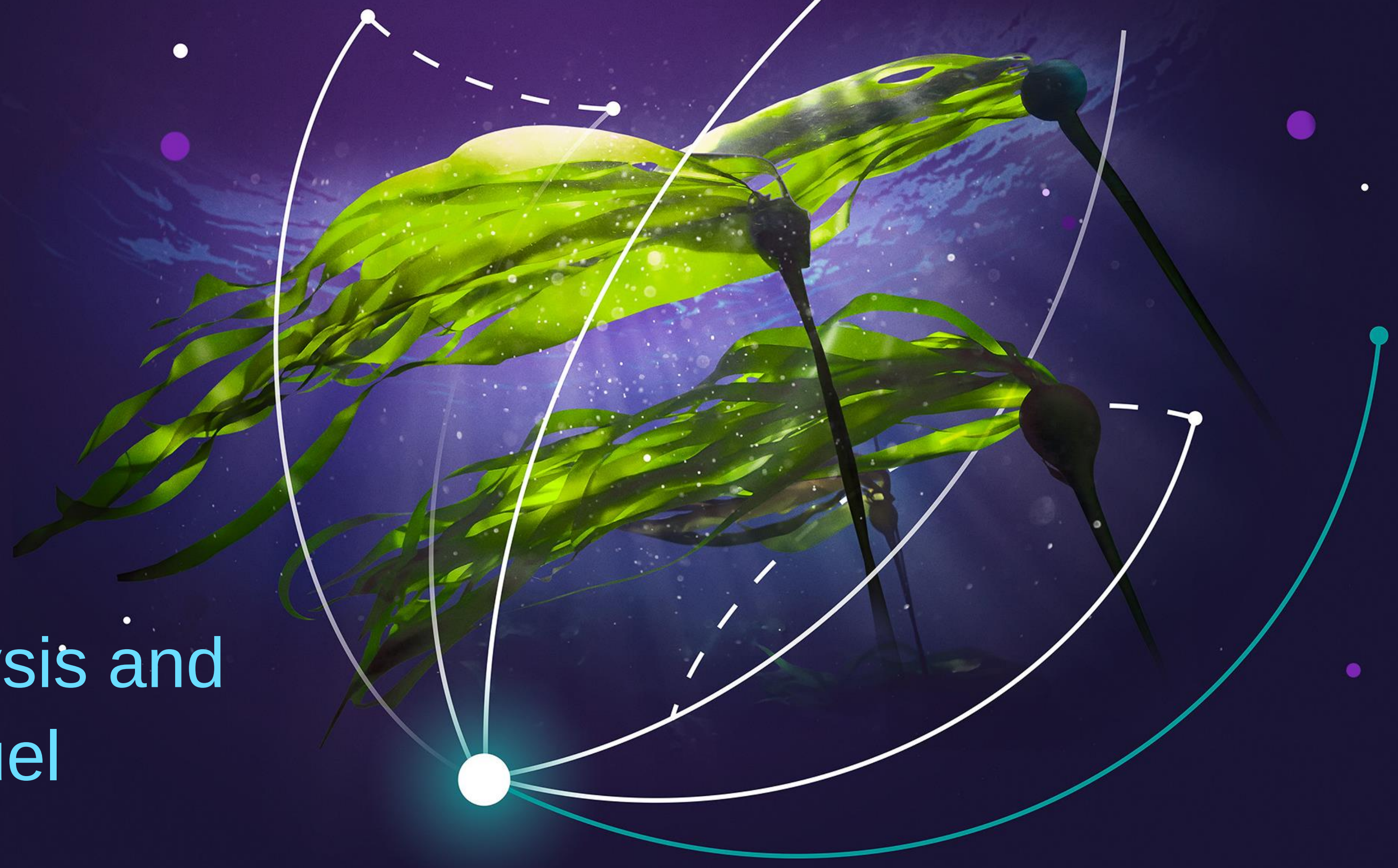
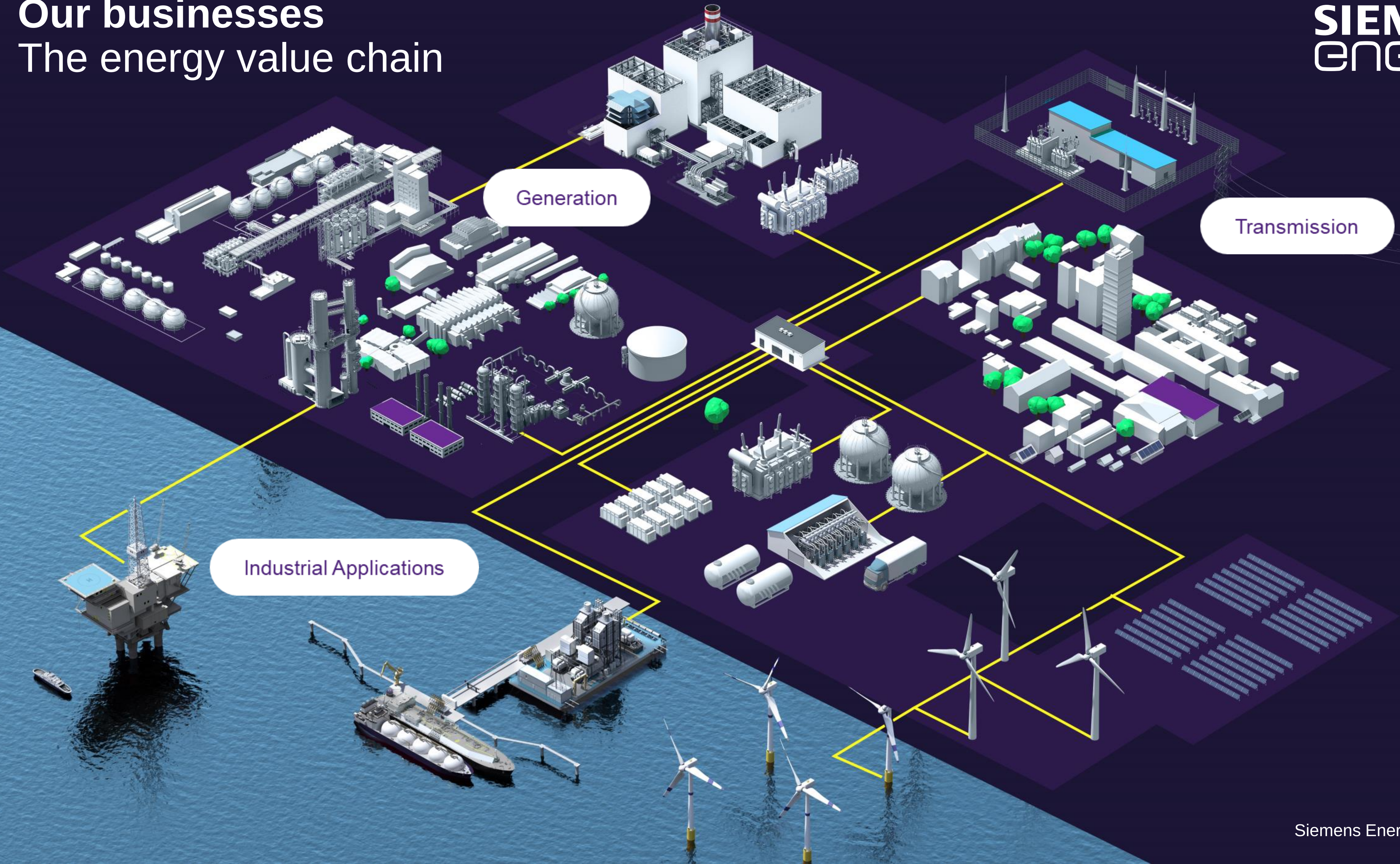
Cigre BiH
Sarajevo 2022

