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H2-Gasturbinen zur Dekarbonisierung der Residuallast - Status quo und Ausblick

17. Niedersächsische Energietage, Fachforum 2
Hannover, 3. Dezember 2025

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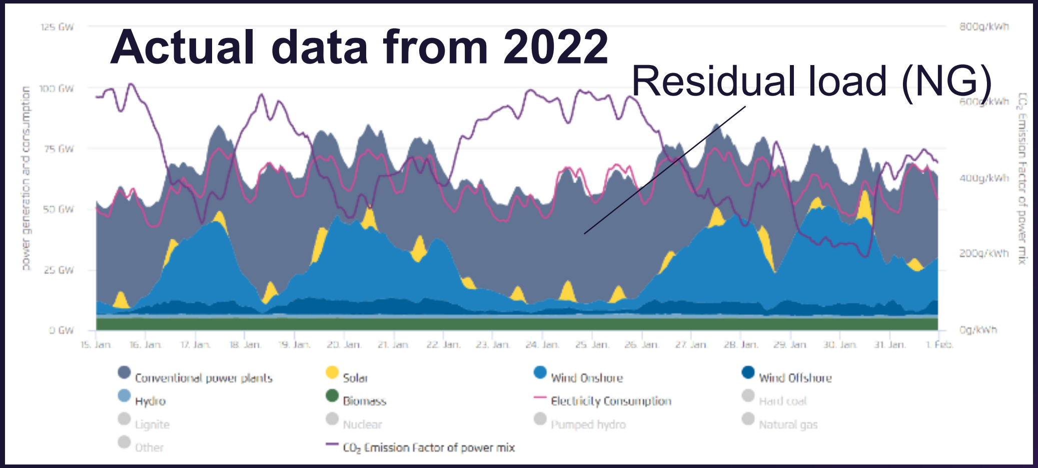
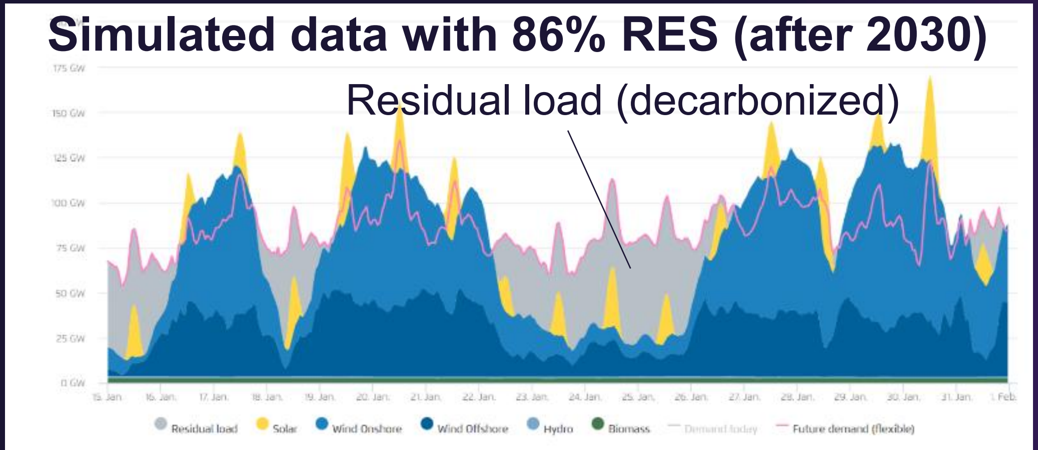
VP Hydrogen & Decarbonization Strategy

Gas Power Plants operating with Decarbonized Fuels will ensure Security of Supply by providing Residual Load in grids largely dominated by Renewables





Source: Agora Energiewende, Future Agorameter, Data for Jan. 15th-31st, 2022

Residual Load Definition: Remaining load required to bridge the gap between demand and renewable energy production at any point in time.

