Hydrogen & green fuels in turbines

Enabling sustainable energy systems

December 2023

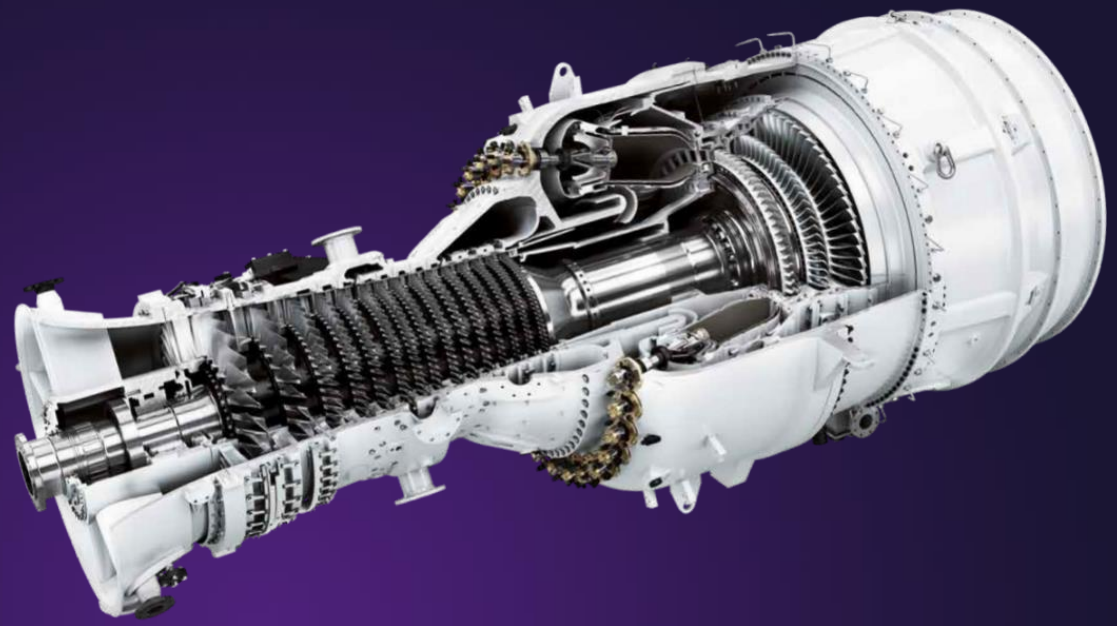
Agenda