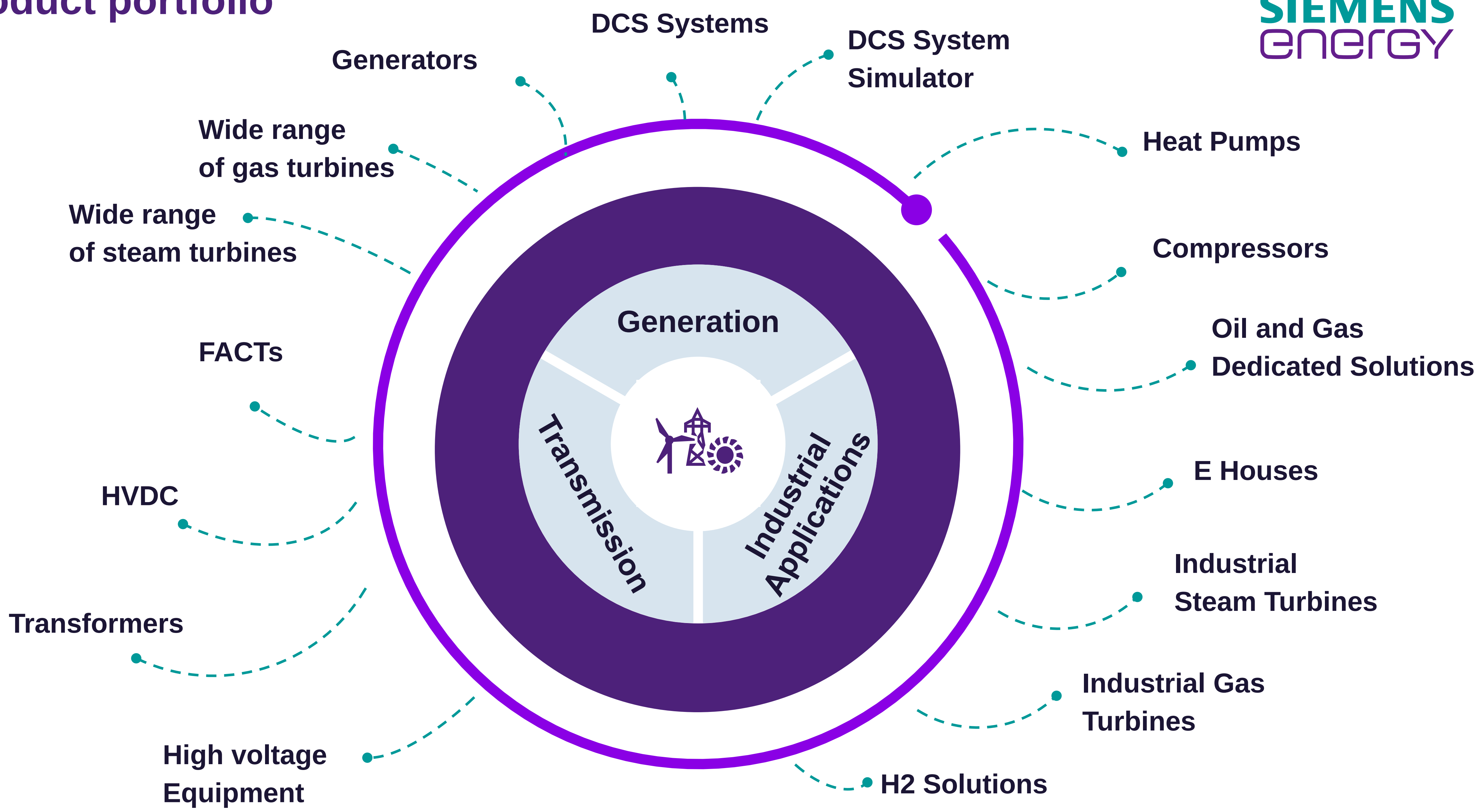


Large Scale PEM Electrolysis and Gas Turbines with green fuel

Our businesses
The energy value chain

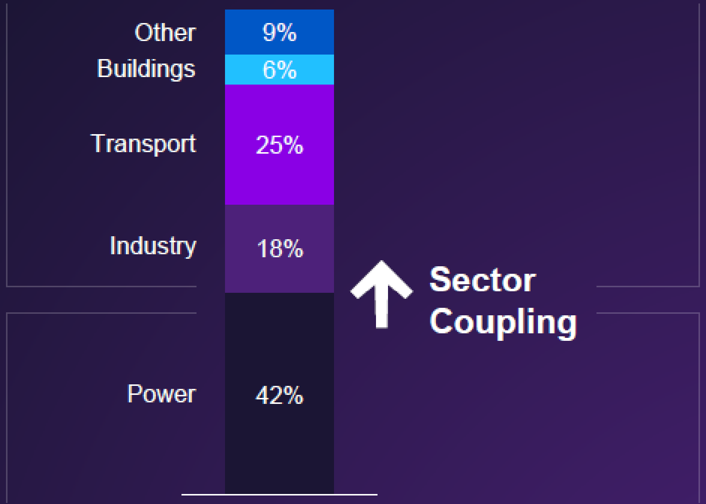


Product portfolio



Shares in global CO_2 emissions by sectors

Leverage green electricity in other sectors
Share on CO_2 emissions: 58%
Share of Renewables: 11%



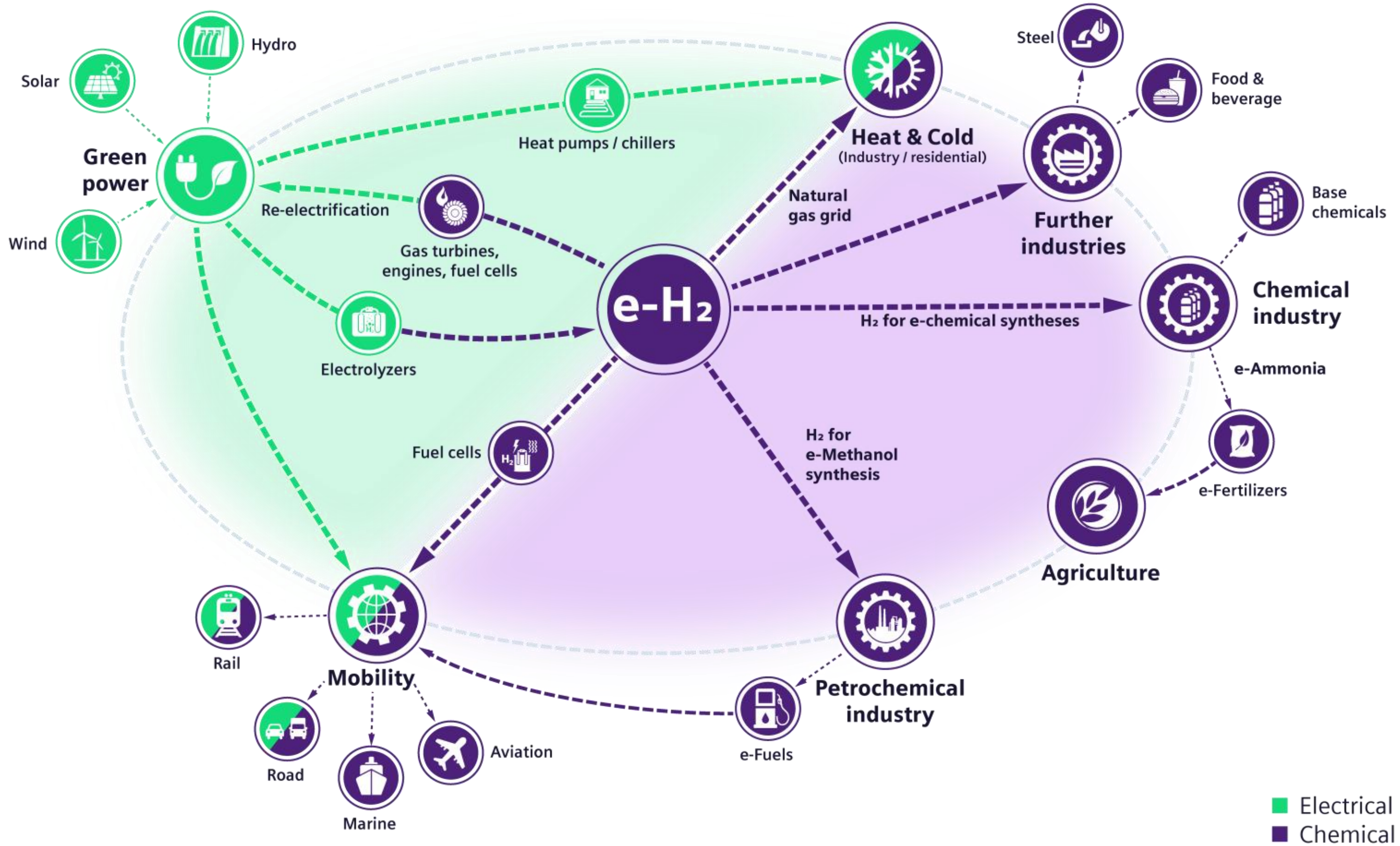
Successful integration of renewables in Power
Share on CO_2 emissions: 42%
Share of Renewables: 27%