Characteristics of Residual Load:

- For regions with high RES penetration, the residual load demand may drop to 15-25% of the hours of the year
- New build residual load gas power plants must be ready to be upgraded to decarbonized fuels (e.g. hydrogen, bio- or e-fuels) as soon as these fuels become available.
- Future RES load surpluses will increasingly be used to produce the H_2 required for later re-electrification especially to cover seasonal RES variations

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

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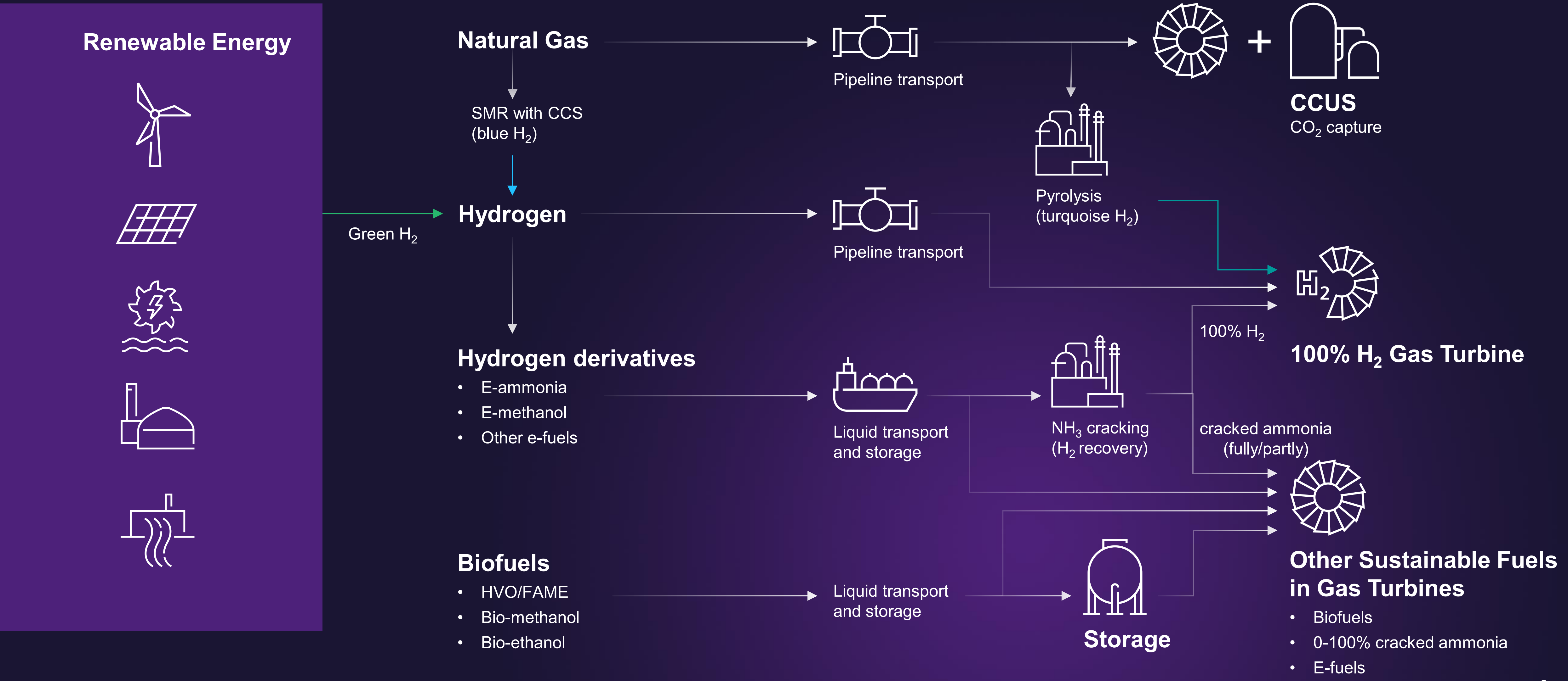

Hydrogen does not produce CO_2 emissions, but challenging physical properties require rapid design and testing cycles