Introduction

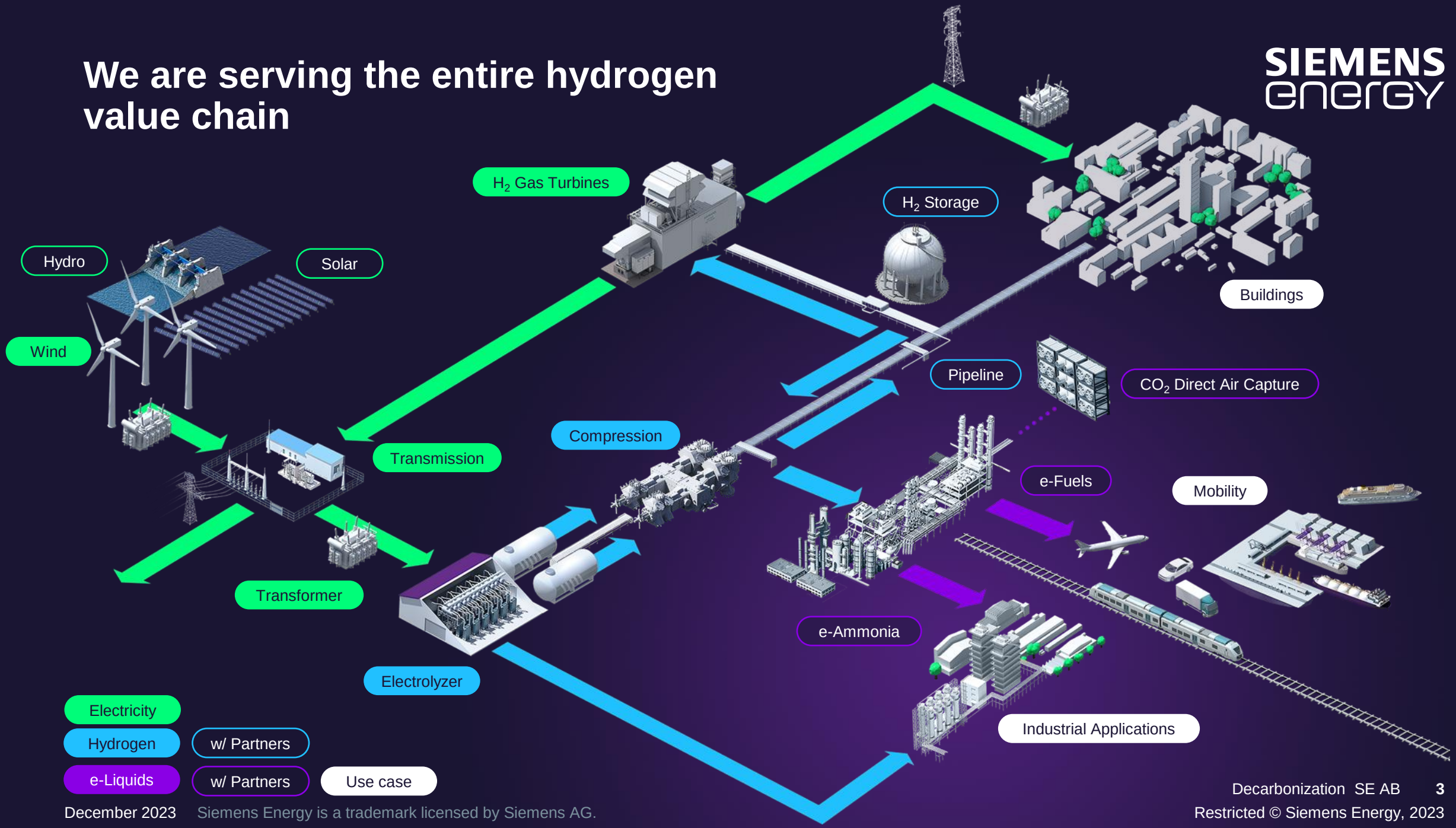
Net-zero city

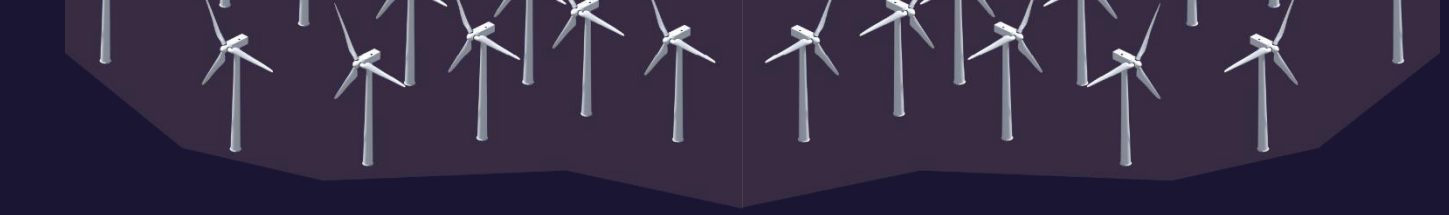
Hydrogen & green fuels

Ancillary services

