Hydrogen Capabilities of Siemens Energy Gas Turbines, An OEM Perspective

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Introduction

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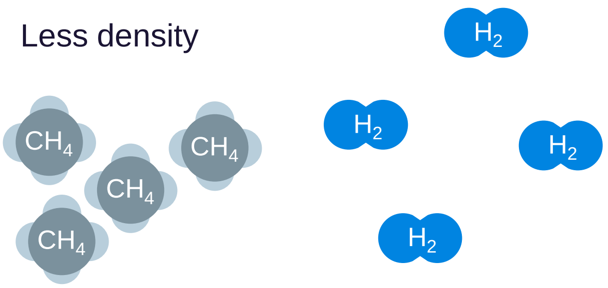
- Hydrogen is a promising fuel on the way to achieving future decarbonization targets.
- Conversion of excess renewable electricity via electrolysis to hydrogen adresses both fluctuation of renewable energy and storage issues, as well as creating sector coupling opportunities
- Utilisation of hydrogen in gas turbines ensures reduction of carbon footprint and future-proofing of power generation assets
- Initial plans are gradual blending of hydrogen with natural gas followed by full hydrogen operation
- Siemens Energy has committed to 100% hydrogen capability by 2030
- Based on long-standing field experience with syngas combustion systems, a technology program is well under way for 100% hydrogen DLN combustion systems

Zero Emissions via Hydrogen Combustion
Some physics to be handled in the system

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

Physics of hydrogen

Less density

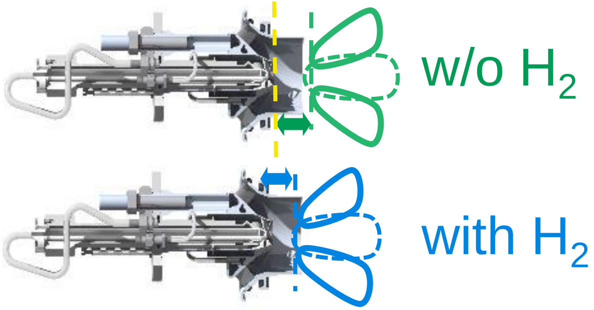


Higher
diffusivity

H_2 Volume Impact on Package

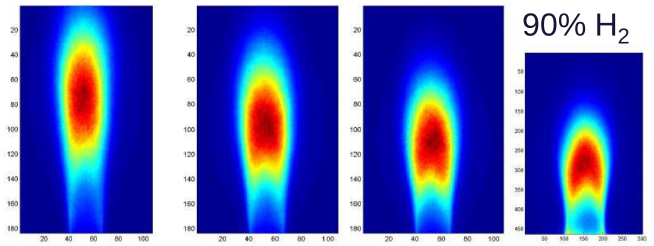
- Larger fuel flows to be handled in fuel system for same energy content
- Hydrogen gas travels ~3x faster than Methane gas
  → Flame speed ~10x faster
  → Explosive mixtures created quickly
  → Jet Momentum less coherent for mixing control
  → Flame stabilizes further upstream
- Decreasing CO_2 with increasing H_2% admixture