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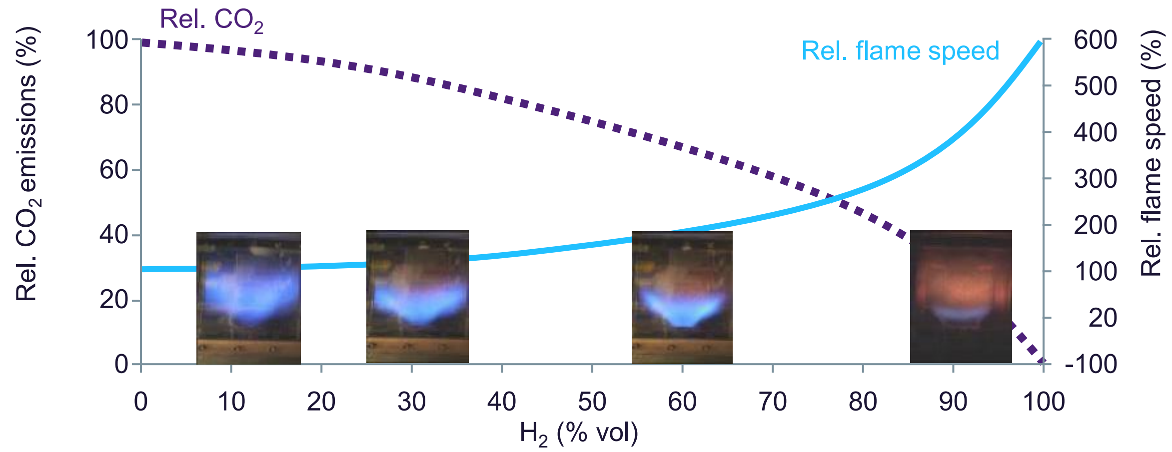
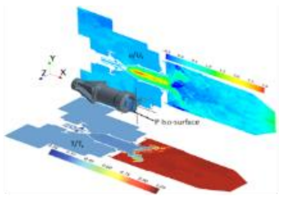
Challenges

- **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 explosion or flashback
- **Higher flame temperature** can lead to local hotspots if imperfectly mixed and thus increased NOx emissions

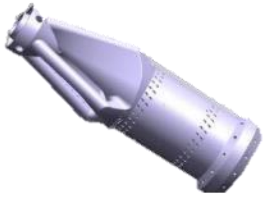


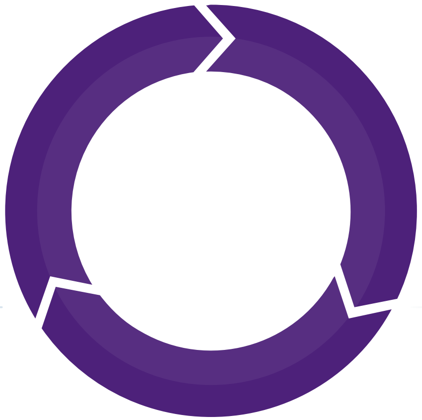
Values shown are relative to natural gas (indicative only)

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

Siemens Hydrogen Gas Turbines for our sustainable future

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

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Frequency	Gas turbine model	Power Output[1]	H_2 capabilities in vol. %	CO_2 reduction[2)] [%]
50Hz	SGT5-9000HL	593 MW	50	23%
	SGT5-8000H	450 MW	30	11%
	SGT5-4000F	329/385 MW	30	11%
	SGT5-2000E	198 MW	30	11%
60Hz	SGT6-9000HL	440 MW	50	23%
	SGT6-8000H	310 MW	30	11%
	SGT6-5000F	265 MW	30	11%
	SGT6-2000E	119 MW	30	11%
50Hz or 60Hz	SGT-800	45 to 62 MW	75	47%
	SGT-750	39 to 41/40 to 42 MW	40	17%
	SGT-700	33 to 35/34 to 36 MW	75	47%
	SGT-A35	31 to 37/32 to 39 MW	15 / 100	5 / 100%
	SGT-600	24/25 MW	75	47%
	SGT-400	10 to 14/11 to 15 MW	30 / 65	11 / 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%
	SGT-50	2 MW	5 / 30	2 / 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 6.1, March 2025

2) Compared with 100% natural gas operation

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

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

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 medium Industrial Gas Turbines expected mid 20s

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

100% **Green Gas Turbines**

CO_2-free pilot demonstration of power-to-H_2-to-power using 100% H_2 DLE gas turbine