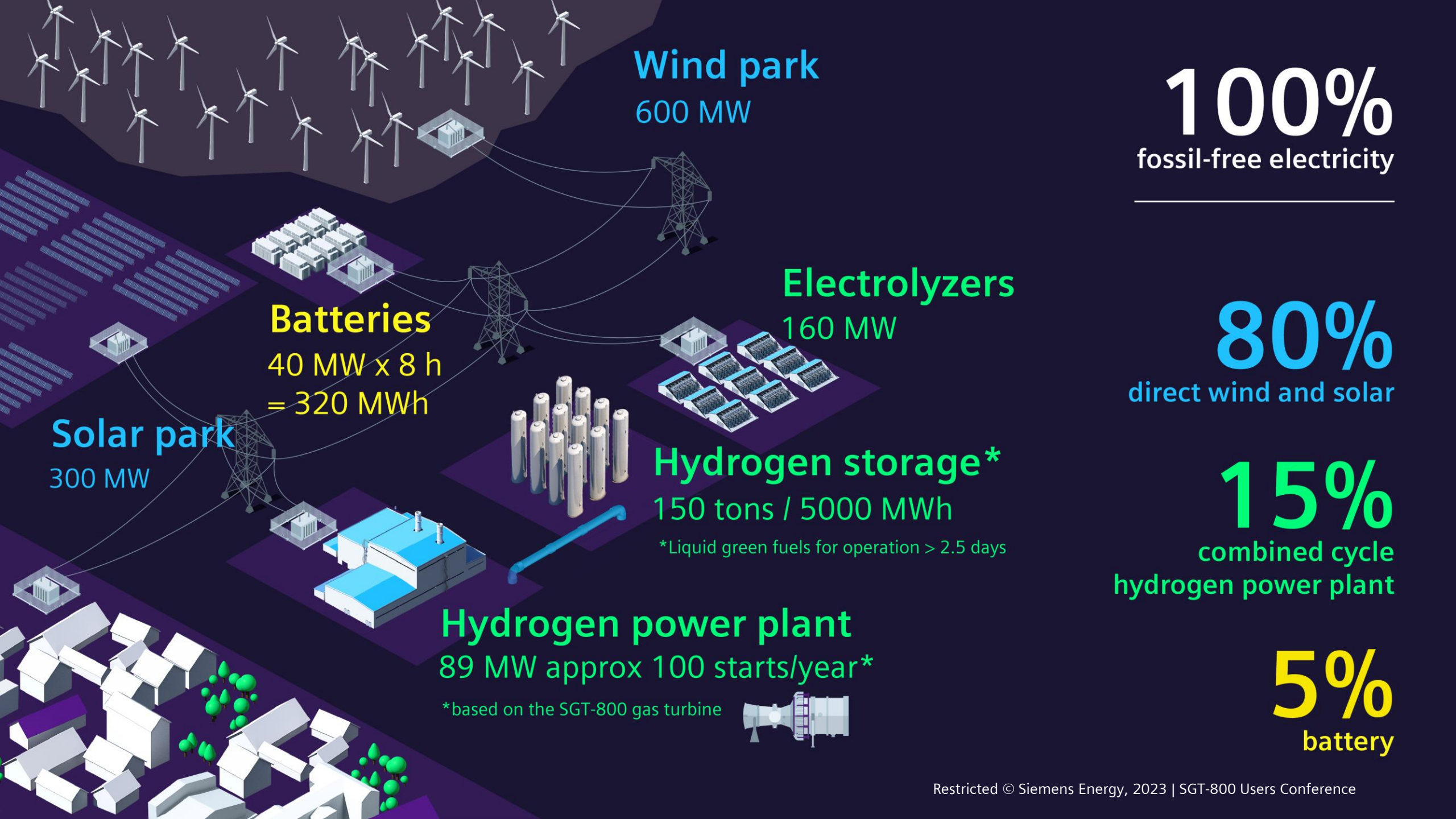


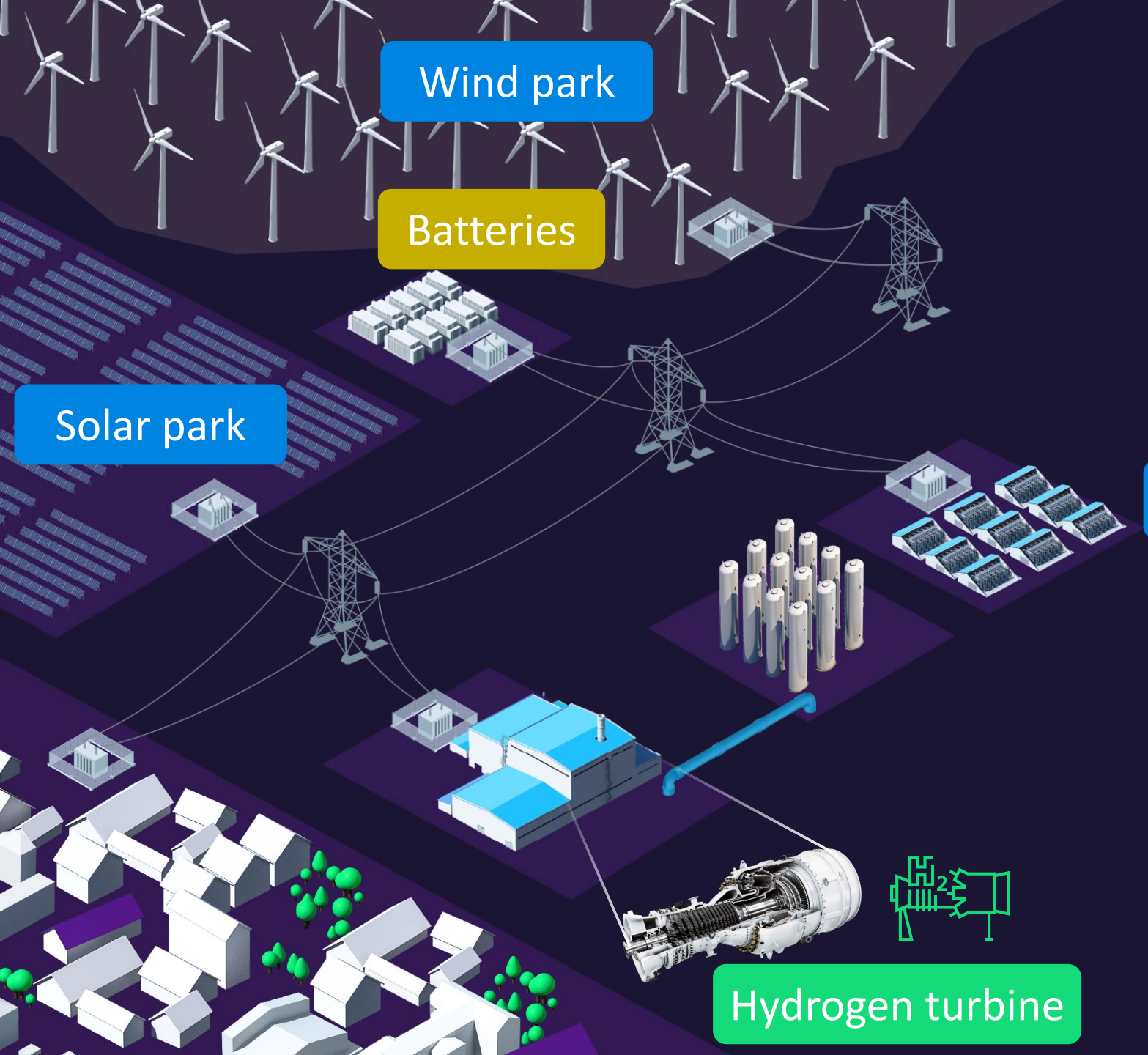
We are serving the entire hydrogen value chain





