H_2 Readiness, Challenges and Solutions – the OEM View”

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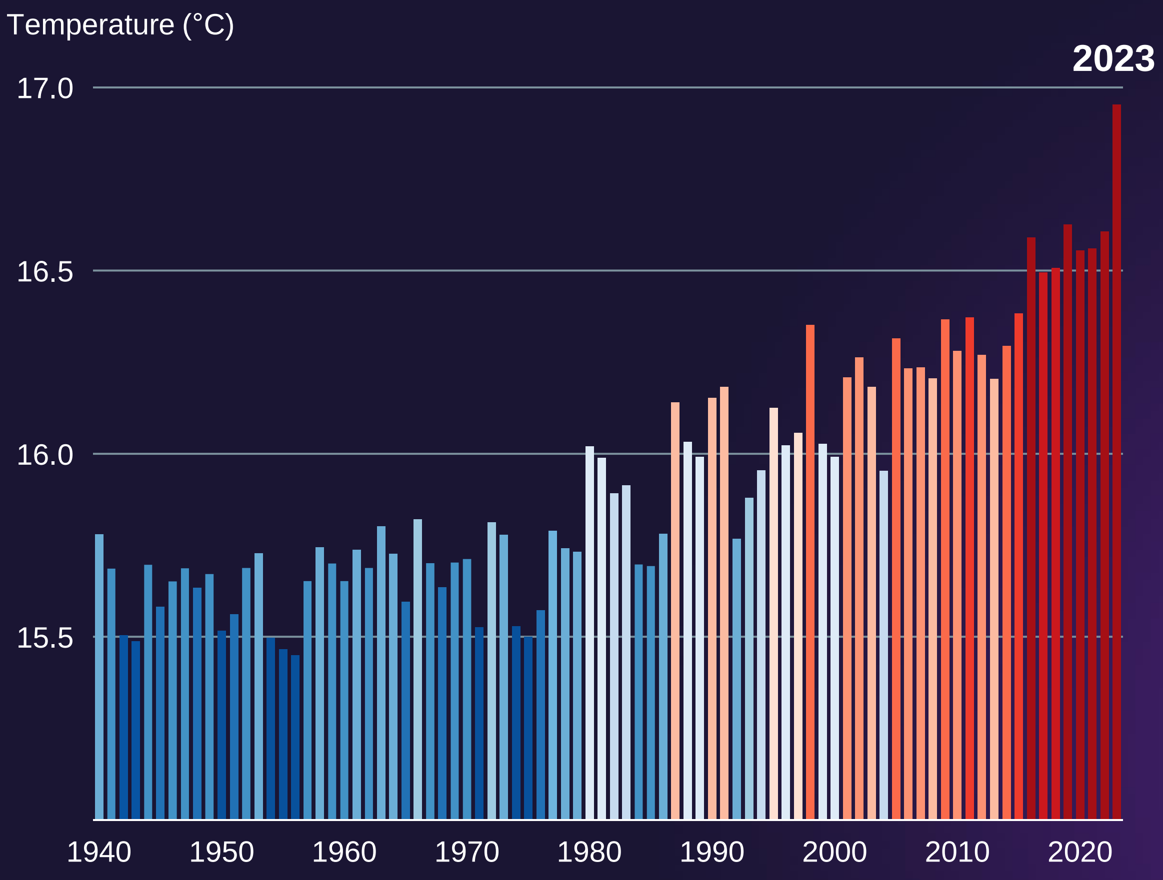
2023 was the warmest year on record. By a record margin!