Source: 2018-2019 data from IEA and own estimates

"Sector Coupling"

Key lever for decarbonization of all end-user sectors

The role of hydrogen – a versatile molecule



There are different ways to produce hydrogen

"Colors"	Evaluation
Grey/black Hydrogen: Produced from natural gas (SMR) with CO_2 emissions (traditional business)	98% of today´s production at 1.5-2.5 $/kg. Not sustainable - has no future in a decarbonized world.
Green Hydrogen: Produced from renewable energy (RES) through electrolysis	Large RES requirement, high price (2-6 $/kg, but significant cost reduction potential), water source required.
Blue Hydrogen: Produced from methane via SMR[1)] with CCS[2)]	Requires CCS. Not considered as 100% sustainable. But: Can be a transitional technology, as still cheaper than Green H_2
Turquoise[3)] Hydrogen: Produced from methane via pyrolysis inside gas field with carbon remaining underground	Technology not yet mature. As with Blue H_2, a solution for Gas companies to "save" their traditional business and assets.
Yellow[4)] Hydrogen: Produced from nuclear energy through electrolysis	Partly limited social acceptance. Potential for existing Nuclear Power Plants, but too expensive in the long-term for new builds.

1) SMR: Steam Methane Reforming
2) CCS: Carbon Capture and Storage
3) Sometimes also referred as "cyan" or "purple" hydrogen
4) Sometimes also referred as "purple", "pink" or "red" hydrogen

Silyzer portfolio scales up by factor 10 every 4 – 5 years driven by market demand and co-developed with our customers

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Silyzer portfolio roadmap

0.1 MW

2011

Silyzer 100
Lab scale demo
~20 kOH[1]
~30 t of H_2

1 MW

2015

Silyzer 200
~130 kOH[1]
~1700 t of H_2

World's largest Power-to-Gas plants with PEM electrolyzers in 2015 and 2017 built by Siemens Energy!

10 MW

2018

Silyzer 300

Biggest PEM cell in the world built by Siemens Energy!

100 MW

2023+

Next generation
Under development

1,000 MW

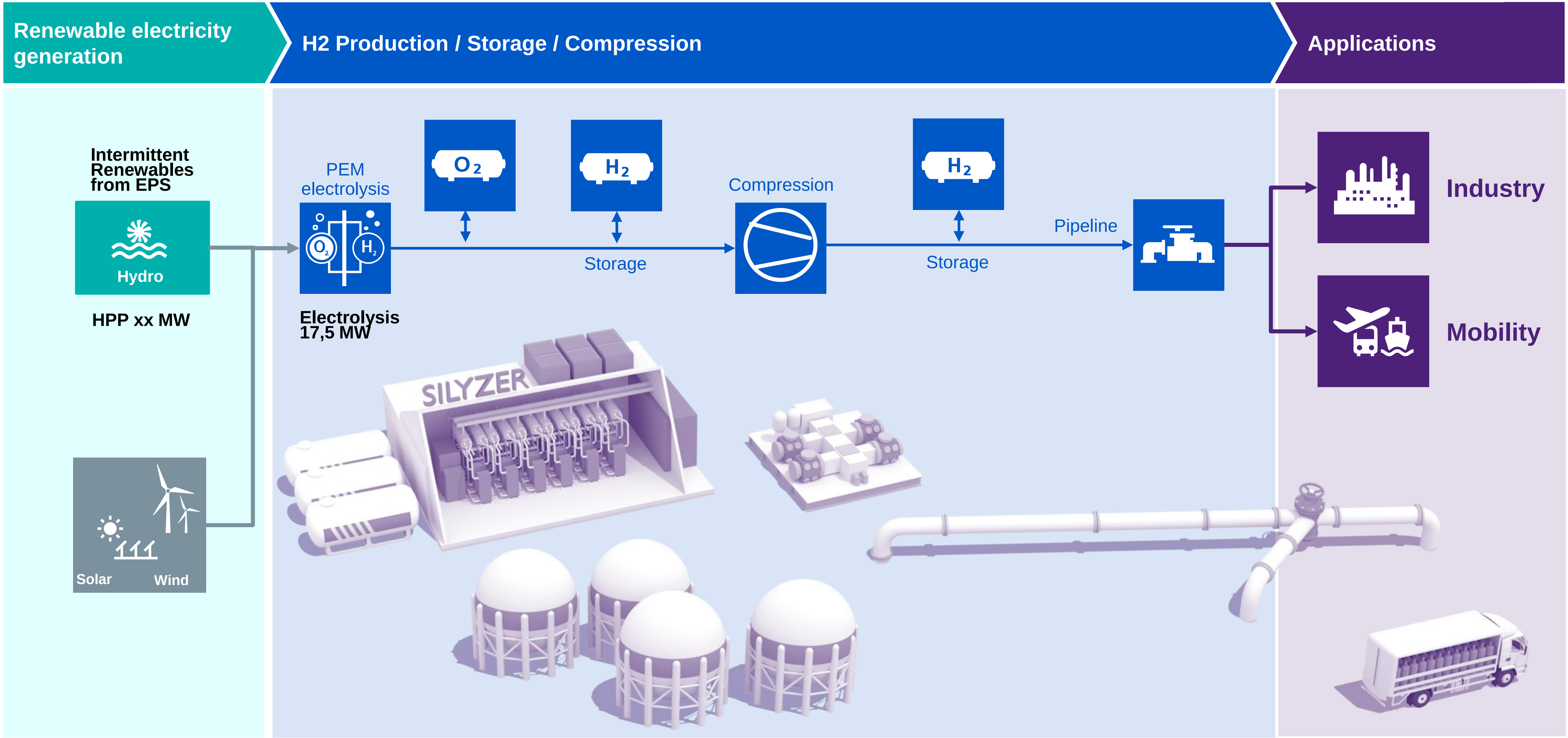
2028+

First investigations in cooperation with chemical industry

1 1000 accumulated Operating Hours; Data OH & tons as of Oct 2020

Green hydrogen value chain

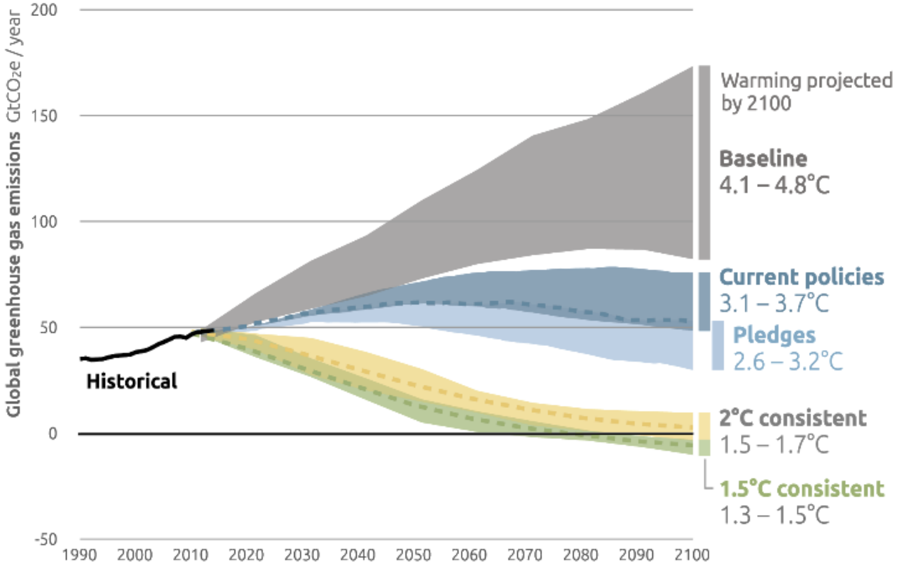
Industrial & Chemical Park Prahovo, Serbia