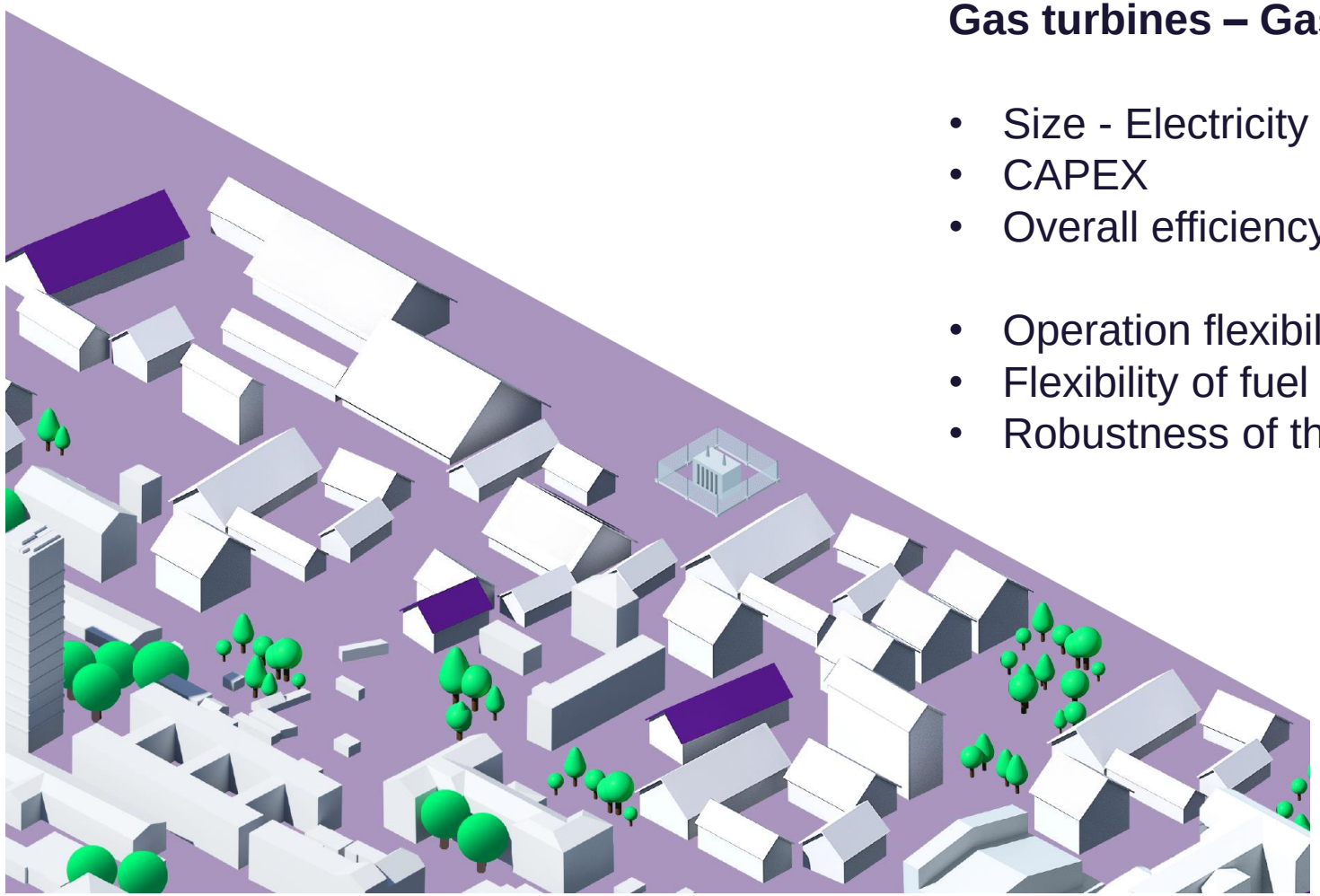
How to build a **Net-Zero electricity system** for a city with 250,000 inhabitants





Flexible mixing of hydrogen with biogas or other sustainable e- and bio-fuels strengthens the GTs competitiveness as it allows cost optimized operation and energy system resilience

Sizing and operating profile of H2 re-electrification



Gas turbines – Gas engine – Fuel cells

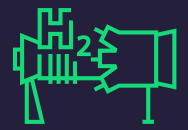
- Size - Electricity demand
- CAPEX
- Overall efficiency (Combine electricity & heat)

- Operation flexibility
- Flexibility of fuel
- Robustness of the electrical system

RISE lead study: HyCoGen project report
(incl. comparison of Fuels cells and hydrogen gas turbines) Lead by RISE
https://www.ri.se/sites/default/files/2023-08/HyCoGen%20Slutrapport%20Produktion%20av%20v%C3%A4tgas%20med%20sektorkoppling%20till%20fj%C3%A4rrv%C3%A4rme.pdf