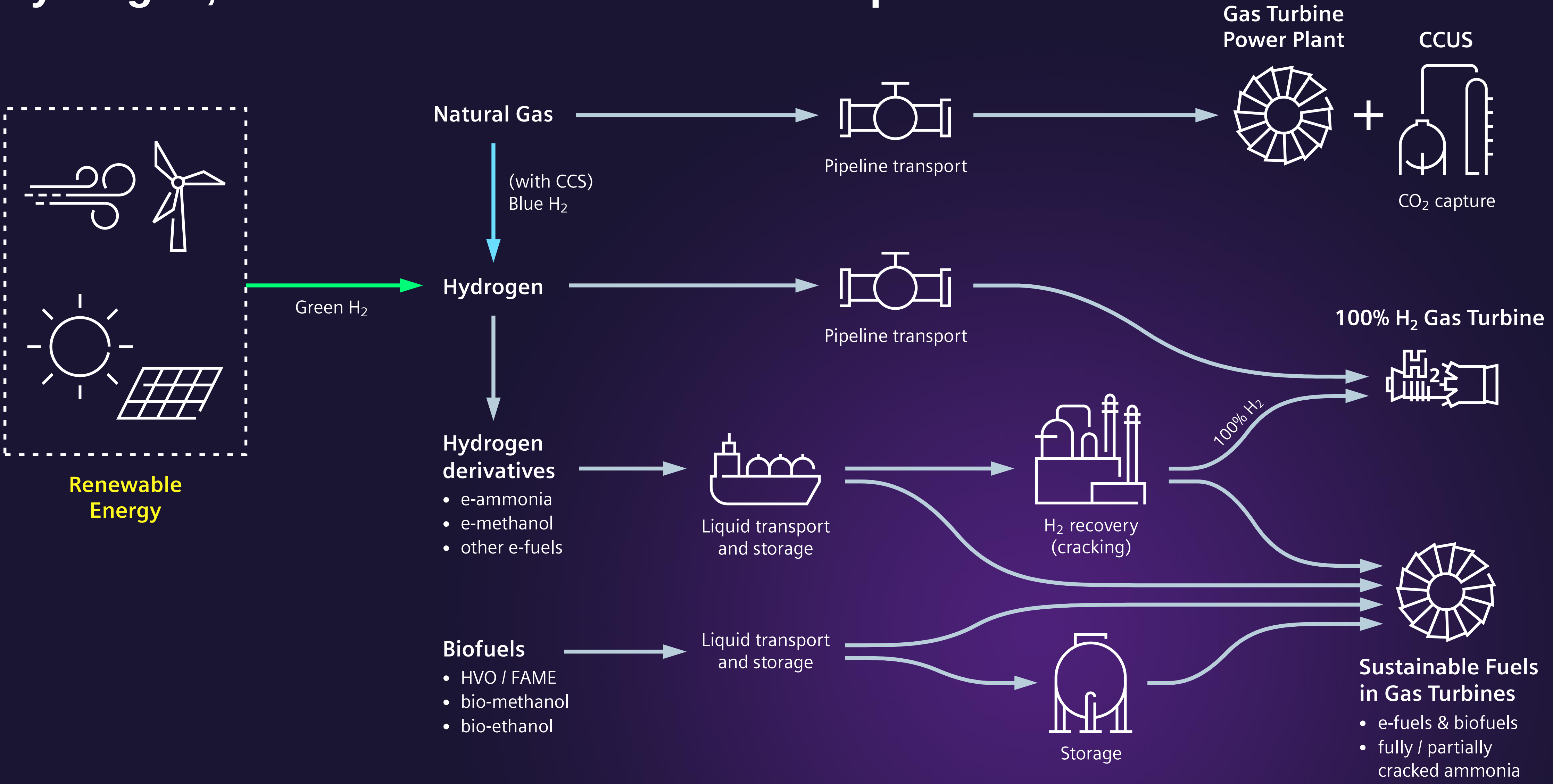
Global surface air temperature (July)



Source: C3S, on behalf of EU Commission; Documentary “Voice of the glaciers”

Glacier in Svalbard (Norwegian archipelago in Arctic Ocean)

Decarbonization pathways for gas turbines
Hydrogen, sustainable fuels or carbon capture?



Zero Emissions via Hydrogen Combustion
Fuel Characteristics

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

H_2 Properties are different from NG

Hydrogen has lower density & volum. energy content (~1/3 of NG)
Prone to leakage. Requires larger flows to be handled by fuel system, but the Wobbe Index remains in natural gas range, i.e., 37 – 49 MJ/Nm³.

Hydrogen has wider flammability limits (H_2: 4-75% NG: 5-15%)
Much wider range of fuel/air-ratio to burn compared to natural gas. Adaption required of ventilation and gas detection system as well as fuel system.

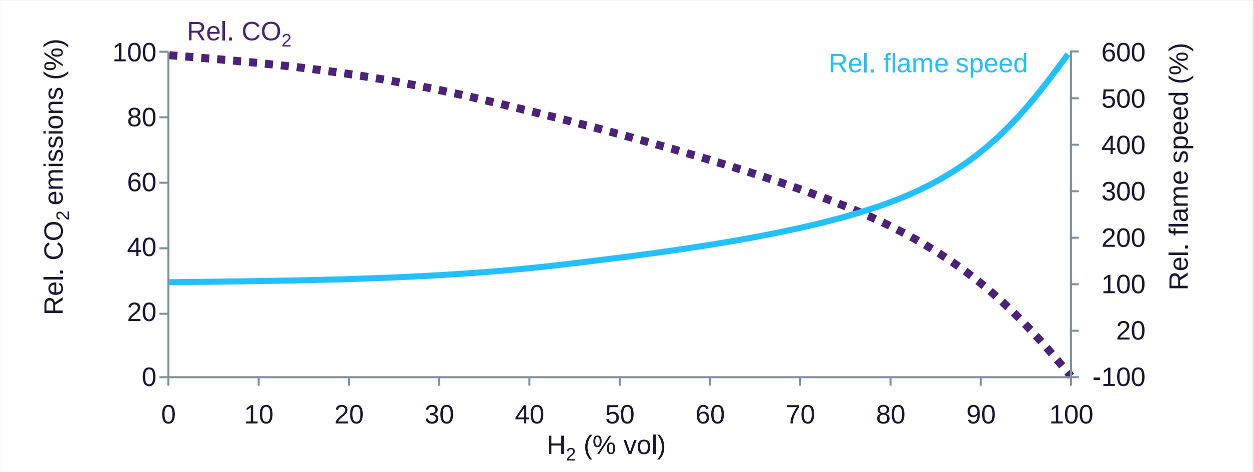
Hydrogen has lower ignition energy (~15 times lower than NG)
Only a fraction of ignition energy is needed to get H_2 "going" compared to natural gas