Elimination of CO_2 emissions is critical to limit global warming

Paris Agreement

requires drastic reductions of CO_2 emissions



Source: IEA 2019

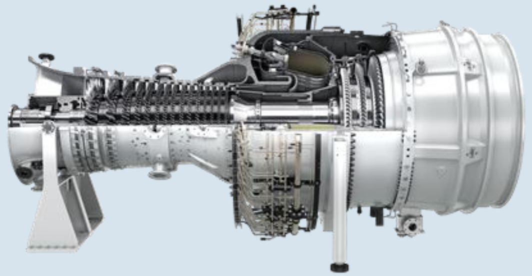
Decarbonized gas turbine operation

through low-carbon fuels

- **Significant reduction of CO_2 emissions** operating a gas turbine on low-carbon fuels compared to natural gas/CH_4
- Meet demand **for additional energy with minimal CO_2 footprint**
- **Fuel flexibility** through capability to operate on different fuels with possibilities to switch during operation

Reduction

of up to 97% or 636 g CO_2 per kWh electricity[1] for an SGT-800 (57 MW) gas turbine



1 Taking into account the full life-cycle of the fuel

Hydrogen in gas turbines
Fuel characteristics

Hydrogen ignites/burns fast

H_2 combustion moves flame closer to injector – avoidance of “flash-back” by optimizing air and fuel distribution.

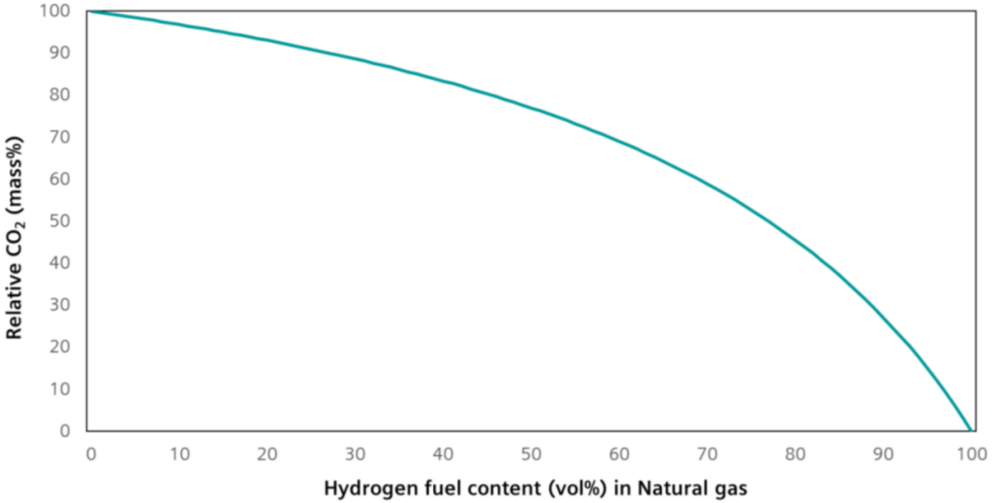
Hydrogen has a wide flammable region

Much wider range of fuel/air-ratio to burn compared to natural gas. Adaption of ventilation and gas detection system as well as fuel system.

Hydrogen has a low ignition energy

Only a fraction of the ignition energy is needed to get H_2 “going” compared to methane.

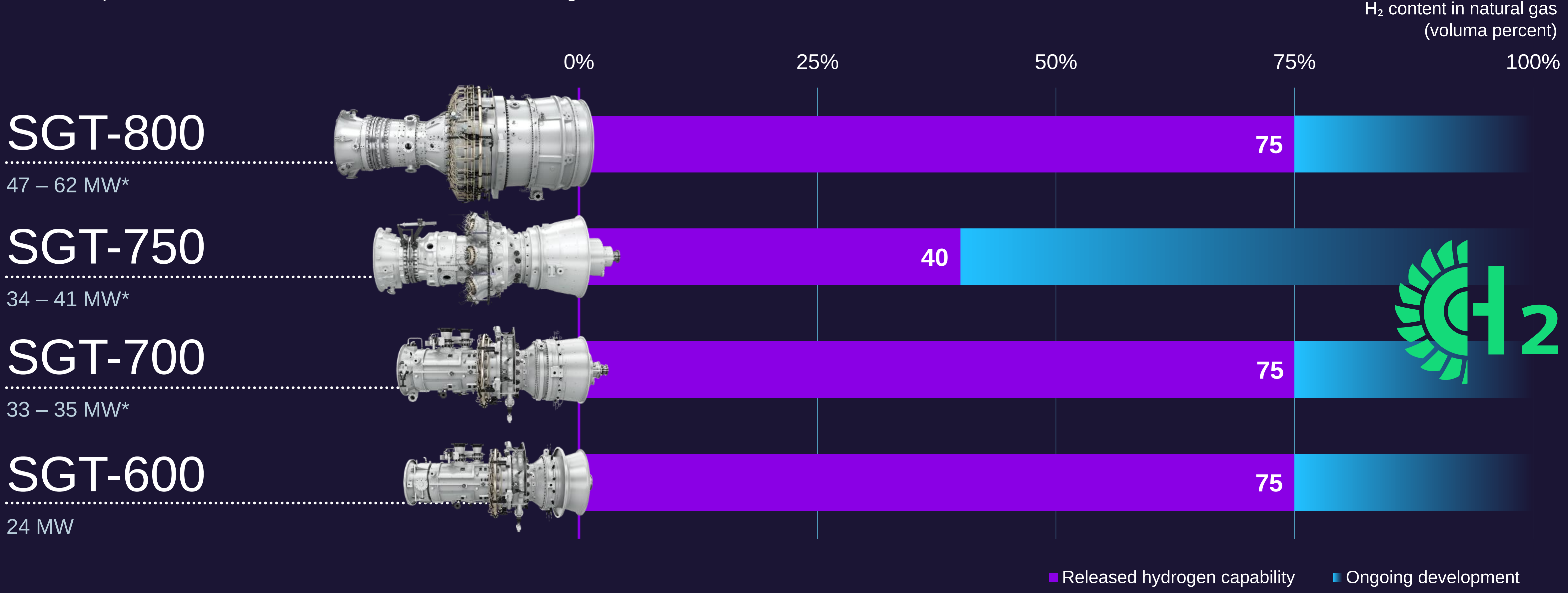
0% volume by H_2 | 30% volume by H_2 | 60% volume by H_2 | 100% volume by H_2



Hydrogen capability
Siemens Energy medium size gas turbines

All turbines equipped with DLE burner technology

Power output in MW at ISO ambient conditions and natural gas

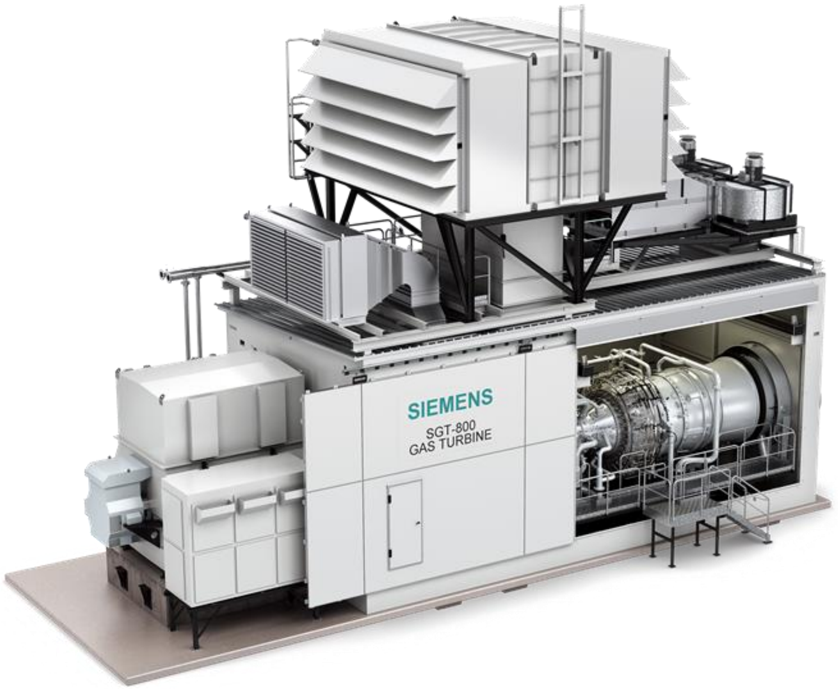


*The performance may be reduced based on H2 concentration, emissions requirement and power rating