Green fuels roadmap – Medium sized gas turbines

Acceleration through collaboration and partnership

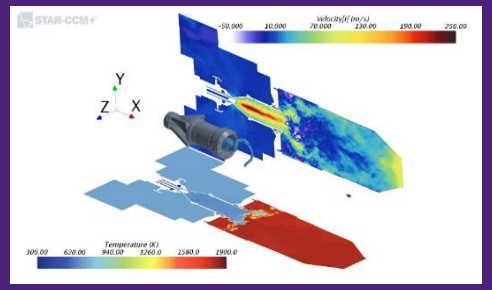
	Current	Near term	Road map
Gas phase	H_2 40 – 75% 	H_2 100% SGT-800 / 700 / 600	H_2 100% (latest 2030)
	Biogas		
	50% cracked ammonia[1]	100% cracked ammonia[1]	Ammonia
Liquid phase	Biodiesel HVO100[2] / FT[4]	Methanol FAME[3] (i.e., RME)	Ethanol SAF[5]

1: Fully cracked (hydrogen/nitrogen mix)
2: HVO = Hydrogenated Vegetable Oil
3: FAME = Fatty Acid Methyl Ester
4: Fischer-Tropsch diesel
5: Sustainable Aviation Fuel

Burner development enabling hydrogen and green fuel operation

Simulate: High fidelity simulations

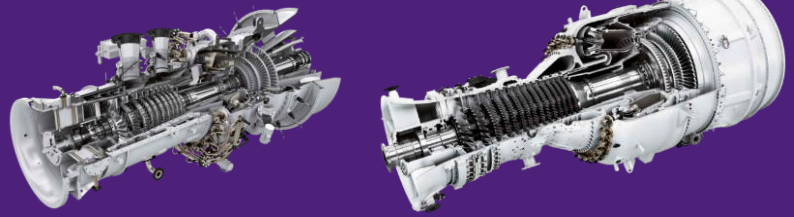
Advanced CAE tools can provide automated optimized design



Scale up:

Scale up to full engine testing

Final testing in full engine green fuels test center in Finspång



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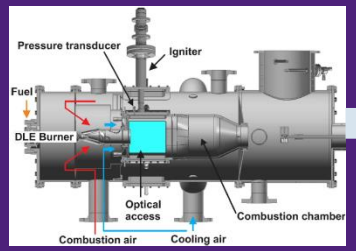
Prototype: Rapid prototyping using additive manufacturing

Additive manufacturing reduces lead time and enables better designs

Test: Combustion rig testing

Atmospheric combustion rig testing followed by full pressure combustion rig testing at real gas turbine conditions.



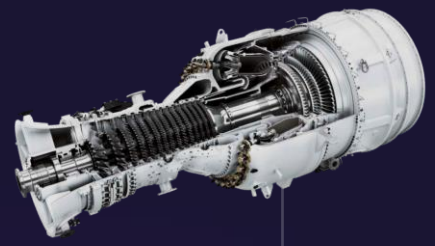
Atmospheric combustion rig in Finspong

Combustion test center in Berlin

Hydrogen achievements & roadmap

Continuous development and experience across the fleet

Additive Manufacturing in-house capability enabling new geometrics and rapid prototyping



Dedicated SGT-800 green fuels test engine

Sector (five-burner) feed in full engine
100 vol-% H_2 (SGT-800)
(planned)

2008

Experience of H_2 combustion in conventional diffusion burners and auxiliary systems since 1980's (~90% H_2)

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

2017

SGT-800 full engine test with standard welded burners, bid ready 50 vol-% H_2 at 25 ppm NO_x and derated load

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

2020

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

Sector (five-burner) feed in full engine test 75 vol-% H_2 (SGT-800)

2021

High pressure single burner test

100 vol-% H_2 SGT-800 62MW conditions

2022

High pressure single burner test (SGT-800)

100 vol-% fully cracked ammonia

2023

Sector (five-burner) feed in full engine test 100 vol-% H_2 (SGT-800)

2024

2030

Target 100% H_2 with DLE

Liquid green fuels achievements & roadmap

Continuous development and experience across the fleet

1970's

Methanol demonstrated as a viable fuel
Methanol explored as alternative fuel during oil crisis in aero-derivative gas turbines

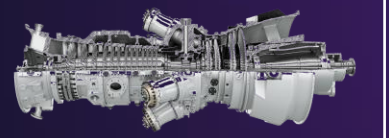
1983

Rig testing on Olympus (Rolls-Royce, now SE) non-DLE burner. Results showed 80% reduction in NOx and no ignition problems.

2021

Methanol spray testing of SGT-A20 / 400 / 800 injectors at university college London.

SGT-750 engine test with 20% of the energy input from liquid methanol

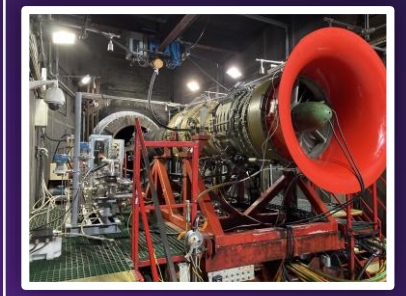


2022

SGT-800 full engine test on HVO100 and RME on customer site

2023

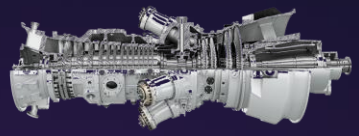
SGT-A20 full engine testing on methanol yielding 80% reduction in NOx at full power



