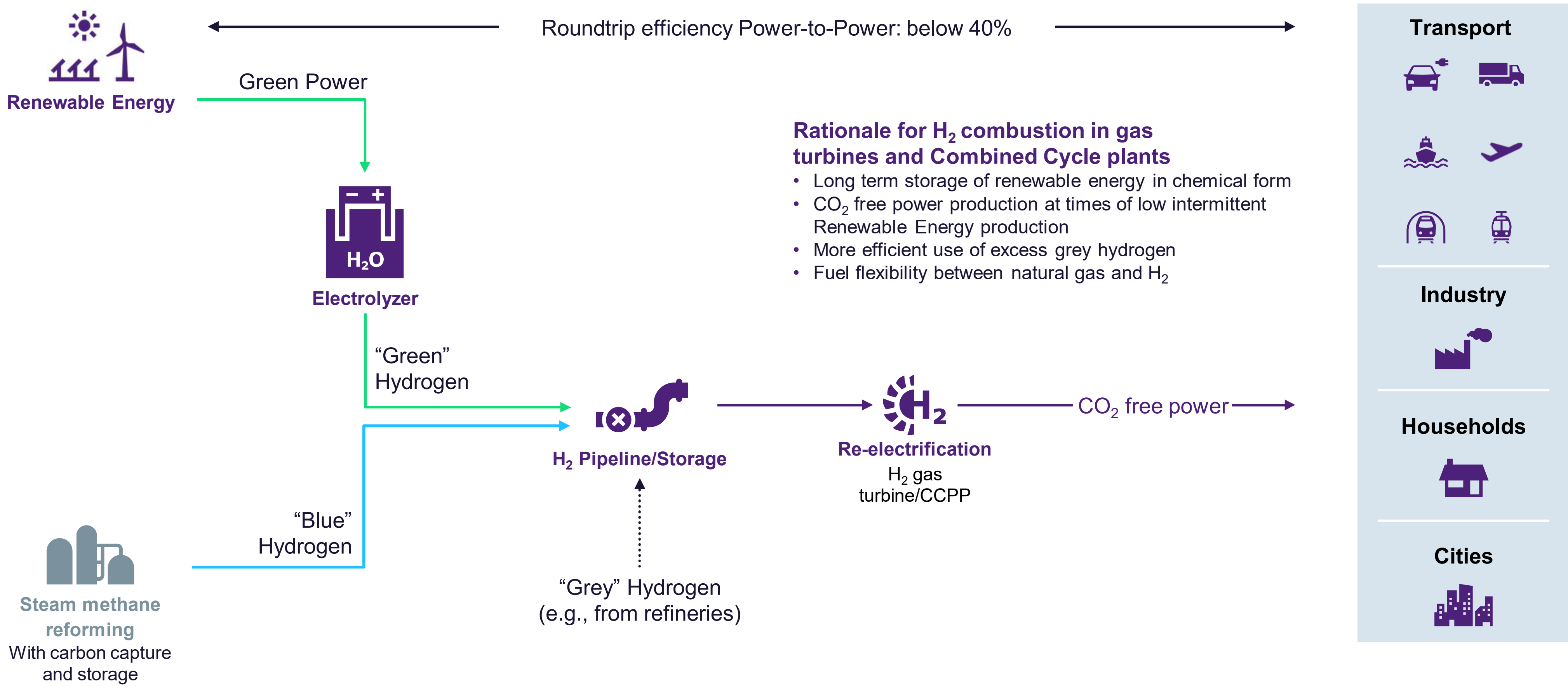
Hydrogen Combustion in Gas Turbines

Status, Challenges & Concerns

2023 A&WMA Louisiana Section Annual Conference

October 26, 2023

Hydrogen combustion in gas turbines enables CO_2 free power production to compensate volatility of renewable energy sources