Siemens Energy, June 2021

Hydrogen in gas turbines
Examples of installation adaptions to consider

Examples of installation adaptions to consider	5-15%	15-30%	30-75%
Burner flash-back supervision	✓	✓	✓
Burner flash-back control			✓
Adjusted burner design[1]		✓	✓
Ignition fuel & central gas/purge air system		✓	✓
Enclosure gas detection system	✓	✓	✓
Enclosure fire detection system		✓	✓
ATEX/CFD-considerations & ventilation adjustment	✓	✓	✓
Gas fuel system (material, valves etc.)		✓	✓
Additional monitoring		✓	✓



Logics, procedures & approvals:

- **Operation and control:** Updated settings in the control system and modified start-up sequence. Adjustment of operation including turbine inlet temperature may be required depending on fuel constituents including level of H_2 and emission requirements
- **Additional approvals and certificates** from authorities may be required to get operating permission (customer scope)

Siemens Energy can provide solutions both for new units and existing fleet

1 For older installed SGT-600/700 units, the combustion chamber might need to be updated

Zero Emission Hydrogen Turbine Center

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

- Utilizes excess power from turbine test runs to produce hydrogen in an electrolyzer
- Solar panels for continuous hydrogen production
- A micro grid together with batteries for backup
- Utilize the produced hydrogen as 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

Operation starts in 2021

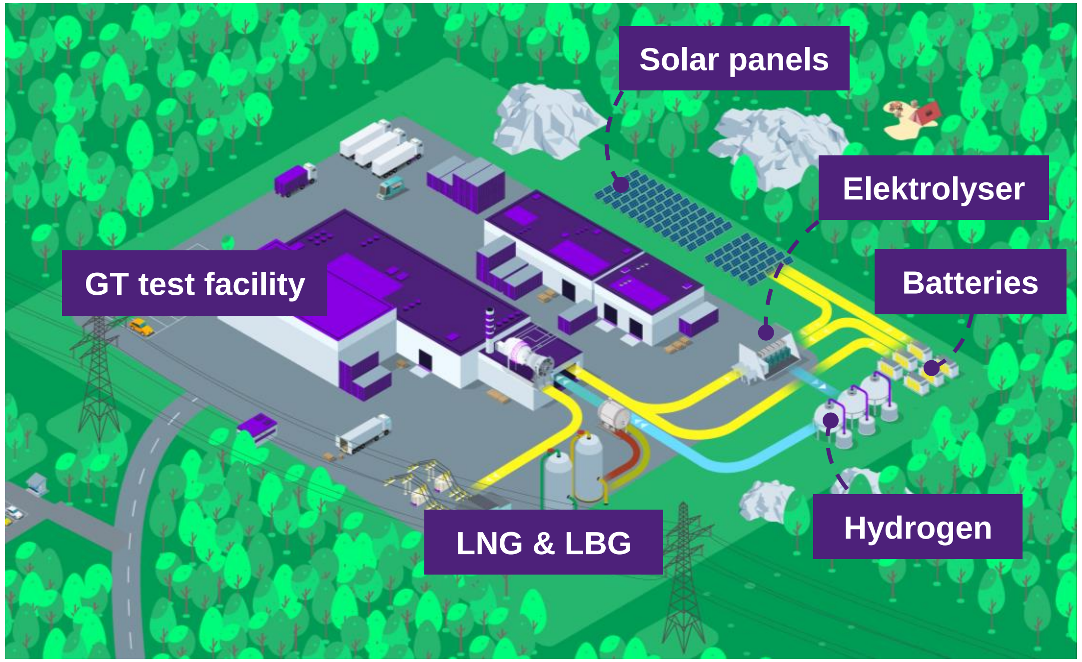
Supports Siemens Energys efforts in achieving

100% hydrogen ready gas turbines by 2030

climate neutral own operations by 2030

green electricity 100% of own power consumption by 2023

The **future energy system** on display



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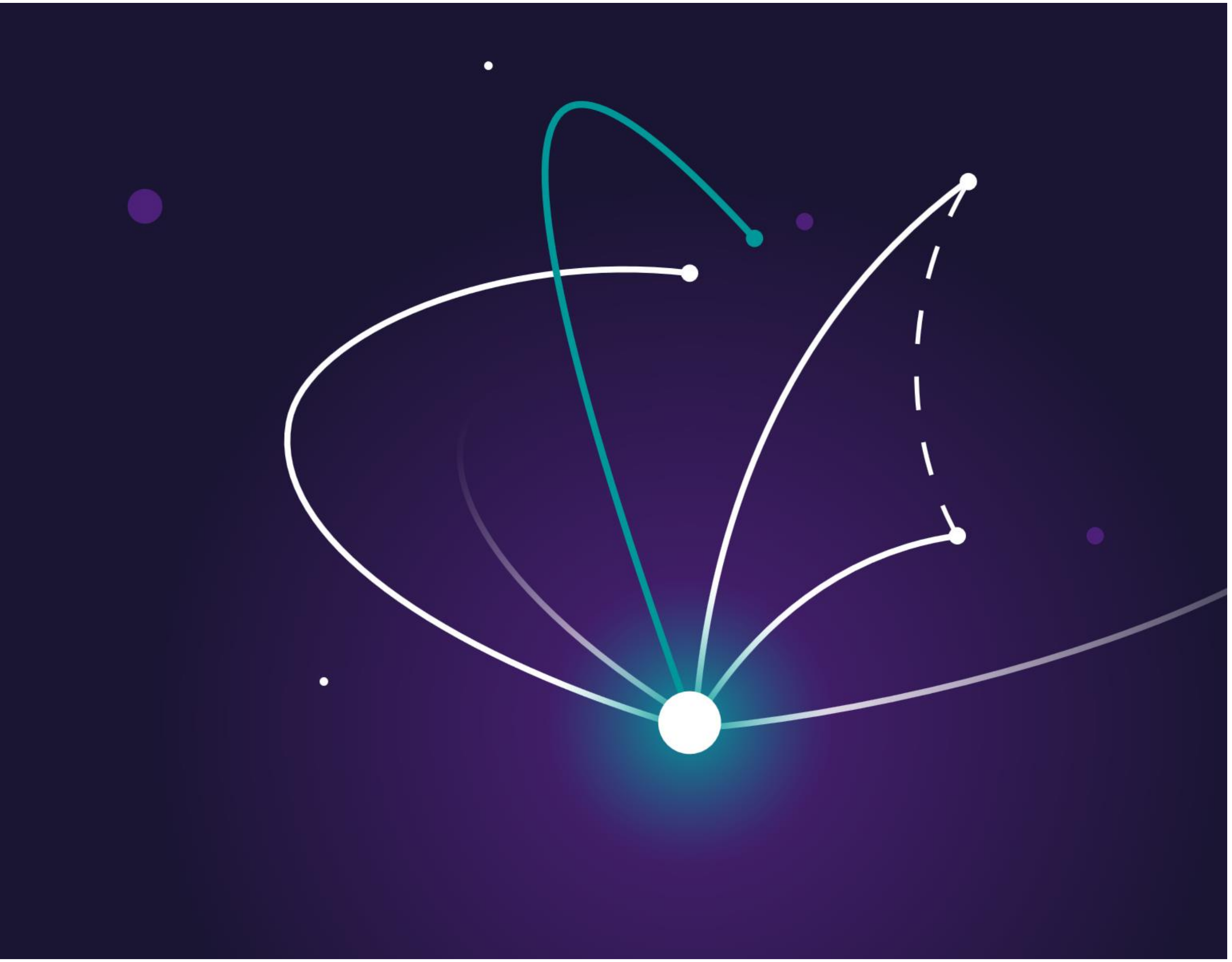
CHALMERS UNIVERSITY OF TECHNOLOGY
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA
LÄNSSTYRELSEN ÖSTERGÖTLAND
FINSPÅNG
THE LINDE GROUP

Thank you!



