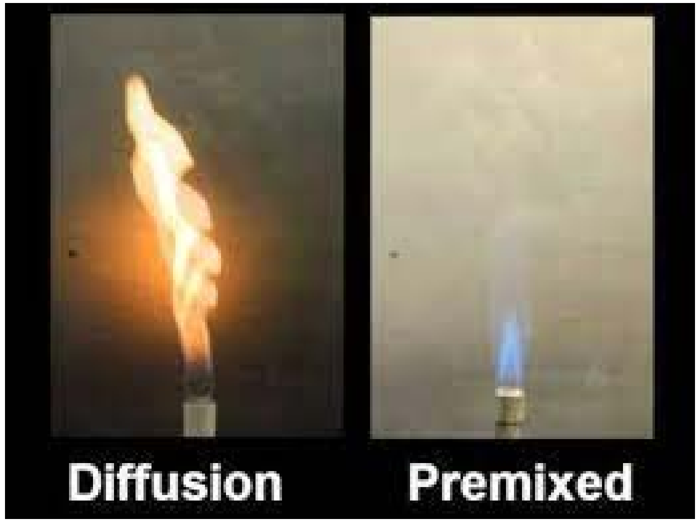
Diffusion Flame Combustor

Gas Turbine Combustion Technology
Dry Low Emissions Combustors (DLE)

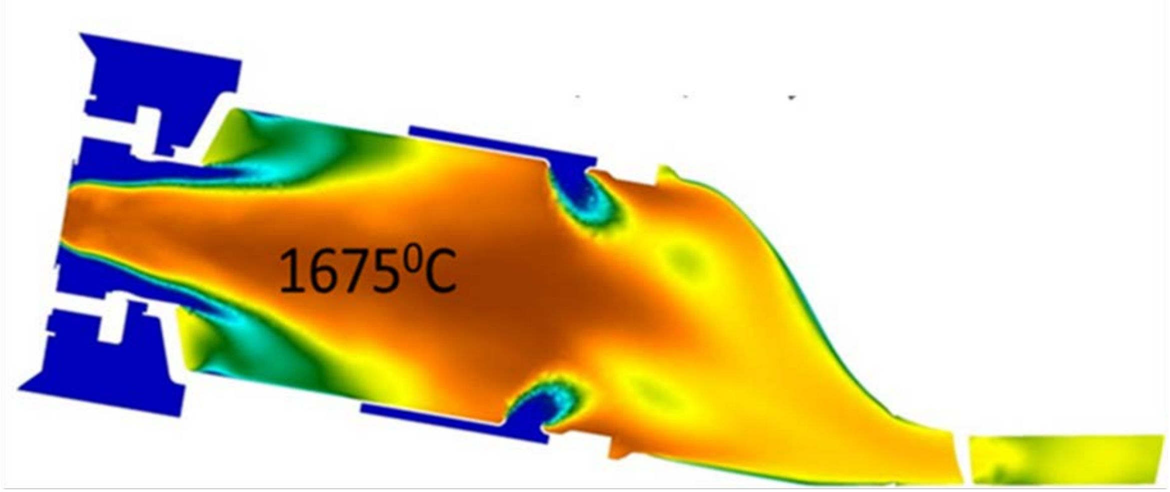
DLE Systems Will Require Significant Engineering Effort

Hydrogen’s higher reactivity poses specific challenges for the mixing technology in DLE systems:

- Flashback
- Lower Auto-Ignition
- Shift in Heat Release Distribution within the Combustor



https://www.youtube.com/c/firesciencetoolscom



DLE Combustor

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Siemens Energy Solution for different H_2 levels

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Differences in Design between “standard” and H_2-Gasturbines:

System/Procedures	H_2 Volume Impact on Package: 0% – 10% – 30%[1]	10% – 30%[1] – 50% – 70%[1]	50% – 70%[1] – 100%
Burners and combustion chamber	No change	Modified burner may be required	New burner design
Combustion monitoring system	n.a.	Changes required	Changes required
Fuel supply system	No change	Ensure all components Stainless Steel	Pipe diameter increase Purging system
Control/protection systems	No change	Additional gas detection Electrical: Gas Group IIC	
O&M Procedures	No change	Leak check of gas fuel system after maintenance inspections	Start-up/shutdown on conventional fuel
	No modifications needed	**Smaller modifications may be required**	**Modifications needed**