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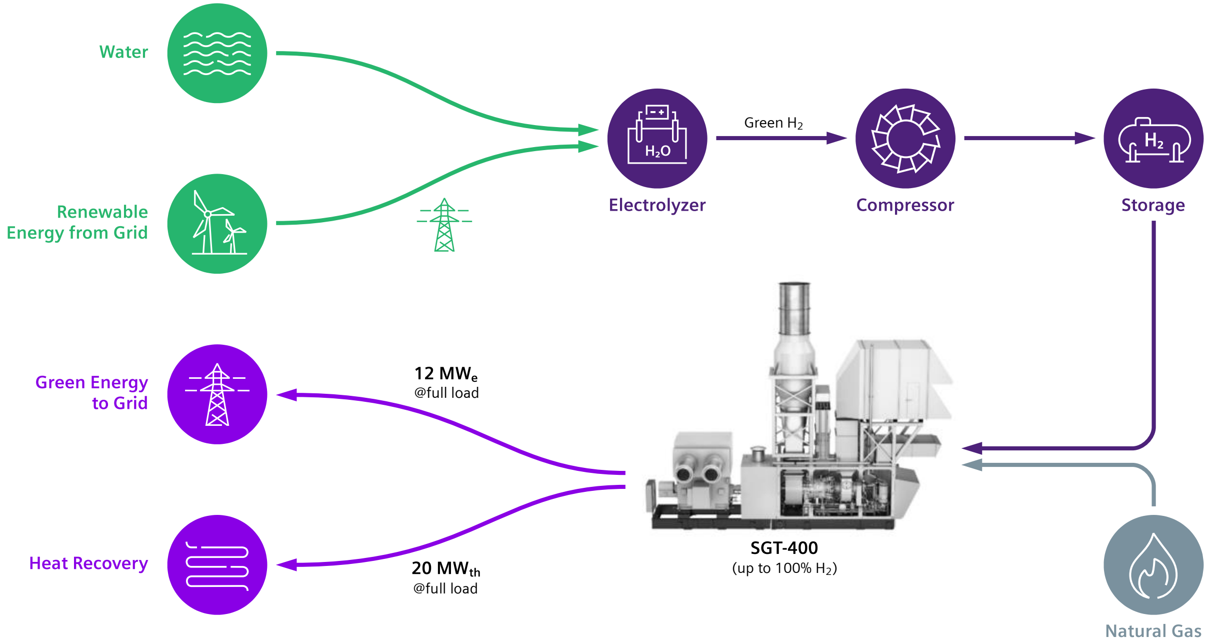
EU-funded HYFLEXPOWER project*

2021 — Installation of the H_2 production, storage and supply facility at site.

2022 — Initial demonstration of advanced plant concept with natural gas / hydrogen mixtures.

2023 — Pilot up to 100% H_2 for carbon-free energy production from stored excess renewable energy (CO_2 saving 65,000 tons per year).

Smurfit Kappa SGT-400 cogeneration plant, Saillat-sur-Vienne, France



* HYFLEXPOWER received funding from the EU Horizon 2020 research and innovation program (GA #884229).

Gas turbines built for natural gas combustion can be upgraded at later stages to hydrogen when required

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Potential future developments

- **Hydrogen content in gas pipeline likely to increase** in future e.g., due to electro-lyzers gaining wider acceptance and discharging hydrogen into the gas grid
- Changes in legislation enforcing decarbonization of power sector, leading to a **requirement to co-burn increased content of sustainably-produced hydrogen**

Upgrade requirement

- Requirement to modify existing gas turbines and combined cycle power plants to burn hydrogen in the future
- Minimization of risk of having future “stranded investments” when deciding today on new GT/CCPP power plant construction projects

Siemens Energy gas turbines

with ability to burn hydrogen (with full NOx emission compliance!) enabled to be upgraded for future hydrogen combustion as future-proof investment

Several GT Package Systems will Require Modifications when Retrofitting to Hydrogen Operation

Main systems requiring modification when upgrading to higher H_2 content

Fire Protection System
Gas Detection System

Gas Group IIC[1]
electrical equipment
Additional ventilation

Additional Flame Control and
Combustion Monitoring Systems

Burner Adjustment/Exchange
Purging System

Fuel Gas System
material and set-up

H_2 compatibility of plant
auxiliary and peripheral systems

Consequences and solution

- Project specific evaluation and decision on required modifications
- Power output control to ensure compliant NOx emission levels
- Conventional/non-H_2 fuels may be required for start-up and shutdown
- Re-certification with respective authorities might be required

1 In NFPA regions alternatively NEC 500 Class I Div 2 Group B

“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

H_2 Ready Concept with TÜV Süd Certificate

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

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CONCEPT CERTIFICATE

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TÜV Süd Concept Certificate

for Bidding Phase

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

The Certificate confirms that SE offering is H_2 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[1]
Safety	Safety Integrity Levels definition and design