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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

330 kg
hydrogen per hour

Cost-optimized and pre-engineered solutions for Silyzer 300 – can be multiplied up to Gigawatt-scale solutions

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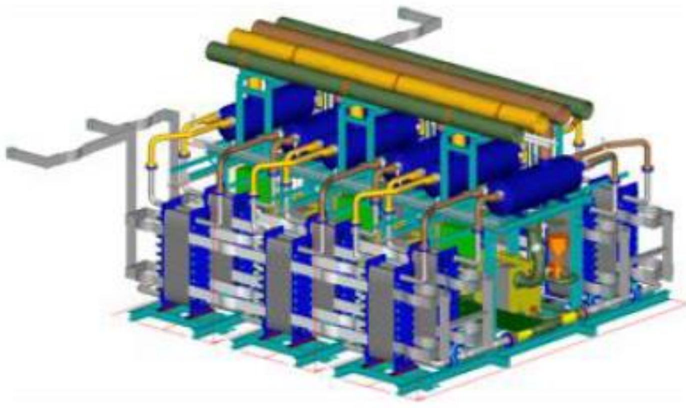
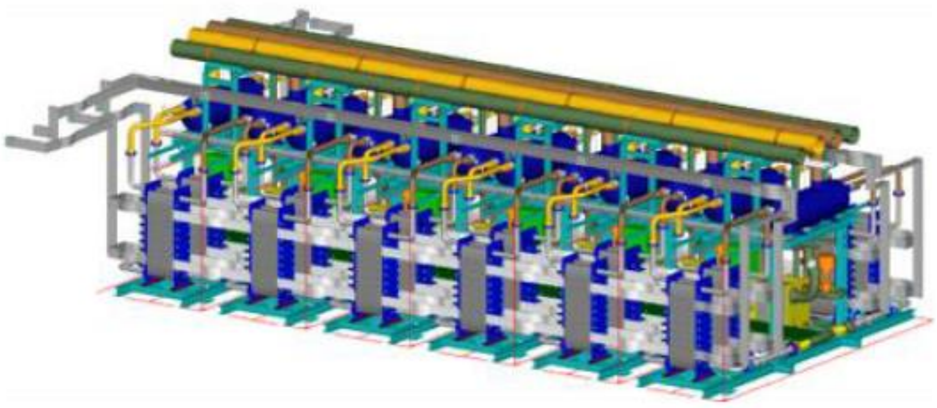




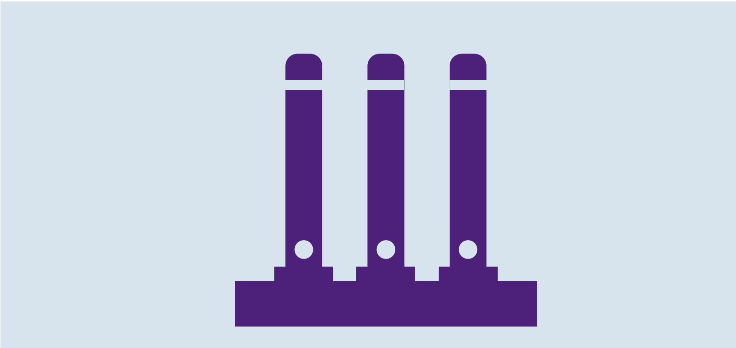
	Half Array – 12 Modules	Full Array – 24 Modules
Rated H_2 production	165 kg/h at rated power	330 kg/h at rated power
Rated Silyzer 300 plant power[1]	8.7 MW	17.5 MW
Plant efficiency Silyzer 300[1]	>75.5%	>75.5%
Dimension array	8.0 x 7.5 x 3.7 m	15.0 x 7.5 x 3.7 m
Output pressure	Array: 100 mbar(g); Plant: project specific	
Hazard concept	Standard industrial building, only water no additional chemicals	

1 Power demand and efficiency calculated for the air-cooled plant, new and clean, T_{amb} = 15°C, HHV = 39.45 kWh/kg

Hydrogen Storage from MWh up to GWh range is possible

Some examples

Cylinder tank – MWh range

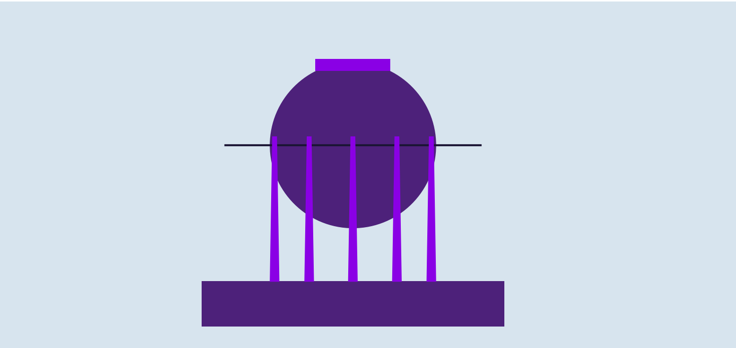


- Typical size: 10 – 100 m³
- Typical pressure: 18 – 40 (100) bar
- Pressure range: Approx. 60 – 200 bar

Example

100 m³ H_2 @ 35 bar ≈ 13 MWh th

Spherical tank – GWh range



- Typical size: ~ 2,000 m³
- Typical pressure: ≤100 bar

Example

2,000 m³ H_2 @ 100 bar ≈ 700 MWh th

Salt cavern – TWh range

- Typical cavern size: 0.5 to 1 Mio m³
- Depth: 600 – 2,000 m
- Pressure range: Approx. 60 – 200 bar

Example

1 Mio m³ H_2 @ 100 bar ≈ 0.4 TWh th

6 MW

Power demand based on Silyzer 300

1,200 Nm^3

of green hydrogen per hour

H2FUTURE

A European Flagship project for generation and use of green hydrogen

Project

- Partner: VERBUND (coordination), voestalpine, Austrian Power Grid (APG), TNO, K1-MET
- Country: Austria
- Installed: 2019
- Product: Silyzer 300

Use cases

- Hydrogen for the steel making process
- Supply grid services

Challenge

- Potential for “breakthrough” steelmaking technologies which replace carbon by green hydrogen as basis for further upscaling to industrial dimensions
- Installation and integration into an existing coke oven gas pipeline at the steel plant
- High electrolysis system efficiency of 80%

Solutions

- Operation of a 12-module array Silyzer 300
- Highly dynamic power consumption – enabling grid services
- State-of-the-art process control technology

Green fuels – An overview

Most common production pathways

Feedstocks	Process	Fuel
Biomass	Gasification	Biomethanol, biomethane Hydrogen (green)
Biomass	Fermentation	Biogas, biomethane, bioethanol
Biomass	Hydrogenation, transesterification	Biodiesel e.g. HVO, FAME**
Renewable electricity	Power to X	Hydrogen (green) E-fuels (e-methanol, e-ammonia) E-gas (e-methane)
Natural Gas	Steam methane reforming (or auto-thermal) with CCUS*	Hydrogen (blue)

*Carbon capture, utilization and storage
**HVO - Hydrogenated Vegetable Oil, FAME- Fatty Acid Methyl Esters

Customer value
Low-carbon fuels in gas turbines

From the reduction of CO_2

- **Meet current and future market requirements** for sustainable power and heat production – viability of investment and continued license to operate and increased dispatch/effect reserve participation
- **Reduced carbon cost** (expected to increase steeply in line with commitments regarding decarbonization[1])
- **Meet owners' targets, commitments and strategies** regarding decarbonization, sustainability and Corporate Social Responsibility
- **Improved company branding** (product, stock, employer markets as well as standing in the local and global community)
- **Become eligible for incentives programs and grants** for investment in CO_2 reduction

1 https://carbonpricingdashboard.worldbank.org/

Additional values

- Fuel flexibility enables optimization of operation, enabling **utilization of off-gas** as well as **optimized fuel sourcing** based on relative market pricing on green fuels
- Possibility to store surplus energy produced by e.g., renewables as e-fuel **(power-to-X)** and utilize when capacity is needed
- **Low NO_x emissions** through DLE (dry low emission) technology

Which are applicable to your installation?