Methanol high pressure rig test on SGT-800 DLE burners at engine conditions

2024

SGT-750 planned full engine test on HVO100

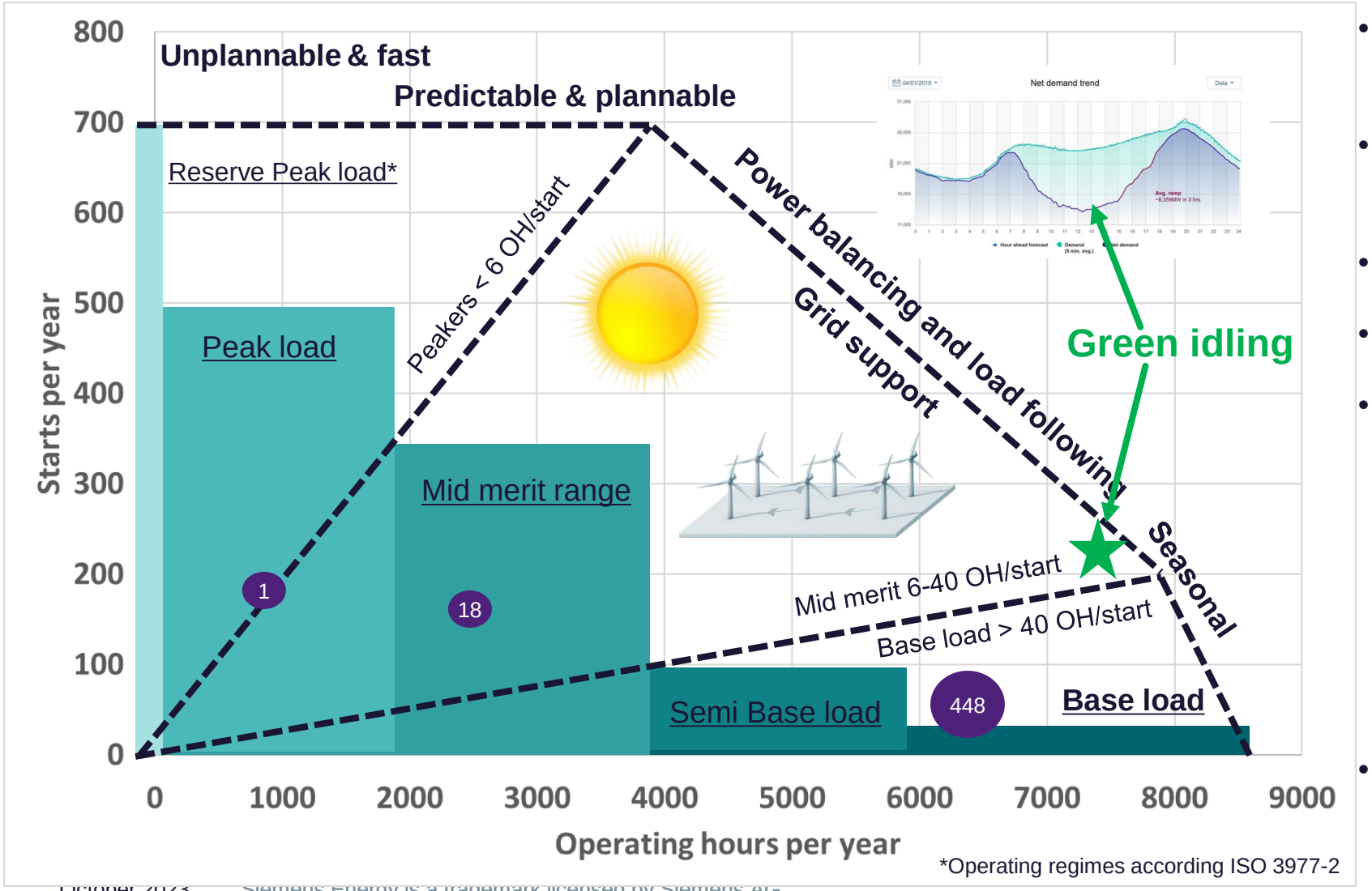


2025>

Planned SGT-800 full engine testing on methanol

Gas turbines to support in new landscape

x Number of SGT-800 Year 2023.