Hydrogen auto-ignites & burns faster (up to 10x faster than NG)
H_2 combustion moves flame closer to injector – avoidance of "flash-back" by optimizing air and fuel distribution.

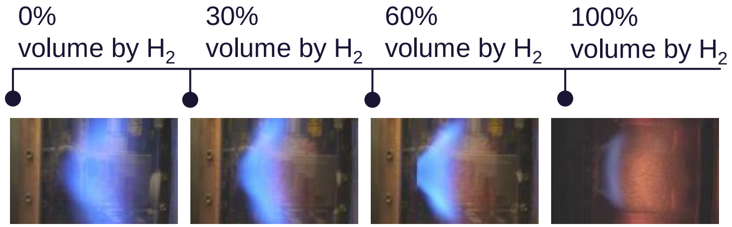
Risk of changing combustion pressure pulsations may damage hardware.

Hydrogen has higher flame temperature (~200°C higher than NG)
Potential for increased NOx emissions from unmixed regions**.**

Hydrogen Reactivity



Values shown are relative to natural gas (indicative only)



NOx emissions are dependent of the fuel used

NOx emissions are usually measured in **relative concentration** units (ppm, mg/Nm^3), referenced to dry exhaust and 15% O_2 content in exhaust

When burning hydrogen, due to the much higher water content in the exhaust gas and lower flue gas volume, the calculated NOx values are **overinflated by up to 37.2%**

➔ A **new emission unit is required** to provide a true and fair comparison of different fuels and power generation technologies (e.g. with a fuel correction factor or measurement in mg/kWh energy output).

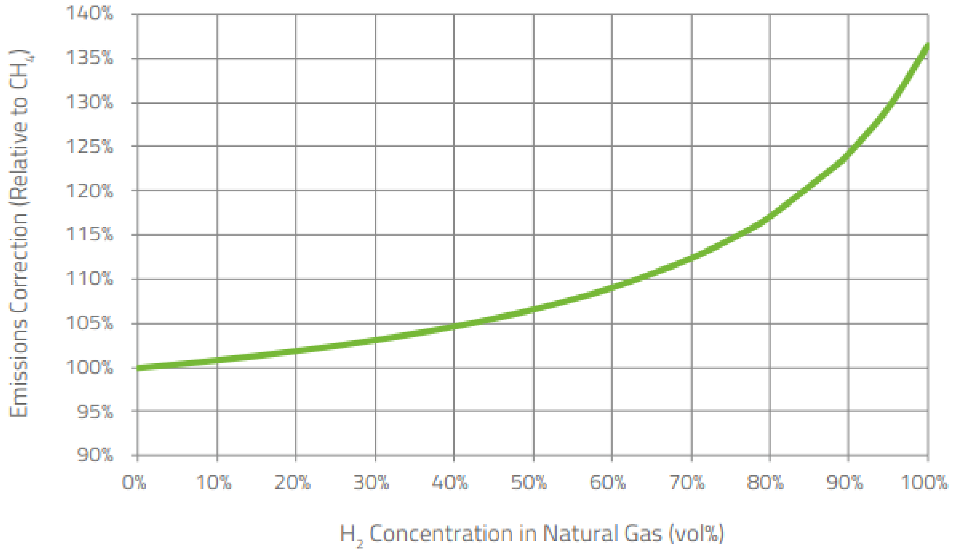


Figure 1. Energy-based emissions correction factor for increasing hydrogen content in natural gas

Source: Position Paper by European Turbine Network, 2023

“H2 Readiness” and “H2 Capability” does not mean the same!

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Step 1: H_2 Readiness

A power plant is considered H_2 ready if the powerplant is pre-equipped upfront for a future retrofit to the defined level of H_2. The pre-equipment is an optimization between initial investment and later retrofit costs and allows for a later conversion with economically reasonable costs/disruption

Step 2: H_2 Capability

A power plant is considered “H_2 capable” if all the installed equipment is fully capable of operating up to that defined level of H_2.