1 Percentage varies from GT model to model and emission limit requirements

Current Decarbonization Effort
SGT-A05 Case Study

Goal

- **100% Hydrogen** capability for both DLE and non-DLE systems

Approach

- Re-design fuel systems, burner components, and control logic upgrades
- Pre-mixer aerodynamic performance improvements
- Incorporate **Additive Manufacturing**

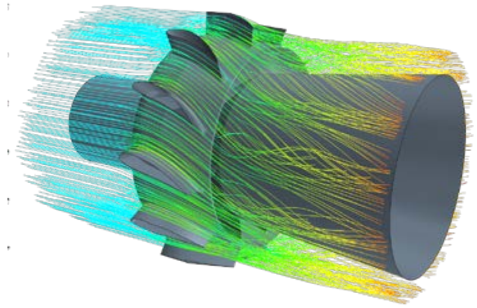
Deliverables

- Utilize **Hydrogen** by-products from petrochemical plants
- **Emissions reduction** from the current SGT-A05 DLE system
- Burn a wide range of hydrogen fuel blends

SGT-A05 DLE Case Study – Targeting Changes

Flame-Holding Margin

- Optimization of the aerodynamics entering, and within the pre-mixer are critical to success.
- Anticipated changes: faster average velocity through pre-mixer, smooth transitions of interfaces between parts, improved mixing aerodynamics
- Novel fuel injection techniques from the surfaces of the pre-mixer.



Emissions

- Shorter, more compact flames, burning closer to the pre-mixer exit will raise residence time for this dilution system influencing NOx.
- However, being a diluted combustor, the SGT-A05 can change primary zone temperature easily.
- Whether it can do so and remain operable over a wide range of hydrogen mixtures, must be proven through rig testing.

Fuel Flexibility

- It is unknown if the current simple fuel staging (pilot and premix) will be adequate to operate across a wide range of fuel properties.
- A change in fuel staging to use both stages in a premix mode may be necessary to achieve the full range of fuel flexibility.
- Novel fuel delivery technology is enabled using AM to minimize impact on system changes.

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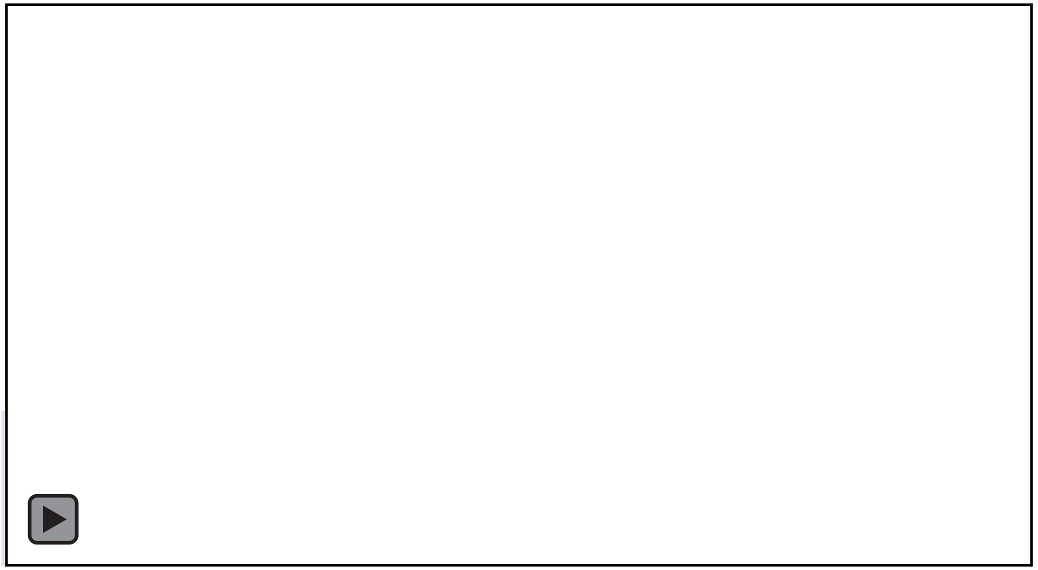
Hydrogen Combustion Key Enablers
High Fidelity CFD

