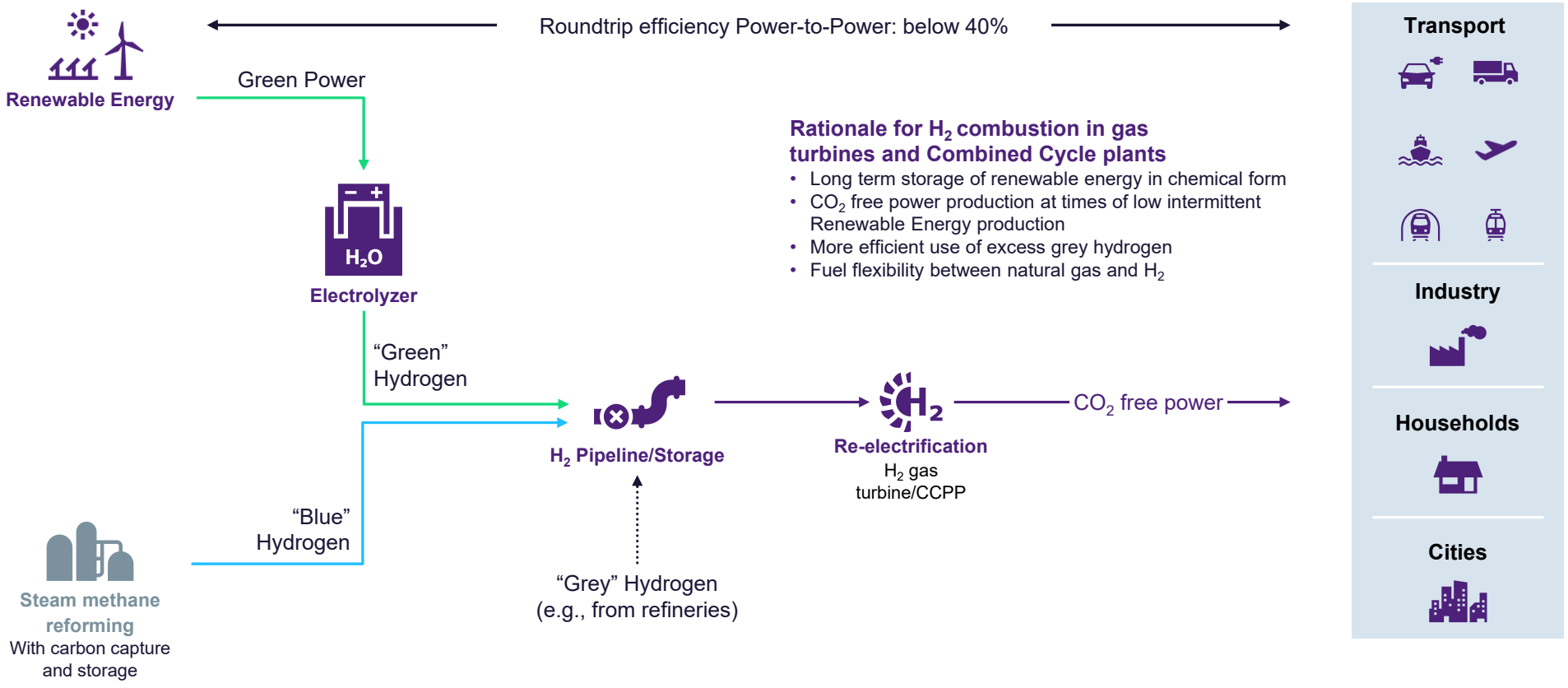
Hydrogen Combustion in Siemens Energy Gas Turbines