Examples:

- 50% “H_2 readiness” means the plant is designed for operation with natural gas, but already prepared for a later retrofit to 50% hydrogen capability
- 30% “H_2 capability” means the plant can operate with up to 30% hydrogen content without any additional changes
- A new plant built “100% H_2 ready” and “30%H_2 capable” means the the plant can operate at 30% initially and is prepared for a later retrofit to 100% capability

H2 Ready Concept with TÜV Süd Certificate

SE is able to offer H_2 ready power plants to customer H2 requirements

- New build power plants prepared for later retrofit to hydrogen (“H_2 ready plants”) when immediate H_2 operation is not required/possible yet:
  - Optimized equipment configuration meeting future plant H_2 roadmap.
  - Plant with low additional front-end investments.
  - Offering allows for future H_2 retrofit with low costs/disruptions.
  - Backed by TÜV Süd Certification scheme for bidding, construction and retrofit phases

TÜV Süd Concept Certificate for Bidding Phase

CONCEPT CERTIFICATE

Industrie Service

The Certification Body of
TÜV SÜD Industrie Service GmbH
Energy and Systems

certifies, that the hydrogen readiness concept for the bidding phase of new build power plants using the SGT-800 gas turbine of the company

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complies with the requirements of the concept certification defined in the TÜV SÜD Standard

Certification Guideline H_2-Readiness of Combined Cycle Power Plants,

issue date November 2021.

This Certificate is based on the Audit report 500603558-50 Rev.2 dated 23.11.2021.

This certificate is valid till 10.11.2024

Certificate – Register-No.: KC/500603558/32/21-1

Munich, 24th November 2021

Dr. Thomas Gallinger
Technical Certifier
Certification Body Energy and Systems

Katrin Hausmann
Certification Body
Energy and Systems

ZERTIFIKAT ◆ CERTIFICATE ◆ CEPTИФИКАТ ◆ CERTIFICADO ◆ CERTIFICAT

The Certificate confirms that SE offering is H2 ready according to technical requirements and customer specific boundary conditions considering:

Areas:	Equipment/Systems considered:
Fuel Supply:	Materials, sizing, aux. fuel, metering, additional systems...
Gas Turbine:	Combustion System, Burner, Package Systems, etc.
Fire/Ex Protection:	Fire/Ex protection concepts, space provision for inert. system
HRSG:	Materials, temperatures, purging requirements
I&C & Electrical:	Design acc. to IIC*
Safety:	Safety Integrity Levels definition and design

*or equivalent NFPA requirement, e.g. “NEC 500 Class I Div. 2 Group B.”

Hydrogen co-firing capabilities of Siemens Energy gas turbines

Heading towards 100% with full fuel flexibility H_2 ↔ Natural Gas

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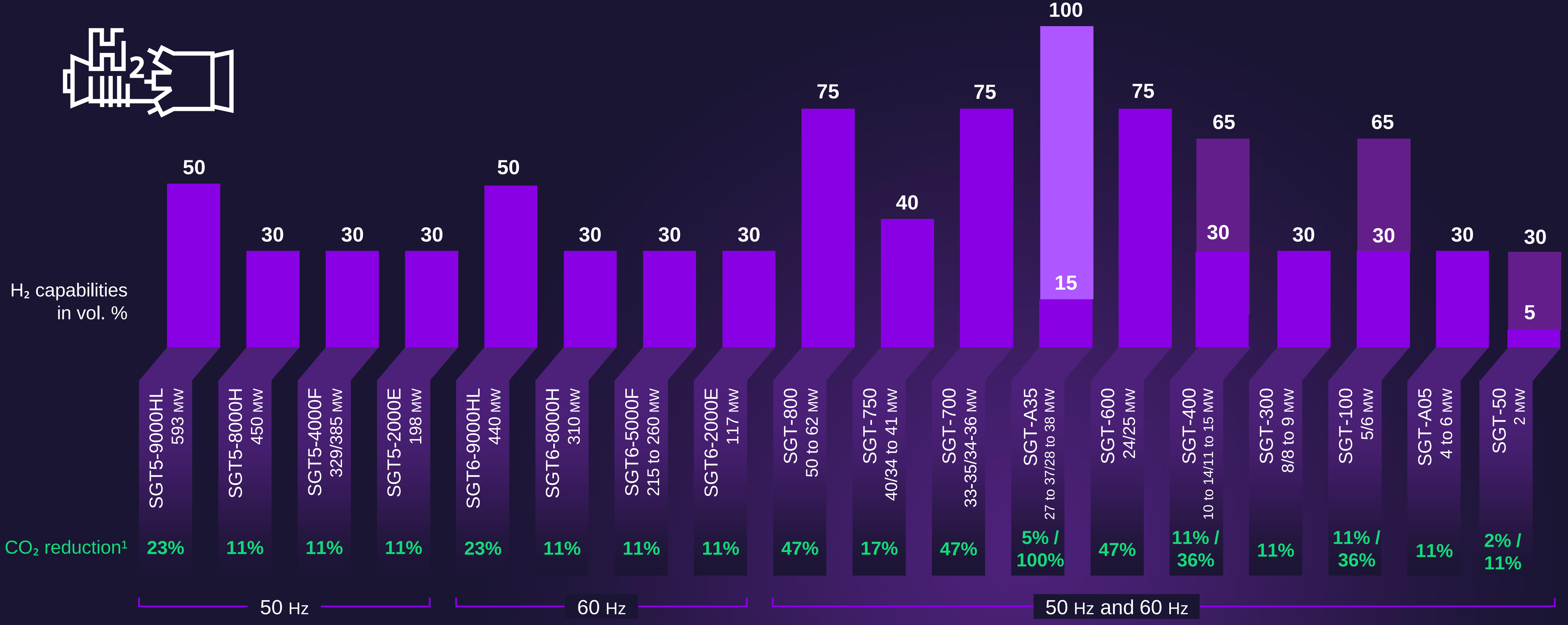