Rationale for H_2 combustion in gas turbines and Combined Cycle plants

- Long term storage of renewable energy in chemical form
- CO_2 free power production at times of low intermittent Renewable Energy production
- More efficient use of excess grey hydrogen
- Fuel flexibility between natural gas and H_2

■ Products available in Siemens Energy portfolio

How is H_2 Different from Natural Gas

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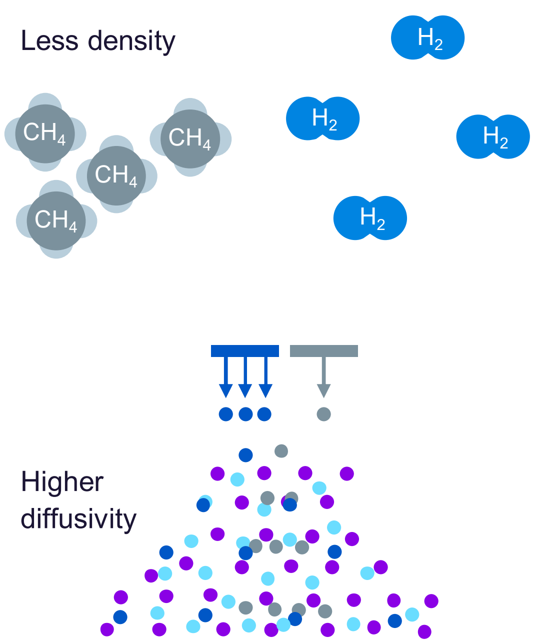
Differences of hydrogen and natural gas as a fuel in gas turbines

Physics of hydrogen

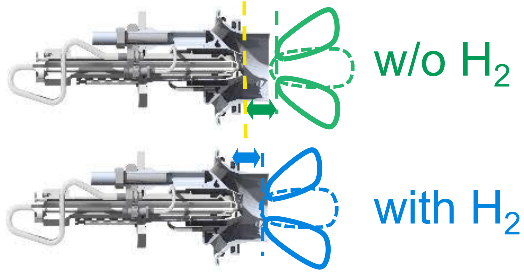


● H_2 ● CH_4 ● O_2 ● N_2

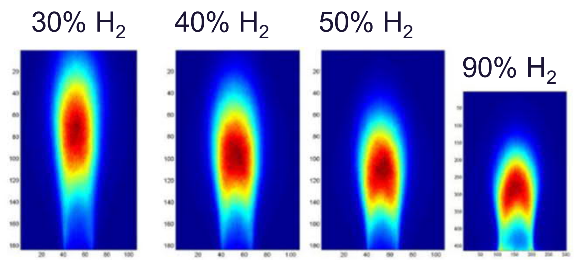
H_2 Volume Impact on Package

- 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

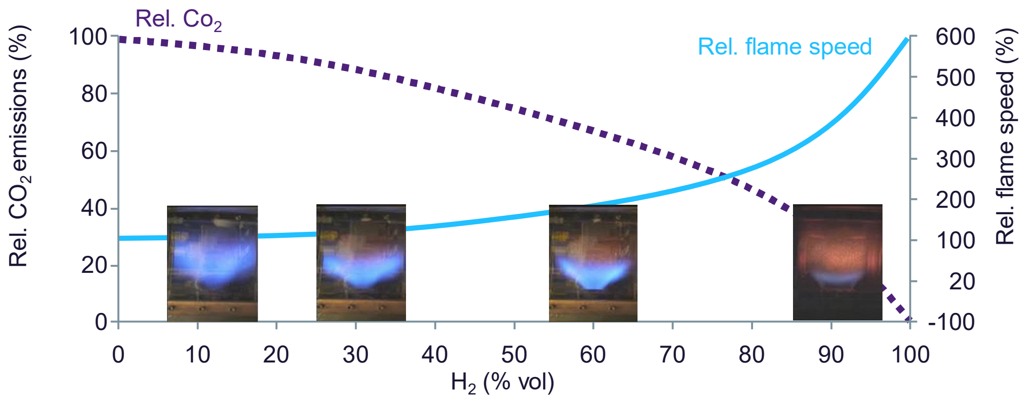
Hydrogen flame



Flame location closer to the burner increases risk of flashback



Combustion Challenges with H_2



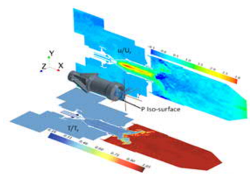
Values shown are relative to natural gas (indicative only)