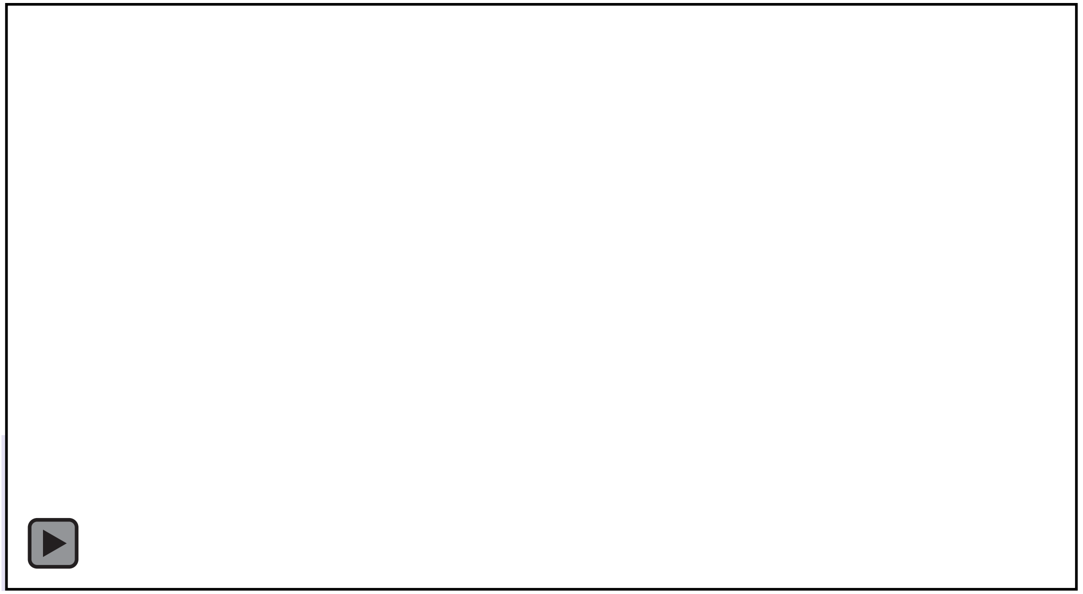
Provides critical insight to guide design decisions and test data

- Understand the velocity distribution in the pre-mixer and into the primary zone to combat flashback
- Insight on temperature distribution to target changes in areas of high NOx production