A&WMA Southern Section Annual Conference
Sep. 21, 2022

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



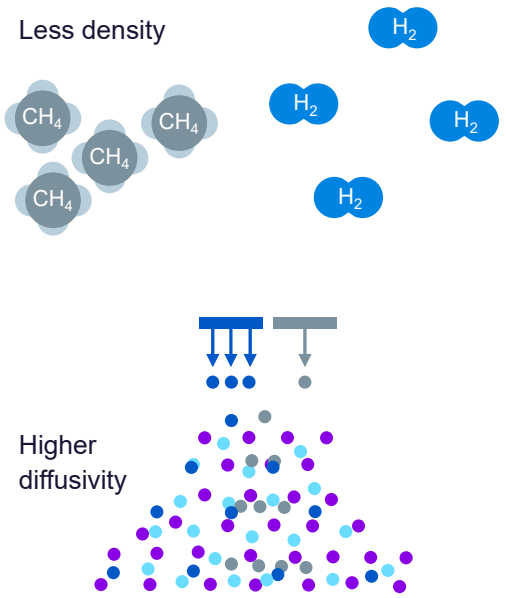
Products available in Siemens Energy portfolio

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

SIEMENS energy

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

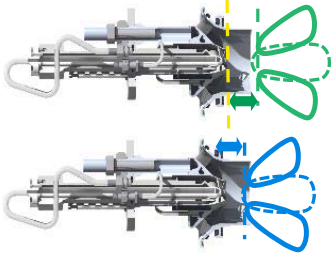
Physics of hydrogen



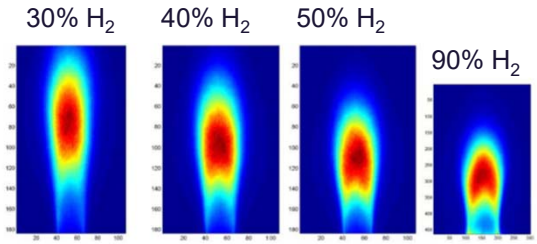
H_2 Volume Impact on Package

- 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

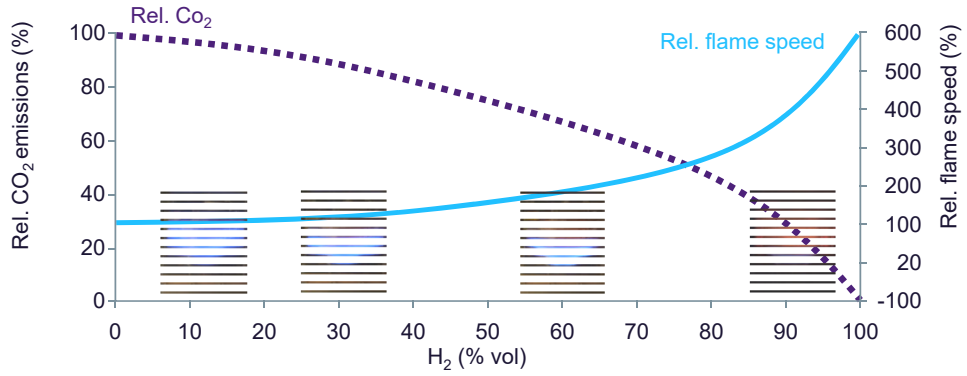


Flame location closer to the burner increases risk of flashback



● H_2 ● CH_4 ● O_2 ● N_2

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

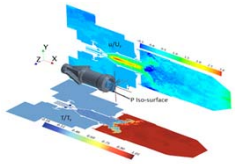


Values shown are relative to natural gas (indicative only)

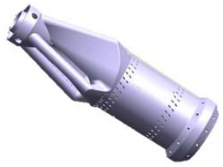
Challenges

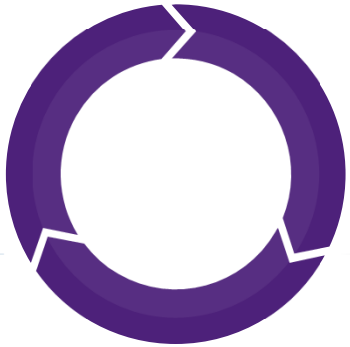
- **H2 embrittlement** requires upgrade to stainless steel materials
- **Lower volumetric energy content** requires larger flows to be handled by fuel system
- **Higher diffusivity** requires changes/re-certification of sealing and flanges
- **Higher reactivity and flame velocity** pushes flame towards 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