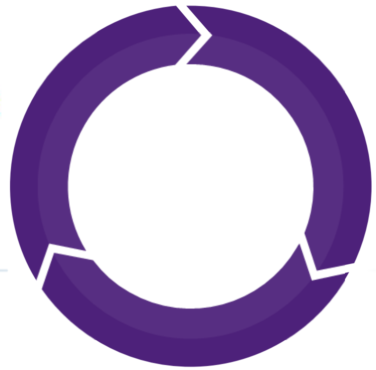
Challenges

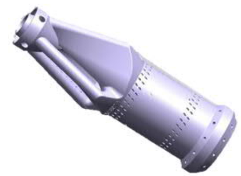
- **H2 embrittlement** requires upgrade to stainless steel materials
- **Lower volumetric energy content** requires larger flows to be handled by fuel system
- **Higher diffusivity** requires changes/re-certification of sealing and flanges
- **Higher reactivity and flame velocity** pushes flame towards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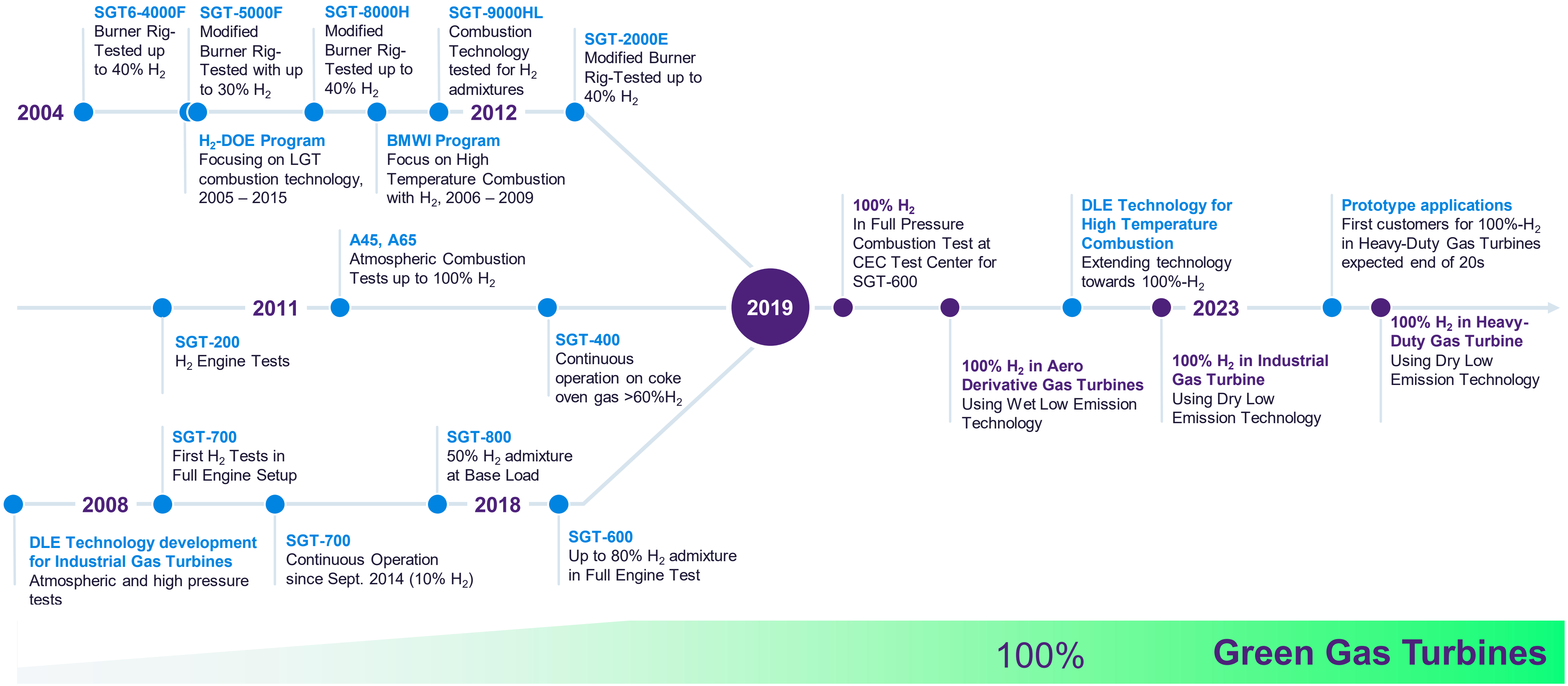