Power output in MW at ISO ambient conditions and natural gas

[1] Compared with 100% natural gas operation

DLE burner

WLE burner

Diffusion burner with unabated NO_x emissions

Hydrogen as a Gas Turbine Fuel

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100% H_2 DLE requires extensive combustion technology developments.
0%-100% H_2 in Natural Gas DLE was demonstrated in SGT-400 in 2023.

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

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

2008

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

Start of cross-frame technology development for 0-100% H_2 GTs

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

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

2023

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

Prototype applications
First customers for 100%-H_2 in Industrial Gas Turbines expected mid-late 2020s

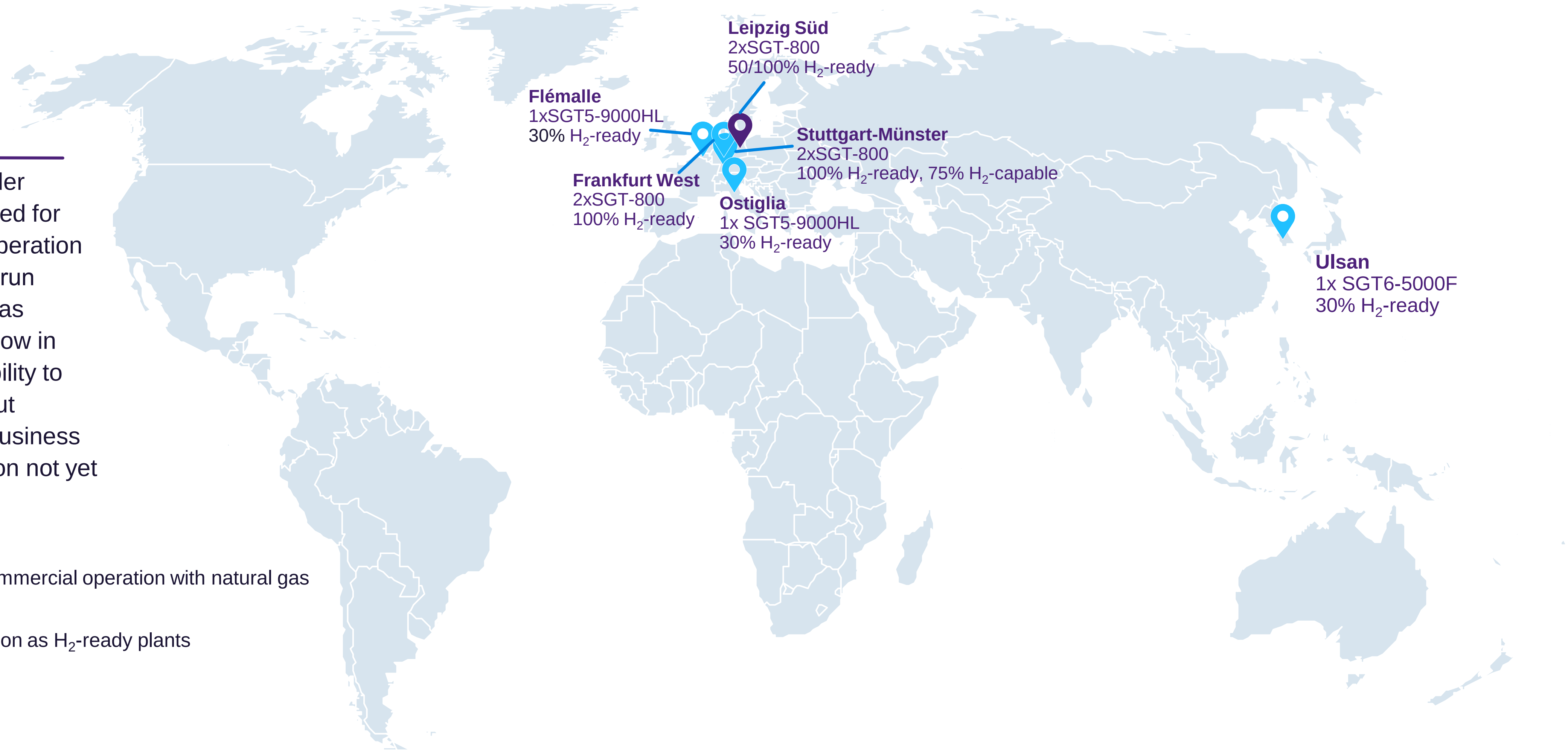
100% H_2 in Heavy-Duty and Industrial Gas Turbines Using Dry Low Emission Technology