Hydrogen flame

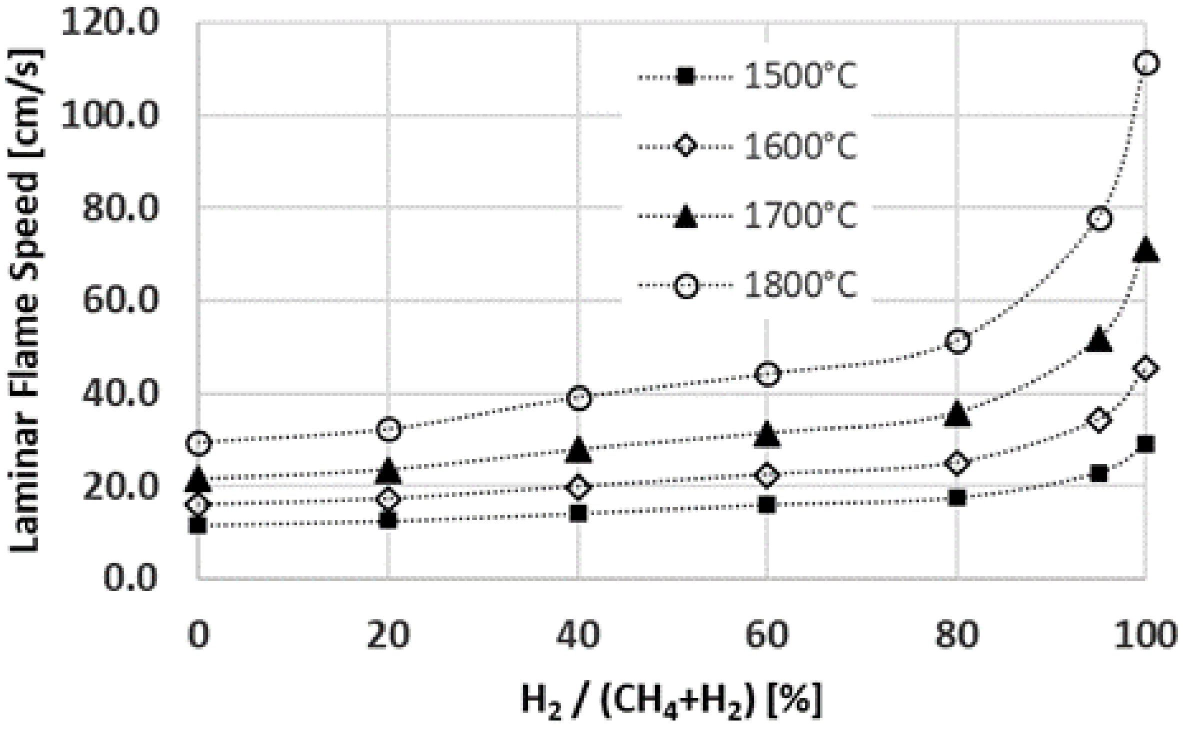


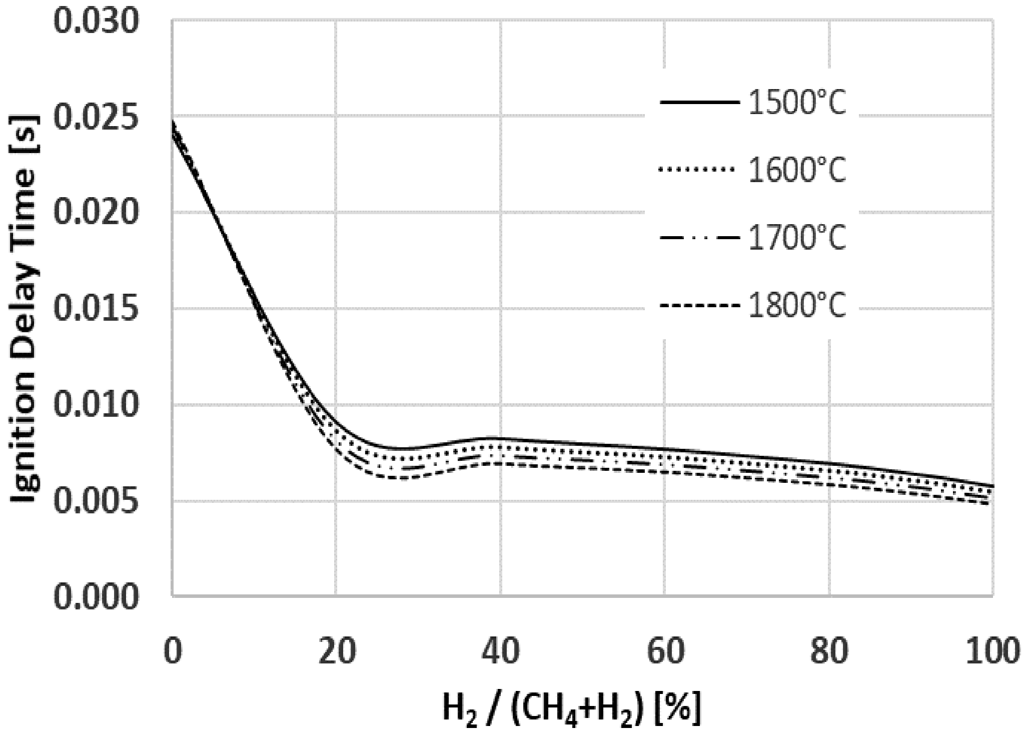
Flame location closer to the burner increases risk of flashback