Siemens Hydrogen Gas Turbines for our sustainable future – The mission is to burn 100% hydrogen

	Gas turbine model	Power Output[1]	H_2 Capabilities in vol. %	CO_2 Reduction[2] [%]
50Hz	SGT5-9000HL	595 MW	50	23%
	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	48 to 62 MW	75	47%
	SGT-750	40/34 to 41 MW	40	17%
	SGT-700	33/34 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	2 / 15	1 / 5%

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 5.1, May 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

GT and Auxiliary Design Differences

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Expected changes in design between “standard” and H_2-Fired GT’s

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

Hydrogen experience across the portfolio

Large Gas Turbines

>45 years experience on H_2 by syngas combustion in IGCC projects

Up to 60% H_2 content tested in full pressure combustion tests with diffusion combustion in can-annular systems (5000F and 8000H).

Experience in annular and silo systems (2000E and 4000F) can be transferred across frames.

Medium-Size Gas Turbines

>10 years experience based on continuous R&D with H_2 admixture

Operation on Refinery Fuel Gas with high H_2 content.

In CCPP, BACT[1] is fulfilled with Siemens DLE Hydrogen turbines, e.g., 2ppm NOx, CO, and VOC with a SCR.

Small Industrial Gas Turbines

≈1 MM op. hours of high hydrogen combustion experience

Operation on Refinery Fuel Gas and Coke Oven Gas with high H_2 content in conventional combustion systems.

Capability to operate on natural gas/hydrogen blends using Dry Low Emissions (DLE) combustion technology.

Aeroderivative Gas Turbines

>100k op. hours of recorded operation on high hydrogen fuels (up to 78 vol%)

Proven operation on fuels with Wobbe Indices from 25 to 80 MJ/m^3.

Extensive experience with online swings in gas fuel composition and dual fuel units are capable of online fuel transfers.

NO_X control with water abatement.

Existing Equipment Upgrades – Burner Adjustment/Exchange for Industrial Gas Turbines

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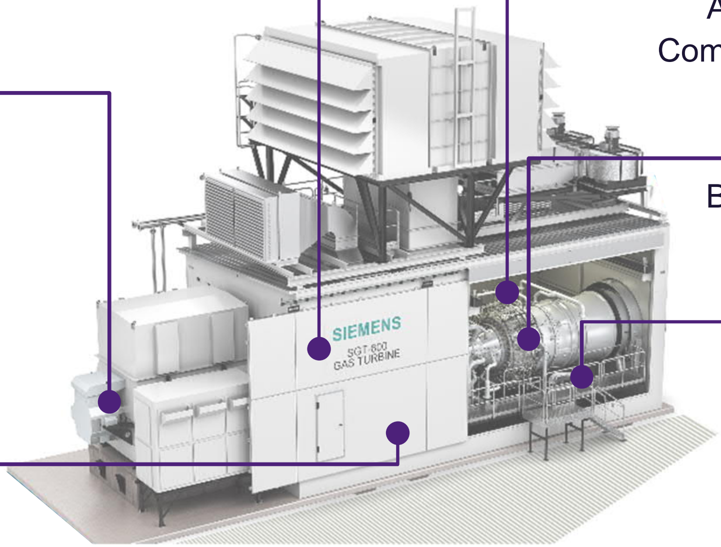
Main systems requiring modification when upgrading to higher H_2 content