100% **Green Gas Turbines**

H2-Ready power plants are increasingly being offered and contracted throughout the world.

H2-Ready

- 7 Gas Turbines under construction prepared for later retrofit to H_2 operation ("H_2-ready"), but to run initially on natural gas
- These units also show in partial actual capability to run on hydrogen, but availability and/or business case for H_2 operation not yet there.



H_2 -ready plants in commercial operation with natural gas

Units under construction as H_2-ready plants

Reference
HKW Leipzig Süd, Germany

Combined heat and power plant

Customer: Stadtwerke Leipzig GmbH
Country: Germany

Commercial operation: 2022

Challenge

- New gas power plant to substitute existing heat supply from nearby lignite power plant
- Successive conversion from natural gas to hydrogen operation
- The plant is expected to **operate with 30 to 50 percent green hydrogen** only a few years after start of commercial operation
- The long-term goal is to operate the facility with **100 percent green hydrogen**

Technology

- 2 x SGT-800 62 MW gas turbines
- 2 x SGen-100A generators
- SIESTART battery energy storage system
- Long term service contract over a period of 15 years

Solution

- The new gas power plant, with combined heat and power technology, will produce electricity and district heat for the city
- Successive conversion to hydrogen operation paves the way for Leipzig's decarbonization
- Electrical capacity of ~125 MW and thermal capacity of ~163 MW
- Up to 93% plant fuel efficiency thanks to district heat production (41% electrical efficiency)
- Commissioning scheduled for end of 2022

Benefits

- High electrical and total plant efficiency
- Lowest emissions in its class with outstanding high fuel flexibility
- Competitive lifecycle costs
- Reliable and secure combined heat and power plant with black start capability
- Sustainable and future proof district heating power plant

60% Hydrogen at 25ppm NO_x

Customer: Braskem

Country: Brazil

Commercial operation: 2022

Hydrogen gas turbine reference
Braskem, Brazil

Challenge

- Low cost for O&M
- Use of hydrogen as fuel gas to reduce use of natural gas, up to 60% but not exceeding 25 ppm NO_x
- Reduced need for external grid supply
- High availability and reliability

Technology

- 2x SGT-600 PG with 3rd generation DLE system for up to 60% H_2 co-firing at 25ppm NO_x
- Operation at up to 88% H2 blending rate has been demonstrated

Solution

- Advanced Additive manufactured burners capable for 100% H_2
- Complete plant delivery, Siemens Energy will build, own & operate the CHP, HRSG and gas compressor
- O&M contract based on delivery of steam and power

Benefits

- Fuel cost savings operation on high levels of hydrogen in DLE, no need for water injection
- Lowest emissions using the latest DLE combustion system and control system <25 ppm NO_x
- Predictable operation and maintenance cost
- Tailor made flexible solutions in all important aspects

Zero Emission Hydrogen Turbine Center

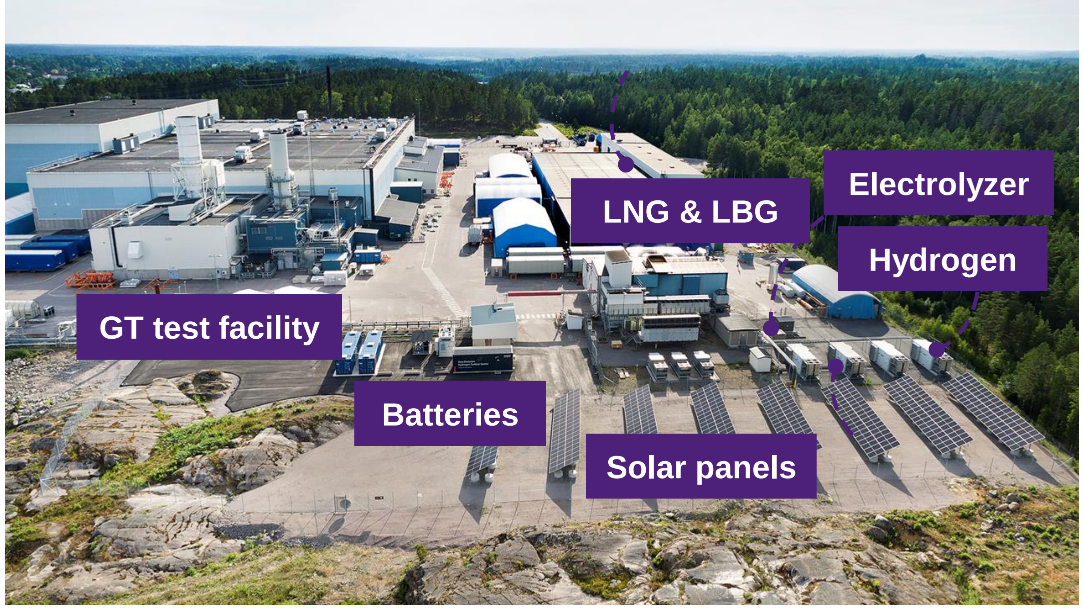
The zero emission demonstrator plant at the gas turbine test facility in Finspång, Sweden