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

Hydrogen production cost projection in Europe

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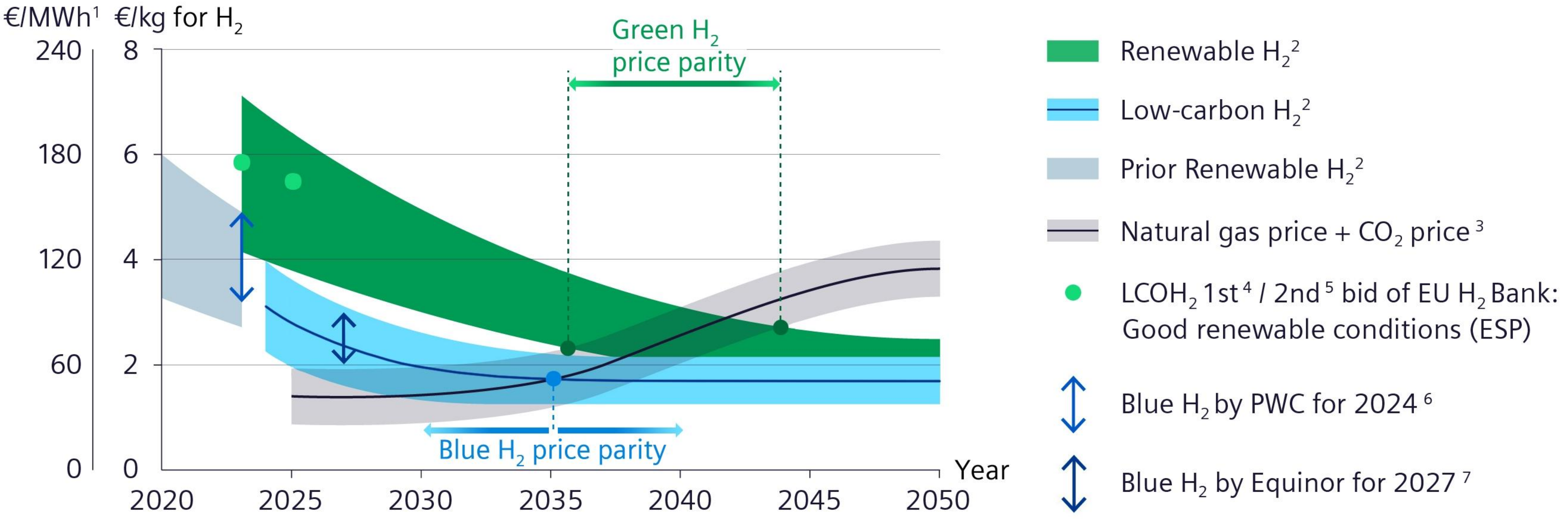

1 Based on LHV; 2 Hydrogen Council (2024); 3 Enerdata & IEA World Energy Outlook; 4 EU Hydrogen Bank (2024); 5 Enagas Financial Report (2025); 6 PWC strategy& – Navigating the hydrogen ecosystem (2024); 7 Equinor (2022);

Synchronous Condenser Option
Ancillary grid services independent of active power production

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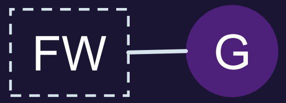
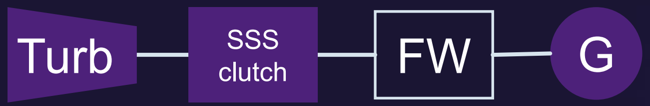
SynCon



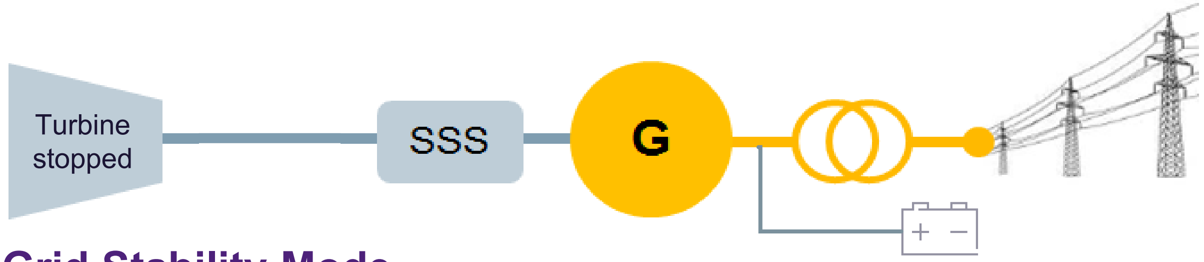
Option: Flywheel (FW)