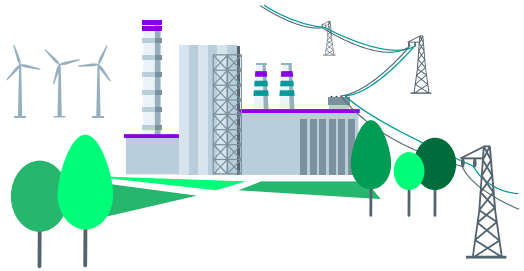


*Operating regimes according ISO 3977-2

Shift towards mid merit range

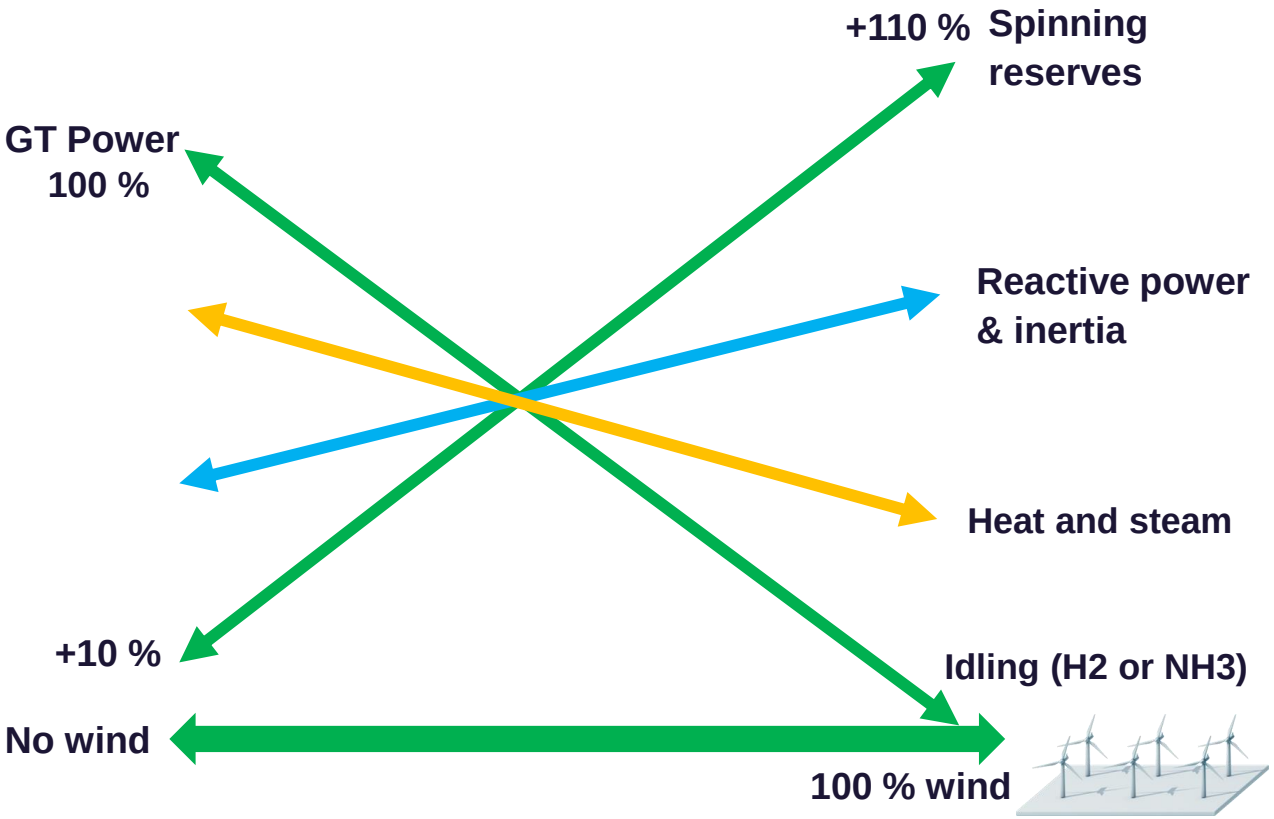
- Decarbonization via less hours, higher efficiencies and green fuels
- Extended load range via Peak, idling and augmentation
- Flexible operation on low-carbon fuels
- Support cost efficient energy storage
- Grid services
  - Controlling frequency
  - Spinning reserve for extremes
  - Inertia & reactive power
  - Short circuit power
  - Quick & Black-start
- Green idling to bridge hours with high share of renewables

Combined cycles to support renewables
Bridge intermittency and for grid firming

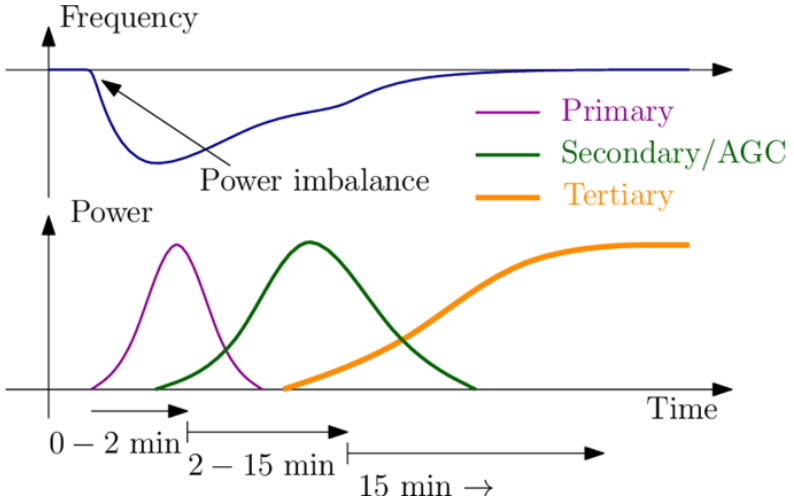


Continuous provision

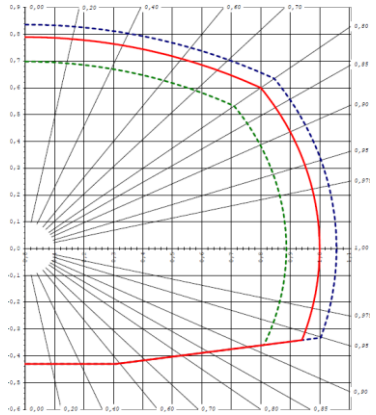
- **Grid stability mechanism**
- **Load balancing**
- **Cogeneration heat**
- **High fuel efficiency**