30% H_2 40% H_2 50% H_2 90% H_2



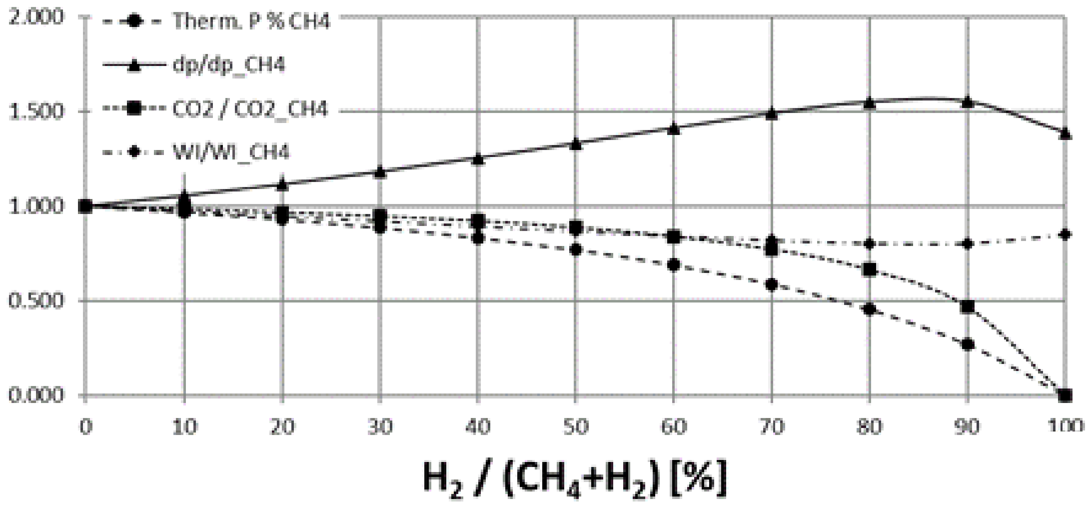
Effect of hydrogen addition on laminar flame speed and ignition delay time





- Laminar flame speed increases strongly above 90% hydrogen, especially at high flame temperatures
- Ignition delay time is shortened significantly already at 20% hydrogen addition to natural gas

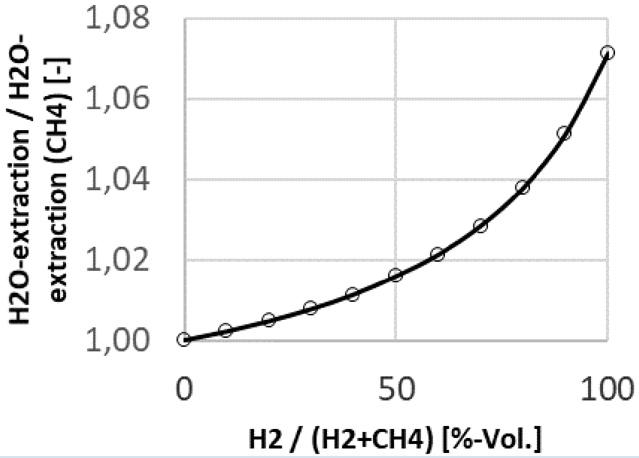
Effect of hydrogen addition on gas pressure drop, CO_2, Wobbe index and NO_x normalization

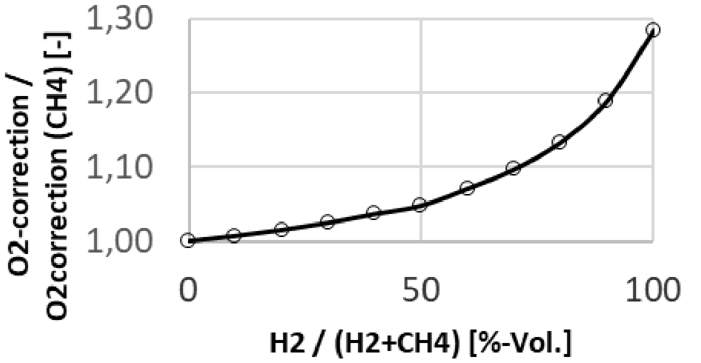


$$NO_x(dry, 15\%\ O_2) = \left[x_{NO} + x_{NO_2}\right]$$

$$* \frac{1}{(1 - x_{H2O})}$$

$$* \frac{0.2089 - 0.15}{0.2089 - x_{O_2}}$$





CO_2 reduction is only 50% at 90% H_2, thus despite all challenges, 100% H_2 is a key target

World fleet experience on high H_2 syngases for refineries and steel mills and other chemical industries