Hybrid SynCon 1.0

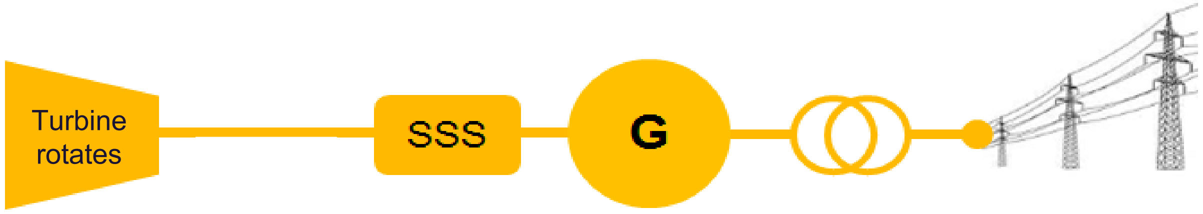
Hybrid SynCon 2.0



G: Generator/SynCon
FW: Flywheel
Turb: Gas/Steam Turbine
SSS: Synchro-Self-Shifting Clutch



Grid Stability Mode
Synchronous condenser operation mode at high solar/wind contribution



Power Generation Mode
Active power production during periods with solar/wind shortage

SynCon Option for steam turbine turbosets

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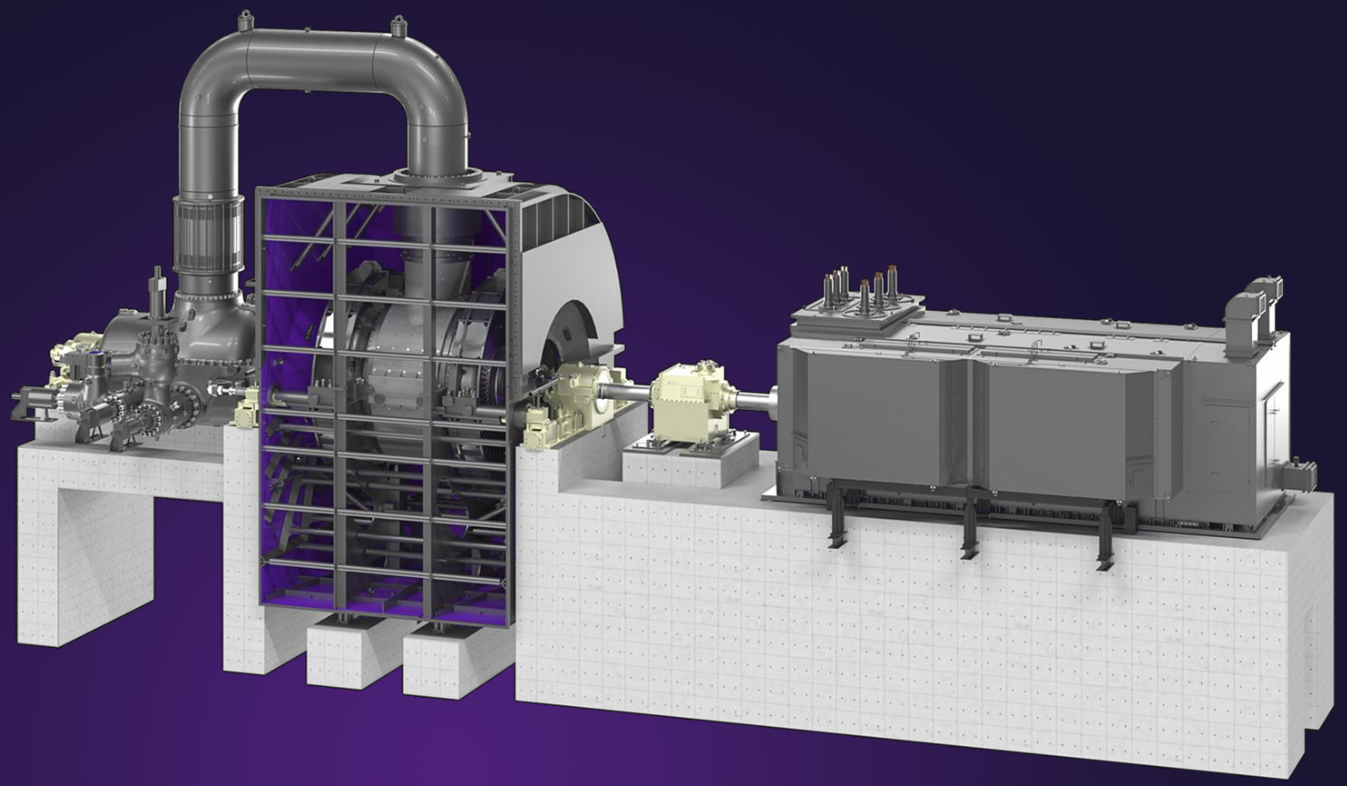
- Easy integration into combined cycle plants
- Uninterrupted change of operation mode: Active Power ↔ Grid stability
- No impact on plant flexibility
- Option: flywheel integration
- Option: increased generator size for enhanced grid stability capability
- Multiple references on operation procedures of SSS clutches with steam turbines: standard for SE in all single shaft applications