Fire Protection System
Gas Detection System

Gas Group IIC
electrical equipment



H_2 compatibility of plant auxiliary and peripheral systems

Additional Flame Control and Combustion Monitoring Systems

Burner Adjustment/Exchange
Purging system

Fuel Gas System
material and set-up

Consequences and solution

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

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“H_2 Ready” Plants can reduce future H_2 retrofit costs

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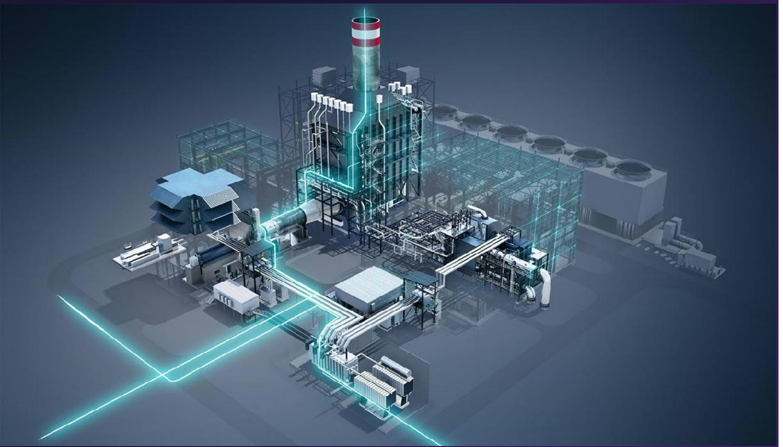

- For new CCPPs not requiring immediate H_2 operation, an optimized configuration can be offered that takes future H_2 retrofit into account (“H_2 ready plants”)
- While keeping front-end investments low, the plant can already be prepared to be retrofitted at a later stage with limited efforts
- Depending on H_2 co-firing time roadmap and requirements, optimized equipment configurations will be offered

Areas:	Equipment/Systems considered:
Fuel Supply:	Materials, sizing, aux. fuel, metering, additional systems...
Fire/Ex Protection:	Fire/Ex protection concepts, sizing of systems
HRSG:	Materials, temperatures, purging requirements
I&C & Electrical:	Design acc. to IIC
Safety:	Safety Integrity Levels definition and design
Certification:	Certification Requirements

Hydrogen Production

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Silyzer 300 – Full Module Array
The next paradigm in PEM electrolysis

Silyzer 300
Full module array
(24 modules) …

17.5 MW
plant power demand

>75.5%
plant efficiency

24 modules
to build a full module array

335 kg
hydrogen per hour

Example: an "F" class gas turbine (~ 260 MW) operating at ISO conditions (sea level), with a 30% by volume hydrogen mix in the fuel, requires ~ 2,200 kg/hr hydrogen and hence, seven (7) Silyer 300 Modules. These modules require ~116 MW (assuming 24 hours per day operation).

Green hydrogen (in the short and medium term) makes sense mostly for use in industry, chemicals, and mobility (and even then, in some cases only with heavy incentives).

NO_X Emissions with H_2 Combustion

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Real and 'Artificial' NO_X Emissions

- H_2 co-firing (and eventually, 100% firing) results in higher flame temperatures than those that occur when firing with natural gas and as previously noted, higher temperature combustion results in a real increase in NO_X emissions.
  - Hence, firing temperature (and therefore, power output) may need to be reduced in some cases to limit engine NO_X emissions.
  - Higher engine NO_X can be controlled with an SCR system … to a point.