- Use of **excess power from turbine test runs** to **produce hydrogen** in an **electrolyzer**
- **Solar panels** for continuous green hydrogen production
- A **micro grid** together with **batteries for backup**
- Utilization of the produced hydrogen as a turbine fuel for upcoming turbine tests to **reduce our own LNG consumption and provide inhouse testing of 3D-printed hydrogen burners**

Three-year project with funding from EU

- **Start of operation in 2021**
- Supports Siemens Energy´s efforts in achieving
  - **100% hydrogen ready gas turbines by 2030**
  - **climate neutral own operations by 2030**
  - **green electricity 100% of own power consumption by 2023**
- Funded by the six partners and EU project **ERA-Net Smart Energy Systems** program through the **Swedish Energy Agency**

The **future energy system** on display

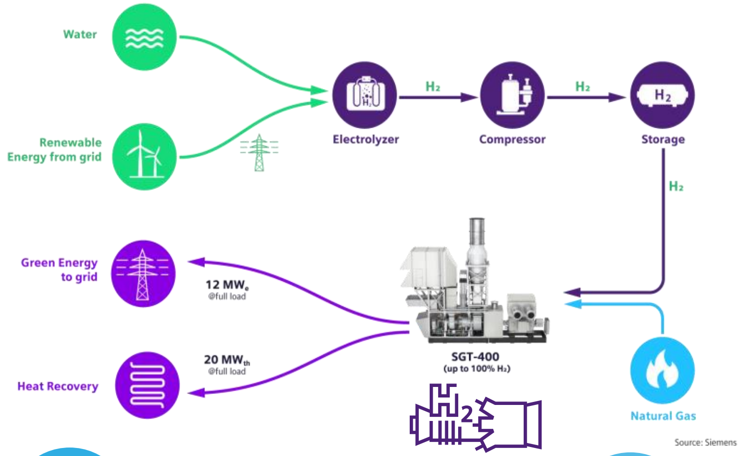


EU-funded HYFLEXPOWER Project

100% H_2 gas turbine in DLE mode demonstrated in Sept. 2023

World-first demonstration of a **power-to-H_2-to-power path for CO_2-free** power generation pilot including an advanced DLE **H_2 gas turbine**

- Decarbonizing papermill by modernizing combined heat and power plant in Saillat-sur-Vienne, France.
- Siemens Energy led consortium of EU funded 4-year project until 2024



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

Milestones

2021
- Installation of the **H_2 production, storage** & supply facility at site

2022
- Initial demonstration of **advanced plant concept** with NG/ H_2 mixtures up to 30%

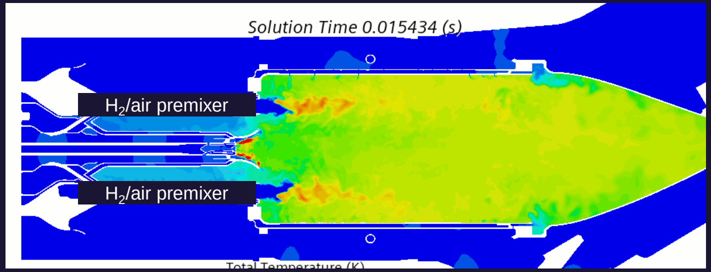
2023
- Demonstration of up to **100% H_2 for carbon-free energy production** from stored excess renewable energy successfully demonstrated in Sept. 2023

HYFLEXPOWER 100% Hydrogen Gas Turbine
DLE Combustion System Development

High Fidelity Simulations

Full system assessment

Massively parallel computations with >1,000 CPUs for ~2 weeks



Automated design optimization

Enabling > 1,000 design iterations

Rapid Prototyping using AM

Additive manufacturing enables

- Monolithic prints
- Complex internal purging features for extended flashback margin
- Internal cooling features
- Advanced mixing concepts for low emissions
- Fast design iterations due to rapid prototyping