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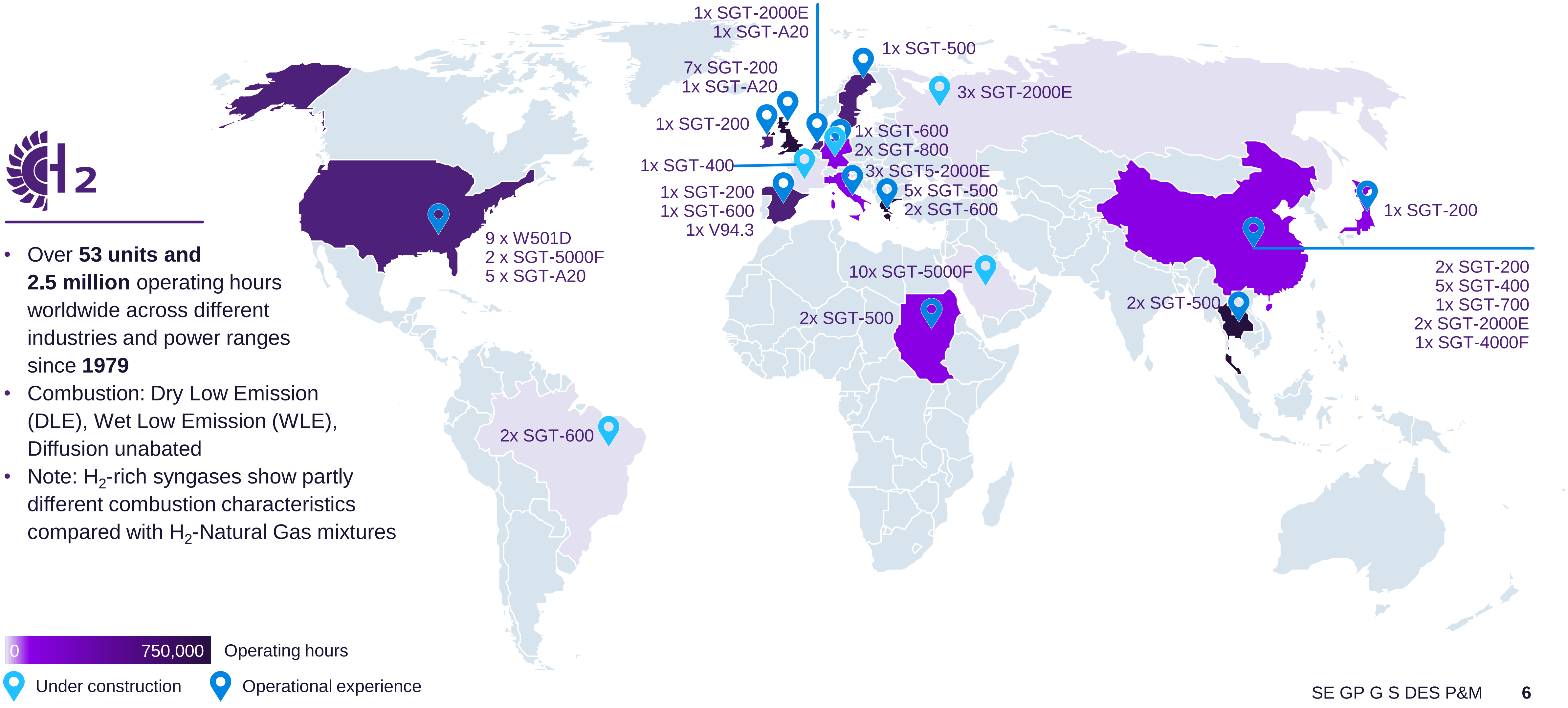
- Over **53 units and 2.5 million** operating hours worldwide across different industries and power ranges since **1979**
- Combustion: Dry Low Emission (DLE), Wet Low Emission (WLE), Diffusion unabated
- Note: H_2-rich syngases show partly different combustion characteristics compared with H_2-Natural Gas mixtures



Siemens Hydrogen Gas Turbines for our sustainable future
The mission is to burn 100% hydrogen

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Gas turbine model		Power Output[1]	H_2 capabilities in vol. %	CO_2 reduction[2)] [%]
50Hz	SGT5-9000HL	595 MW	50	23%
	SGT5-8000H	450 MW	30	11%
	SGT5-4000F	329 MW	30	11%
	SGT5-2000E	187 MW	30	11%
60Hz	SGT6-9000HL	440 MW	50	23%
	SGT6-8000H	310 MW	30	11%
	SGT6-5000F	215 to 260 MW	30	11%
	SGT6-2000E	117 MW	30	11%
50Hz or 60Hz	SGT-800	50 to 62 MW	75	47%
	SGT-750	40/34 to 41 MW	40	17%
	SGT-700	33 to 35/34 to 36 MW	75	47%
	SGT-A35	27 to 37/28 to 38 MW	15 / 100	5 / 100%
	SGT-600	24/25 MW	75	47%
	SGT-400	10 to 14/11 to 15 MW	10 / 65	3 / 36%
	SGT-300	8/8 to 9 MW	30	11%
	SGT-100	5/6 MW	30 / 65	11 / 36%
	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