Green fuel capabilities in Siemens Energy medium gas turbines

SIEMENS energy

Green fuel capabilities of 3rd/4th generation Dry Low Emission system[1]

Building on long experience with DLE and accelerated by additive manufacturing

	Current	Near term	Road map
Gas	**40 – 75% H_2** Bio-methane E-methane Biogas (down to Wobbe Index 22) Bio-propane	→ **75 – 95% H_2**	→ **100% H_2** (before 2030)
Gas/ Liquid[2]		Bio-Methanol E-Methanol Bio-Ethanol	Ammonia
Liquid	**HVO –** Hydrogenated Vegetable Oil	**FAME –** Fatty Acid Methyl Ester (e.g. RME – Rapeseed Oil Methyl Ester)	

Fossil-free Diesels

1 3rd generation used in all SGT-800, SGT-700 and newer SGT-600, 4th generation used in all SGT-750;
2 Liquid fuels that might be burnt in liquid or gaseous form

Development and customer cooperation

- Flexible operation on low-carbon fuels (biological, synthetic, off-gas)
  - Operation on multiple fuels enable optimization based on fuel availability and price fluctuations
  - Fuel switch over while operating
  - Operation on fuel mix (liquid and/or gaseous)
- 3D printed burners enables advanced designs to run on new fuels as well as rapid prototyping and agile development

We are looking for **cooperation with customers** that want to operate on fuels with high levels of **H_2 and/or other green fuels**

- **Not limited** to what is already on the road map
- Common investigation of possible governmental funding

Hydrogen roadmap
Continuous development and experience across the fleet

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- **Since 1980's:** Experience of H_2 combustion in conventional diffusion burners and auxiliary systems since 1980's (~90% H_2)
- **2008:** Atmospheric and high-pressure tests in 2008, 2009 and 2012
- **2012:** Single burner feed in full engine 40/60 vol-% H_2 in 2012 and 2014 (SGT-700)
- **2014:** SGT-700 continuous operation at customer site 10 vol-% H_2
- **2016:** In-house Additive Manufacturing capability – enabling new geometrics and rapid prototyping
- **2017:** SGT-800 full engine test with standard welded burners, bid ready 50 vol-% H_2 at 25 ppm NO_x and derated load
- **Between 2017 and 2019:**
  - SGT-600 full engine test, bid ready 60 vol-% H_2 at 25 ppm NO_x
  - SGT-700 bid ready 55% vol-% H_2 at 25 ppm NO_x
- **2019:** High pressure single burner test with additive manufactured burners verifying 100 vol-% H_2 capability

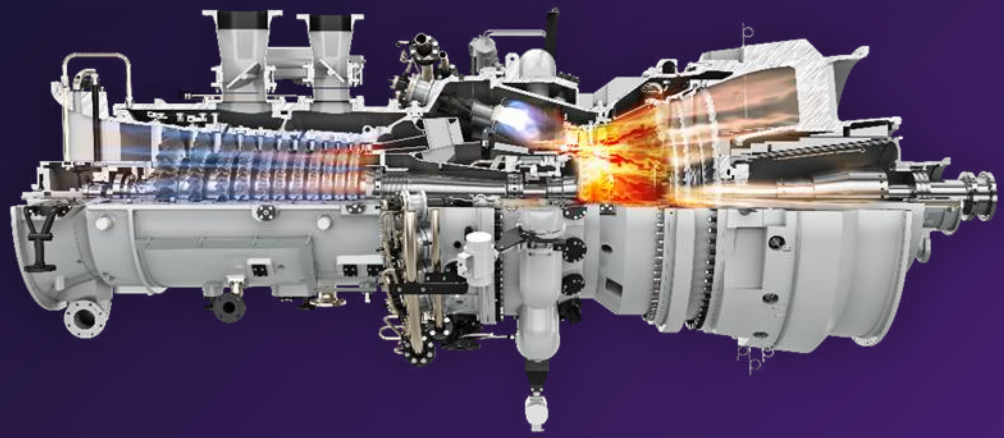
  SGT-600 customer **engine** delivery test verifying: 60 vol-% H_2 at 25 ppm NO_X and full load, reliable operation with 80 vol-% H_2
- **2020:** Sector (five-burner) feed in full engine test 75 vol-% H_2 (SGT-800)
- **2030:** **Target 100% H_2 with DLE** demonstrated at customer site

3rd generation dry low emissions (DLE) burner used in SGT-600, SGT-700 and SGT-800

Hydrogen test at the Siemens Energy test facility, Finspong Sweden

Hydrogen in gas turbines
Boundary conditions to consider

World class leader in Hydrogen combustion



Examples of boundary conditions that need to be clarified are:

Hydrogen reference project
Braskem, Brazil

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60% Hydrogen at 25ppm NO_x

Customer: Braskem

Country: Brazil

Challenge

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

Technology

2x SGT-600 PG with 3rd generation DLE system for up to 60% H_2 co-firing at 25 ppm NO_x

Solution

- Advanced Additive manufactured burners capable for 100% H_2
- Complete plant delivery, Siemens Energy will build, own and 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

https://gasturbineworld.com/working-toward-100-percent-hydrogen/

Reference
HKW Leipzig Süd, Germany

Combined heat and power plant

Customer: Stadtwerke Leipzig GmbH
Country: Germany

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 H_2
- 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

Göteborg Energi and Siemens Energy in cooperation for fossil-free cogeneration

Göteborg Energi

Potential to demonstrate flexible grid services by operation on fossil-free fuel for ultra low spinning reserve capability, zero to negative generation possible, synchronous condenser operation of GTG's and STG. Island mode operation and primary response (GT response, dP/dT 10 MW/s and GT peak firing as well as secondary and tertiary response (peak firing, inlet chilling and black start <10 min).

>> Press release regarding collaboration

By 2025, all district heating in Gothenburg, Sweden, will be produced by renewable or recovered energy sources.

- Electricity from gas turbines has the potential to provide carbon neutral grid balancing in a future energy system with a high percentage of intermittent renewable energy sources such as sun and wind
- A dual fuel burner for operation on green fuels, gaseous as well as liquid, is targeted for demonstration in Rya

Near future test of HVO[1] and RME[2] diesel operation, long-term collaboration on fossil-free operation on cost effective green fuels

Hans Holmström (CEO Siemens Energy AB) and Alf Engqvist (CEO Göteborg Energi)

Additive manufacturing for R&D speed when deve-loping next generation of green burners

1 Hydrogenated Vegetable Oil
2 RME – Rapeseed Oil Methyl Ester

Operation on Biogas @Siemens Energy AB test facilities

Biogas …

… has different gas composition depending on how its is produced and can be very close or identical to natural gas (mostly methane).

… down to Wobbe Index 22 – 25 is currently released for sale.

Rickard Olsson

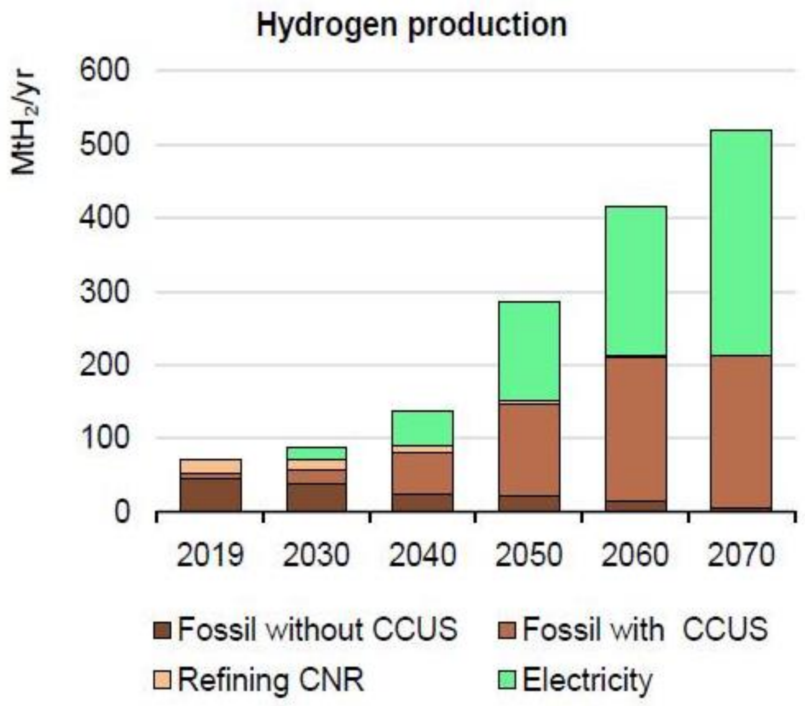
Head of Finspong test facilities, Siemens Energy AB