SynCon Option for new gas turbine turbosets
Special GT start up solution required!

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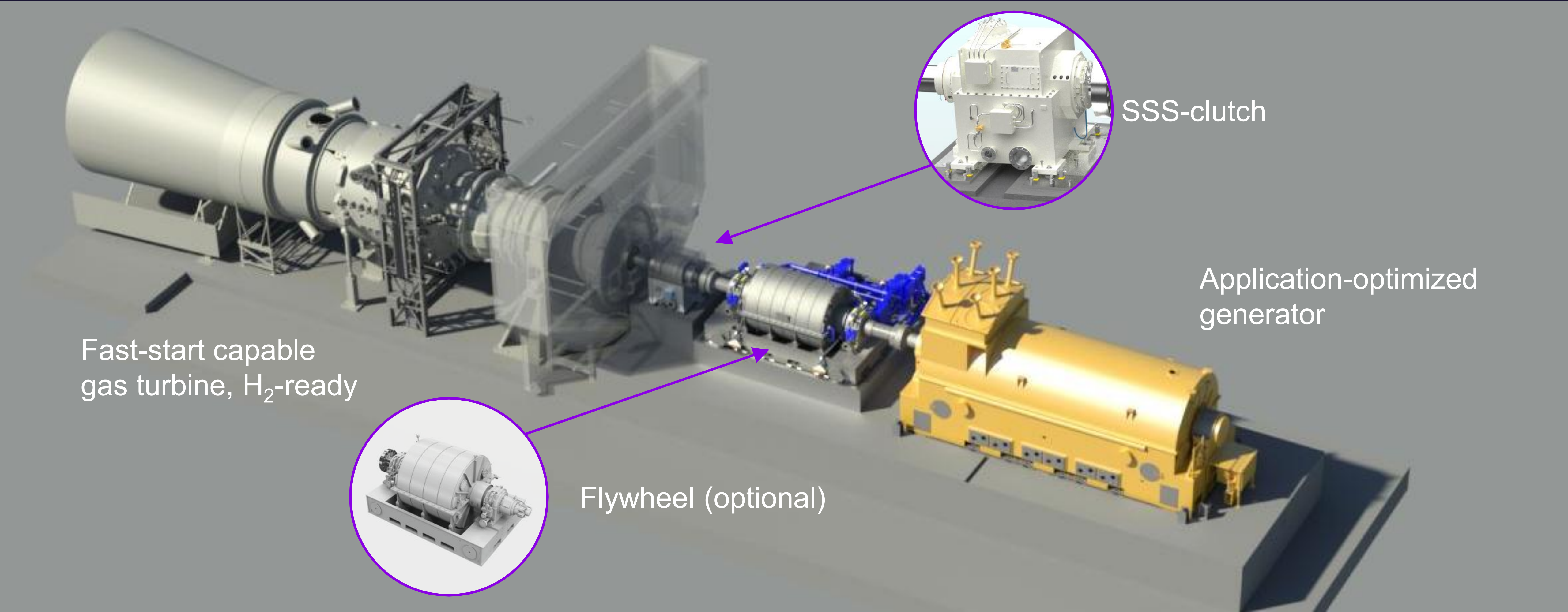