- In addition, most NO_X concentration values (e.g., ppm or mg/m^3) are put on a dry, 15% O_2 basis (for an apples-to-apples comparison between sources, etc.).
  - The correction equations can result in a higher (calculated) value than what is measured.
  - This 'correction' bias becomes even larger when combusting more H_2, which requires a lower stoichiometric amount of oxygen and hence, results in more oxygen being left in the exhaust gas.

NO_X Emissions with H_2 Combustion

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Real and 'Artificial' NO_X Emissions (cont.)

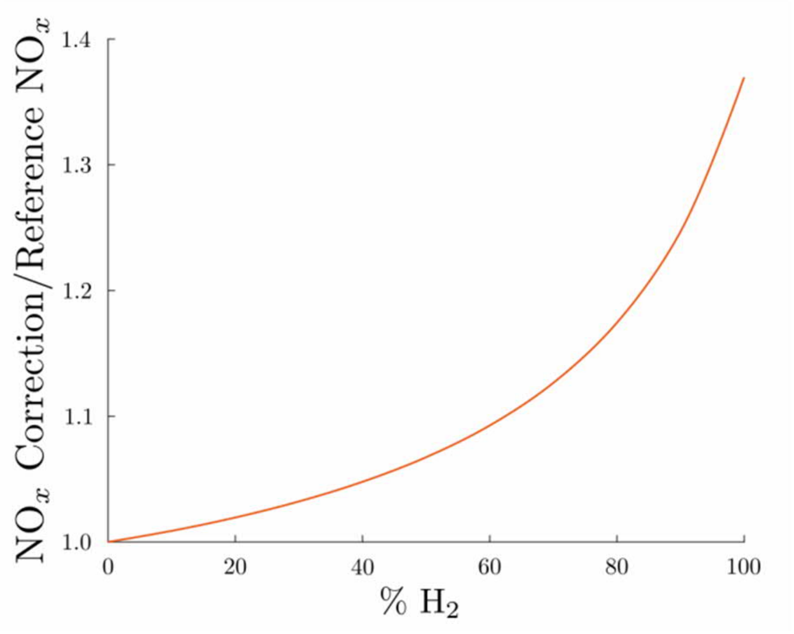
- The apparent, *artificial* increase in NO_X emissions can be as much as 40% (see figure to right, per Georgia Tech. Study). Example equations are as follows:

Lower H_2:

25 ppmvd NO_X x [(20.9 – 15) / (20.9 – 14)] = **21.4**

Higher H_2:

25 ppmvd NO_X x [(20.9 – 15) / (20.9 – 16)] = **30.1**



SOURCE:

NO_X Emissions from Hydrogen-Methane Fuel Blends - GA Tech. – Jan. 2022

NO_X Emissions with H_2 Combustion

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Alleviating the Potential Impacts of 'Artificial' NO_X Increases

- The regulatory community (e.g., USEPA, Canadian EPA, European Commission of the E.U., etc.) as well as equipment end-users (customers) must be educated.
  - SE Orlando, through membership and involvement in the Gas Turbine Association, has submitted a letter to the U.S. DOE (Dept. of Energy) and has had interactions with the USEPA on this subject.
- Perhaps the easiest way to deal with this issue is to simply not utilize units of *concentration* for NO_X (or other) emissions when combusting H_2, but to limit and report emissions based on *mass flow*:
  - Mass per time: g/sec, kg/hr, lb/hr, etc. and/or
  - Mass per energy output or input: g/kWh, lb/MWh, kg/GJ, lb/MMBtu, etc.

QUESTIONS ?

Jordan M. Haywood, MS, PE, QEP –
Discipline Expert (Emissions/Controls)
North America, Central America, Latin America (Orlando Office)
jordan.haywood@siemens-energy.com