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

1 Power output in MW at ISO ambient conditions and natural gas; Version 5.3, September 2021 2) Compared with 100% natural gas operation

Hydrogen does not produce CO_2 emissions, but challenging physical properties require rapid design and testing cycles

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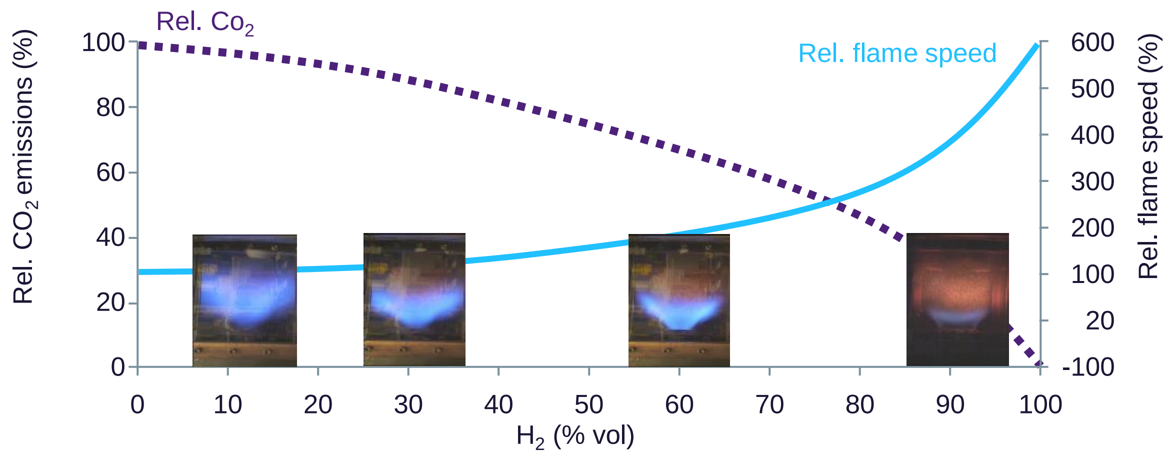
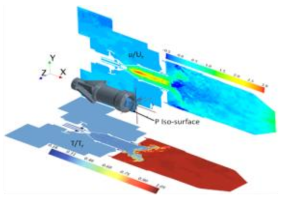


Values shown are relative to natural gas (indicative only)

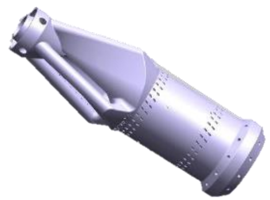
Challenges

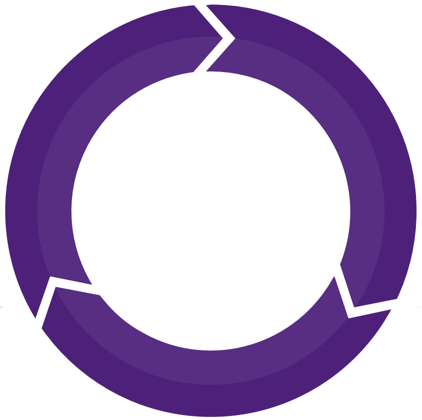
- **H2 embrittlement** requires upgrade to stainless steel materials
- **Lower volumetric energy content** requires larger flows to be handled by fuel system
- **Higher diffusivity** requires changes/re-certification of sealing and flanges
- **Higher reactivity and flame velocity** pushes flame towards burner and increases risk of flashback
- **Higher flame temperature** can lead to local hotspots if imperfectly mixed and thus increased NOx emissions

1. High fidelity CFD
High fidelity CFD tools like LES can provide automated optimized designs



2 Rapid prototyping using AM
Additive manufacturing reduces lead time and enables better designs





3. High-pressure testing at engine conditions
High-pressure burner tests combined with full engine tests

Combustion Test Center in Berlin

Burner Tests

Zero Emission H_2 Test center (Finspong)

Engine Tests

Use of Hydrogen in Gas Turbines with DLE requires extensive Combustion Technology development