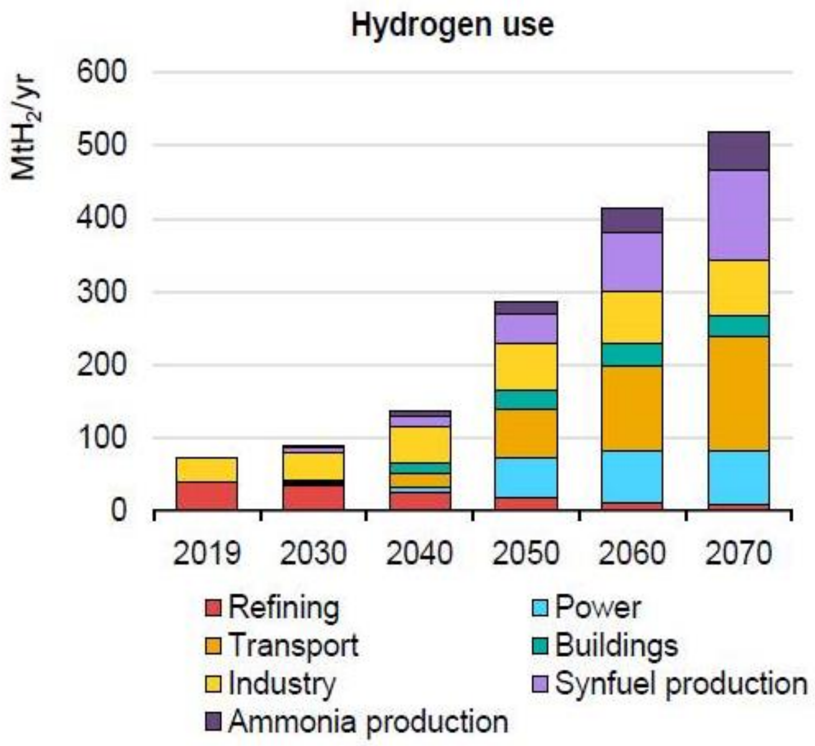
As of April 2020, Siemens Energy in Finspong, Sweden, are mixing in biogas in the gas turbine test facilities with the target to reduce the CO_2 emissions and inspire our cus-tomer to change to operation on low-carbon fuels.

The fuel is produced through the decomposition of organic waste in the region and delivered to the facilities as LBG (Liquid BioGas).

Watch: gas turbines tested on biogas

Global hydrogen production and demand by sector in the Sustainable Development Scenario (including power sector)





* CCUS= Carbon capture, utilization and storage

Source: IEA Energy Technology Perspectives 2020

Low carbon hydrogen produced through electrolysis and from fossil with CCUS* will both play a significant role up to 2070

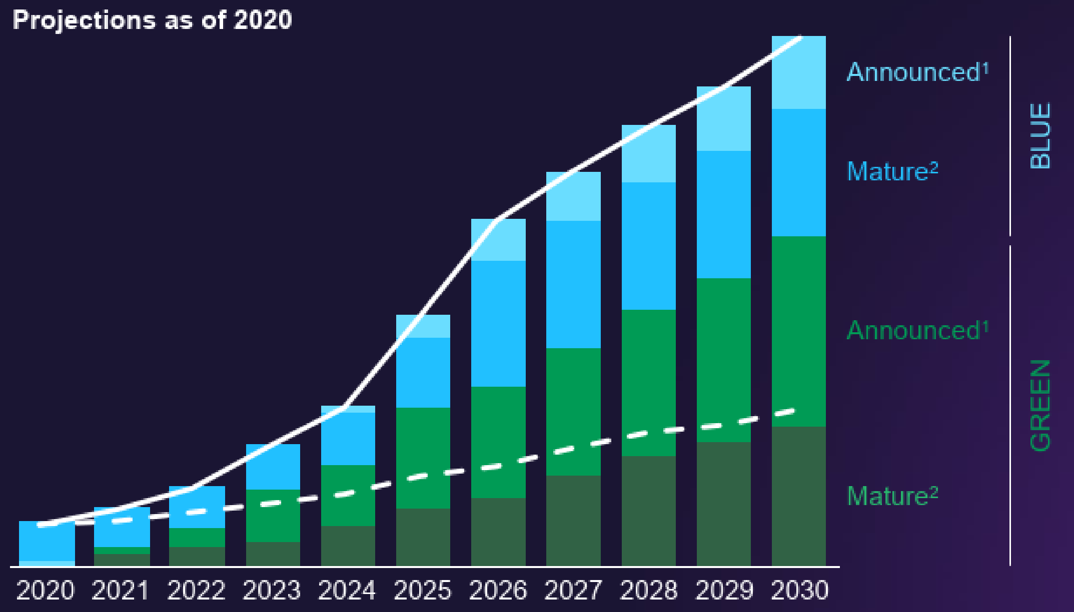
Power sector accounts for 15% of total hydrogen use 2070 supporting flexible generation

Gas turbines and combined cycle power plants running on hydrogen, biomethane and natural gas (under 500 h/y) are the main source of flexibility and reserve capacity by 2070

Strong growth in green hydrogen drives cost competetiveness

Announced clean hydrogen capacity through 2030

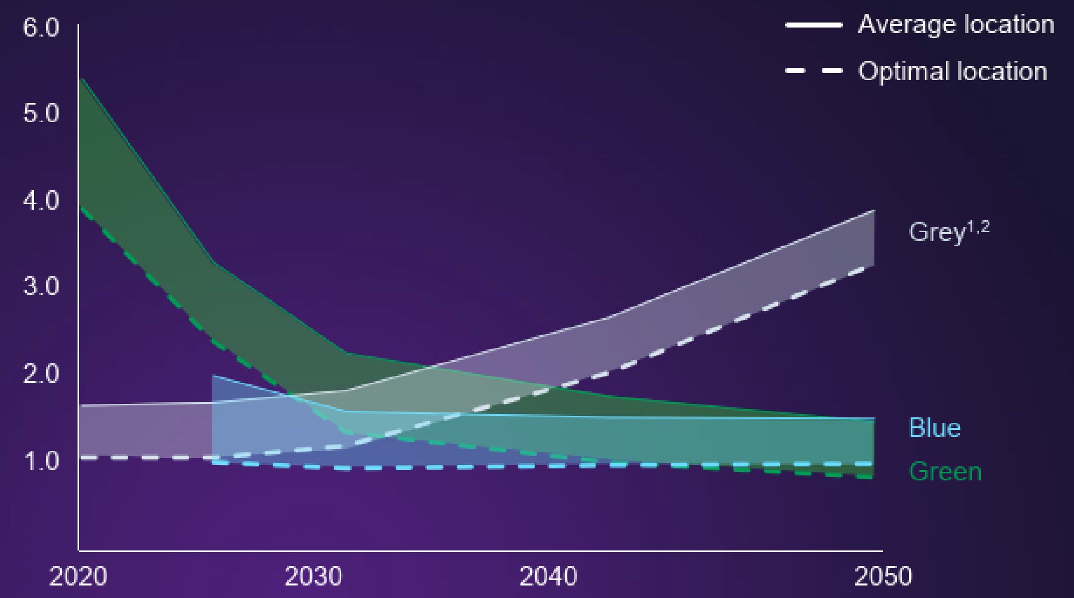
Production capacity
Mt p.a.



1. Includes projects at preliminary studies or at press announcement stage; 2. Includes projects that are at the feasibility study or front-end engineering and design stage or where a final investment decision (FID) has been taken, under construction, commissioned or operational

Hydrogen production pathways, including carbon costs

Production cost of hydrogen
USD/kg



Key assumptions: Gas price 2.6–6.8 USD/Mmbtu
Cost USD/Ton CO_2 30 (2020), 50 (2030), 150 (2040) and 300 (2050)
LCOE USD/MWh 25 – 73 (2020), 13 – 37 (2030) and 7 – 25 (2050)