Siemens Energy Solution for different H_2 levels
Expected changes

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

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%

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

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

Driving the transition towards a decarbonized Energy Mix

Hydrogen co-firing commitment

January 2019: Siemens signed a **commitment on H_2 co-firing** in gas turbines at the #PowerTheEU summit[1]

2019: Operation with **3-5% H_2** content
(→ already achieved for all new GT models)

2020: Operation with **20% H_2** content
(→ already achieved for most GT models)

2030: Commercial availability of turbines for **100% H_2**
(→ already achieved for A35, R&D and implementation plans in place to cover more GT models by 2030)

Siemens Energy R&D activities to increase hydrogen capabilities

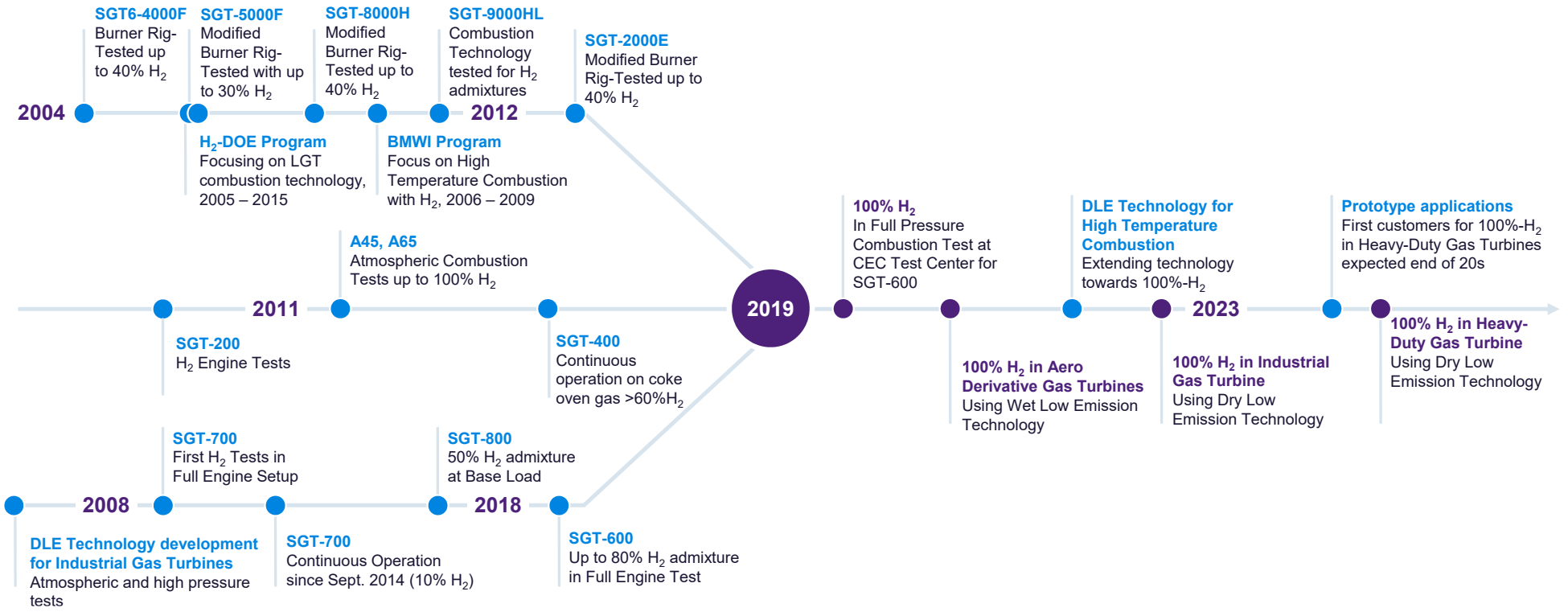
Siemens Energy invested in H_2 testing capabilities at Clean Energy Center in Berlin – single burner tests at engine conditions

Engine tests for SGT-600/700/800 running on H_2 in DLE (dry low emissions) combustion systems has resulted in sales release of 60/55/50 vol%-H_2 respectively

Ongoing development to increase capabilities of our engines

1 https://powertheeu.eu/

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



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.