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2004

SGT6-4000F
Burner Rig-Tested up to 40% H_2

SGT-5000F
Modified Burner Rig-Tested with up to 30% H_2

H_2-DOE Program
Focusing on LGT combustion technology, 2005 – 2015

SGT-8000H
Modified Burner Rig-Tested up to 40% H_2

BMWI Program
Focus on High Temperature Combustion with H_2, 2006 – 2009

SGT-9000HL
Combustion Technology tested for H_2 admixtures

2012

SGT-2000E
Modified Burner Rig-Tested up to 40% H_2

SGT-200
H_2 Engine Tests

2011

A45, A65
Atmospheric Combustion Tests up to 100% H_2

SGT-400
Continuous operation on coke oven gas >60%H_2

2008

DLE Technology development for Industrial Gas Turbines
Atmospheric and high pressure tests for Industrial Gas Turbines

SGT-700
First H_2 Tests in Full Engine Setup

SGT-700
Continuous Operation since Sept. 2014 (10% H_2)

SGT-800
50% H_2 admixture at Base Load

2018

SGT-600
Up to 80% H_2 admixture in Full Engine Test

2019

100% H_2
In Full Pressure Combustion Test at CEC Test Center for SGT-600

100% H_2 in Aero Derivative Gas Turbines
Using Wet Low Emission Technology

DLE Technology for High Temperature Combustion
Extending technology towards 100%-H_2

100% H_2 in an SGT-400 Industrial Gas Turbine
Using Dry Low Emission Technology

2023

Prototype applications
First customers for 100%-H_2 in Heavy-Duty Gas Turbines expected end of 20s

100% H_2 in Heavy-Duty Gas Turbine
Using Dry Low Emission Technology

100% **Green Gas Turbines**

EU-funded HYFLEXPOWER Project (France)

A CO_2 free power-to-power path using 100% H_2 in DLE combustion

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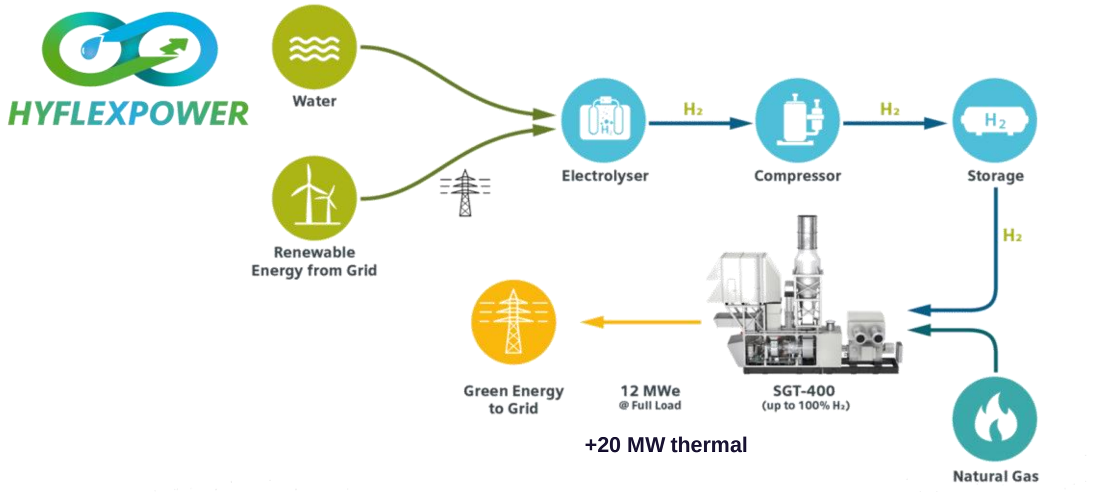

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May 2020 — 2021 — 2022 — 2023

May 2020: Contract finalization and start of engineering development

2021: Installation of the hydrogen production, storage and supply facility at pilot demonstration site

2022: Installation of the gas turbine for natural gas/hydrogen mixtures and initial demonstration of advanced pilot plant concept

2023: Pilot demonstration with up to 100 percent hydrogen for carbon-free energy production from stored excess renewable energy

Source: http://www.hyflexpower.eu/

Conclusions

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- Hydrogen is destined to play a central role in decarbonization of power generation
- Utilization of hydrogen in gas turbines requires special measures in fuel distribution, control and protection systems
- DLE operation of combustion system with 30 to 50% hydrogen is possible with existing combustion technologies
- 100% hydrogen DLE systems are being developed with major changes to the designs and implementation of new technologies with very succesful results
- Conversion of natural-gas based Siemens Energy power generation technology to hydrogen is fully underway as service upgrades and new equipment

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