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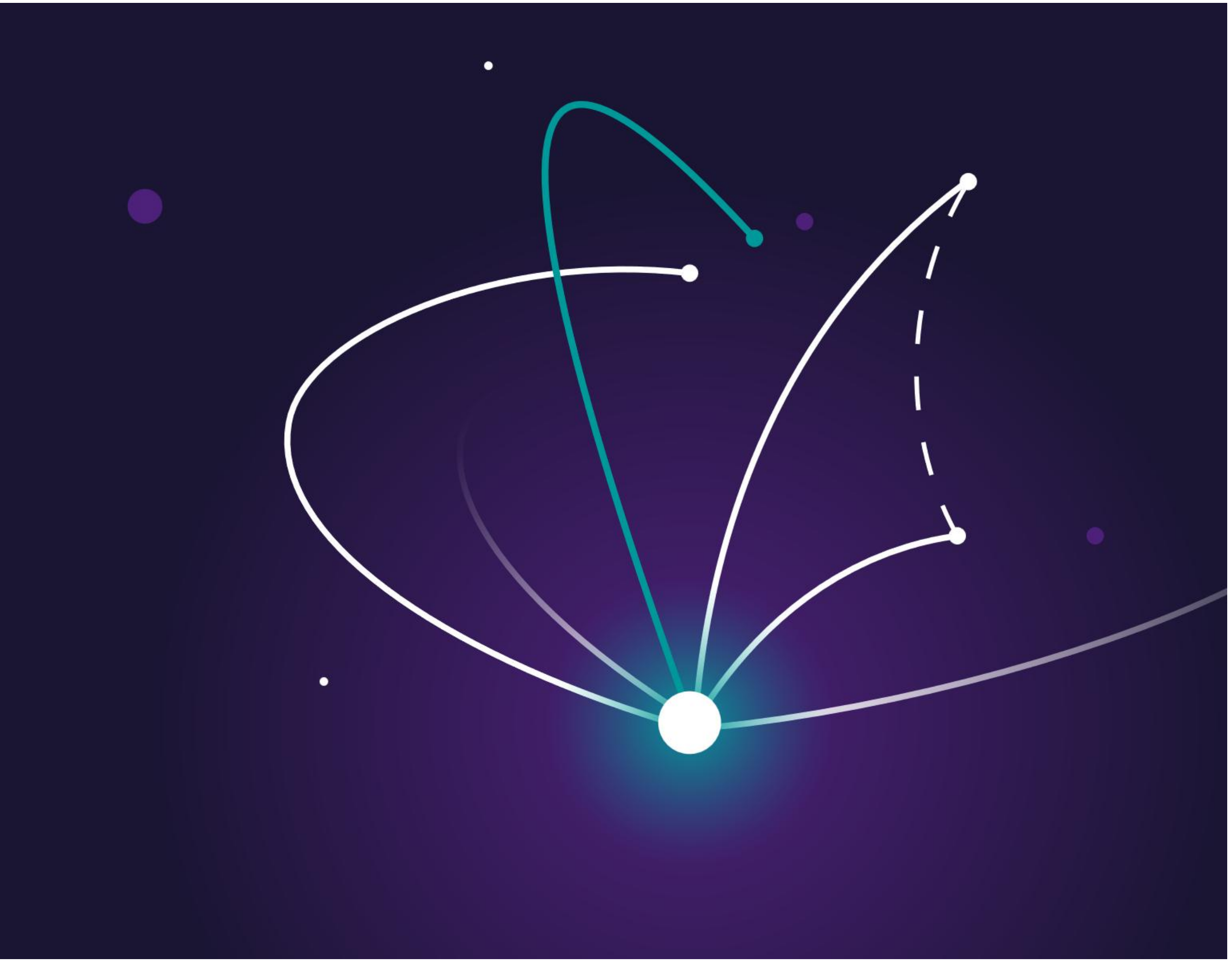

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Further information

- [Siemens Energy H_2 web page]
- [Whitepaper "Decarbonization pathways for gas turbines"] - 2024
- [Hydrogen power with Siemens Energy gas turbines whitepaper - 2025]
- [Sustainable fuels]
- [Hydrogen Decarbonization Calculator]
- [Hydrogen Power Plants]
- [Zero Emission Hydrogen Turbine Center (ZEHTC)]
- [Brownfield Exchange (BEX)]

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