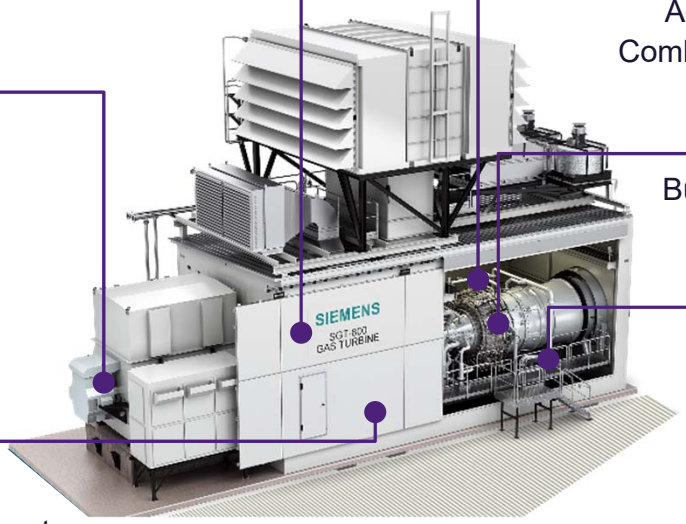
Existing Equipment Upgrades – Burner Adjustment/Exchange for Industrial Gas Turbines

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

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

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

"H_2 Ready" Plants can reduce future H_2 retrofit costs

- 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

Summary

Siemens Energy Hydrogen Combustion Capabilities

- 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 has an implementation roadmap to burn 100% hydrogen fuel in gas turbines by 2030

Conclusions

Existing assets and future **investments in gas turbines are protected** 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

Disclaimer

This document may contain statements relating to the future business and financial performance and future events or developments involving Siemens Energy (together with its subsidiaries, “Siemens Energy”) that may constitute forward-looking statements. These statements may be identified by words such as “expect,” “look forward to”, “anticipate”, “intend”, “plan”, “believe”, “seek”, “estimate”, “will”, “project” or words of similar meaning. Such statements are based on the current expectations and certain assumptions, of which many are beyond Siemens Energy’s control. These are subject to a number of risks and uncertainties. Should one or more of these risks or uncertainties materialize, should decisions, assessments or requirements of regulatory authorities deviate from our expectations, or should underlying expectations not occur or assumptions prove incorrect, actual results, performance or achievements of Siemens Energy may (negatively or positively) vary materially from those described explicitly or implicitly in the relevant forward-looking statement. Siemens Energy does not intend, nor assume any obligation, to update or revise these forward-looking statements in light of developments which differ from those anticipated.

The information and opinions contained in this document are provided as at the date of this presentation and are subject to change without notice. They do not purport to contain all information that may be required to evaluate Siemens Energy and have not been verified independently. The information in this document is of a preliminary and abbreviated nature and may be subject to updating, revision and amendment, and such information may change materially.

This document contains forecasts, statistics, data and other information relating to markets, market sizes, market shares, market positions and other industry data on Siemens Energy’s business and markets (together the “market data”) provided by third party sources as interpreted by us. This market data is, in part, derived from published research and additional market studies prepared primarily as a research tool and reflects estimates of market conditions based on research methodologies including primary research, secondary sources and econometric modelling, which may not be representative.

Nothing contained in this document (and the appertaining verbal presentation, if any) is a warranty, guarantee or representation. All statements, data and information contained herein (and the appertaining verbal presentation, if any) are non-binding and shall not create on Siemens Energy any commitment, obligation or liability whatsoever. Furthermore, they shall not be ground for any claim or argument, regardless whether based on this document (and the appertaining verbal presentation, if any) alone or in connection with a separate agreement or contract.