Can produce optimized designs

- Coupling with additive manufacturing opens this design space





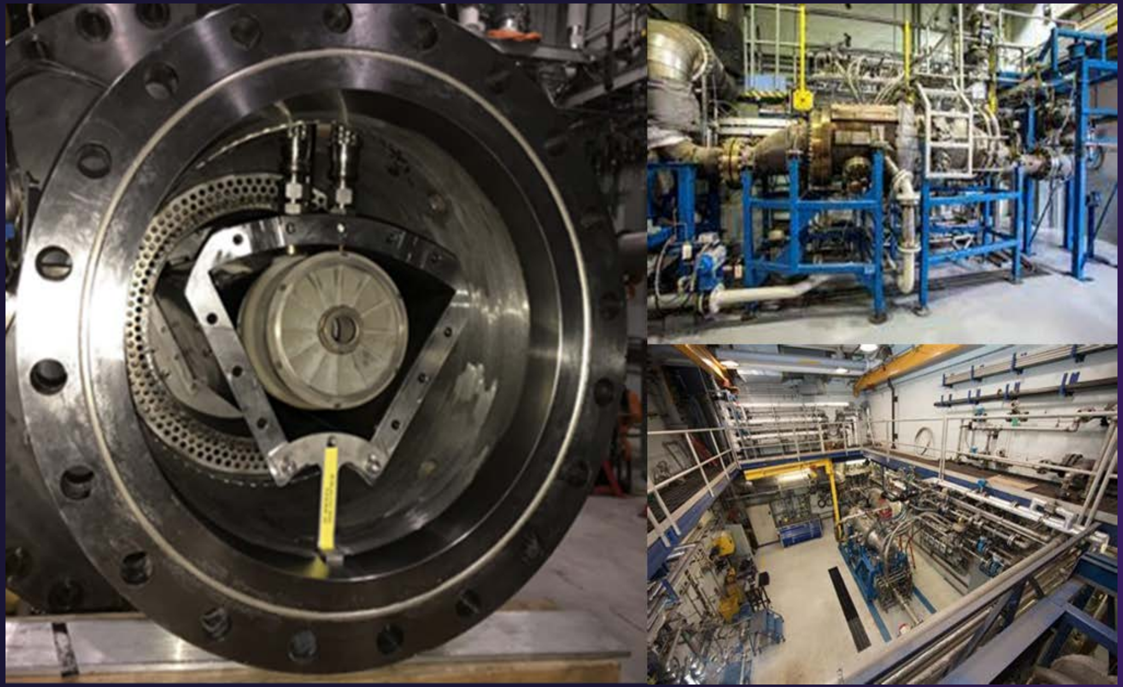
Hydrogen Combustion Key Enablers

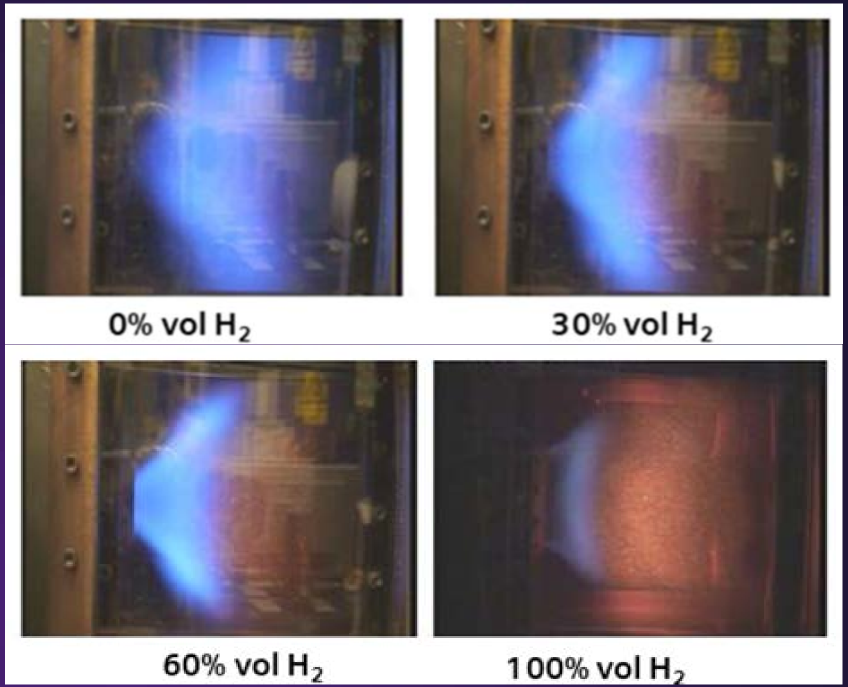
Additive Manufacturing Benefits:

- Enables the integration of innovative design features
- Accelerates technology validation time by up to 75%
- Supports the development of combustion technology that can overcome the challenges of hydrogen applications

Hydrogen Combustion Key Enablers

Extensive High Pressure Rig Testing



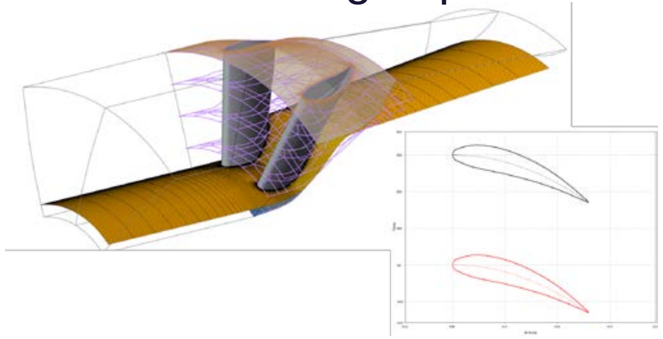


Conclusion

Rapid Design, Manufacture, and Testing Cycles Key to Success

1. Design and Analysis

High fidelity CFD tools like Large Eddy Simulations and design optimization



2. Rapid Prototyping

- Additive manufacturing reduces lead time and enables better designs
- Proven extremely successful for the SGT-A05 development program with entire AM combustion can assemblies reducing cost and lead time

3. High Pressure Testing

High-pressure burner tests combined with full engine tests

Rig Tests

Zero Emission H_2 Test center

Engine Tests

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