26 Hardware variants have been tested

Iteration Loop

Design Validation

High-pressure combustion tests at Clean Energy Center (CEC) in Berlin

48 Test Days In 5 campaigns

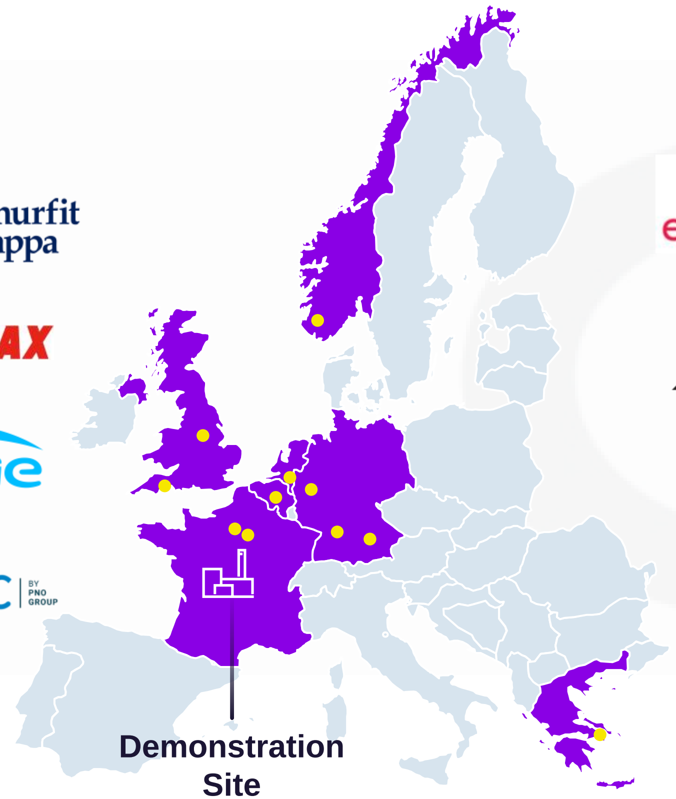
2 x SGT-400 engine tests at customer site

2 Test Campaigns with Natural Gas in Lincoln

Developed and Demonstrated DLE combustion system with 100% H2 at SGT-400 engine conditions

EU Clean Hydrogen Partnership: HyCoFlex Project Executive Summary and Consortium Partners

HyCoFlex



Smurfit Kappa

CENTRAX

ENGIE

ARTTIC BY PNO GROUP

equinor

DLR

SIEMENS energy

National Technical University of Athens

Demonstration of the power-to-H_2-to-power **cogeneration plant** with an **H_2 gas turbine** for flexible operation with **NG/H_2 fuels up to 100% H_2**

- HyCoFlex project will utilize and advance the infrastructure of the HYFLEXPOWER advanced plant concept

- **Key Targets**
  - 100% H_2 capability without derate
  - Operate on blends of H2 and NG from 0-100% H_2
  - <25 ppm NOx (without SCR).
  - Efficiency to be within 0.5%-2.0% at 100% load.
  - Achieve minimum load ramp-rate of 10% @100% H_2
  - Accommodate H_2 fluctuations ±30% vol./min.
  - At least 60 cummulative fired hours of H_2 operation.

- Overall budget: ~ 10.2 M€
- EU contribution: ~ 4.44 M€
- UK contribution: ~ 1.56 M€
- Project Start: February 1, 2024 | End Date: October 31, 2026

This project is supported by the Clean Hydrogen Partnership and its members Hydrogen Europe and Hydrogen Europe Research (GA 101138002).
This project is co-funded by UK Research and Innovation.

Clean Hydrogen Partnership

Co-funded by the European Union

UK Research and Innovation

Siemens Energy is the right partner for hydrogen-fueled gas turbines in a sustainable, hydrogen-based energy world

Hydrogen capabilities in Siemens Gas Turbines

- All newly built Siemens Energy gas turbine types capable to burn different levels of hydrogen in the fuel mix
- Smaller hydrogen contents not requiring any modification compared with standard natural gas turbines (new unit applications)
- Operating gas turbines[1] (field installations) able to be upgraded to burn hydrogen
- Siemens Energy with a roadmap in implementation to burn 100% hydrogen fuel in gas turbines

Conclusions

- Existing assets and future **investments in gas turbines are protected** also in a fully decarbonized world
- **Carbon-free power generation** in gas turbines with green hydrogen
- Hydrogen-capable gas turbines with **increased fuel flexibility** to burn both hydrogen and natural gas
- Siemens Energy gas turbines **fully compliant with emission limits** when burning hydrogen

1 Limits to be evaluated

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Siemens Energy H_2 web page

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