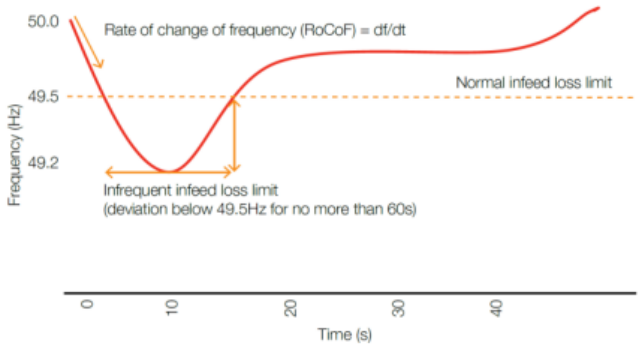
Grid ancillary services



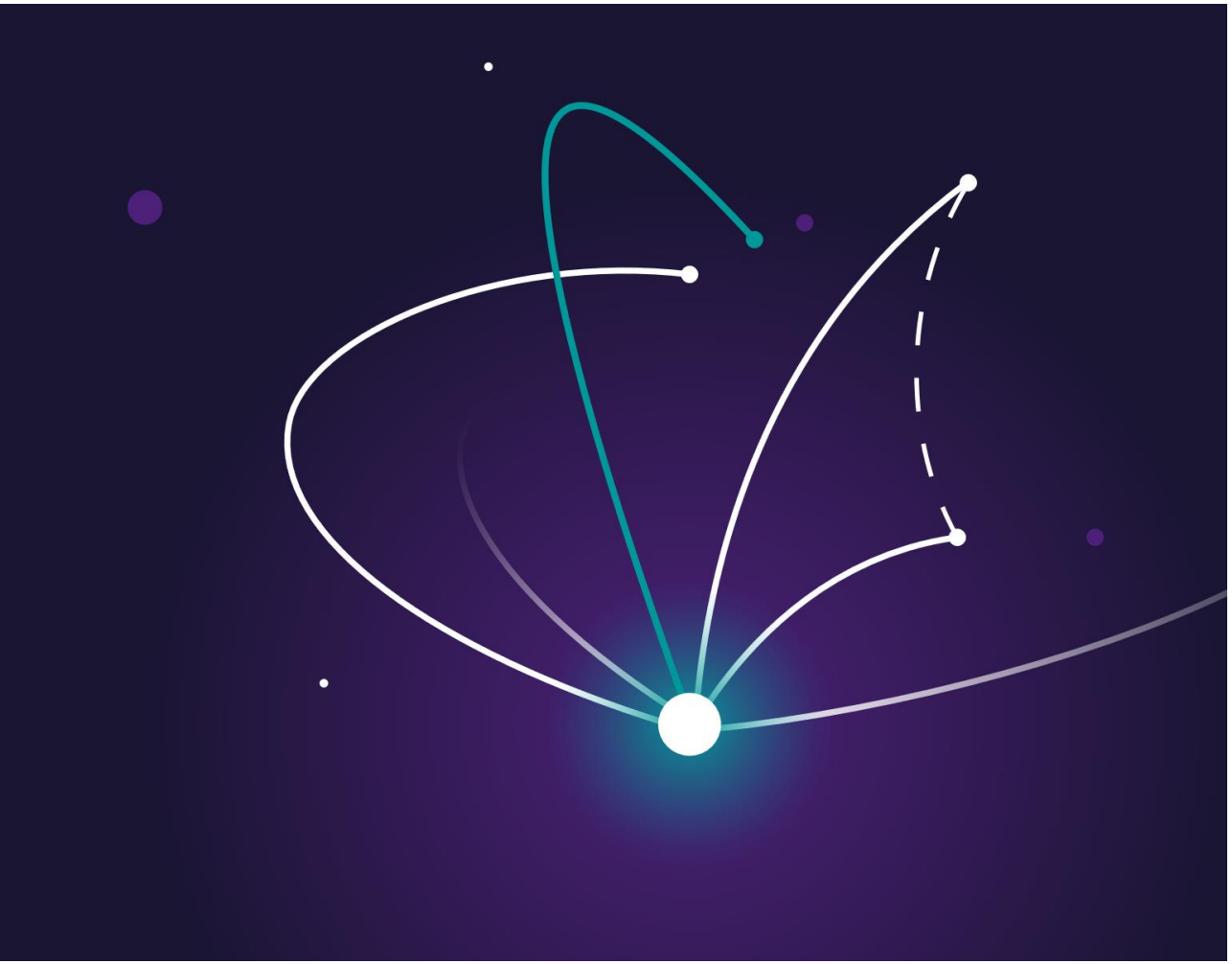
Reactive power



Inertia for RoCoF

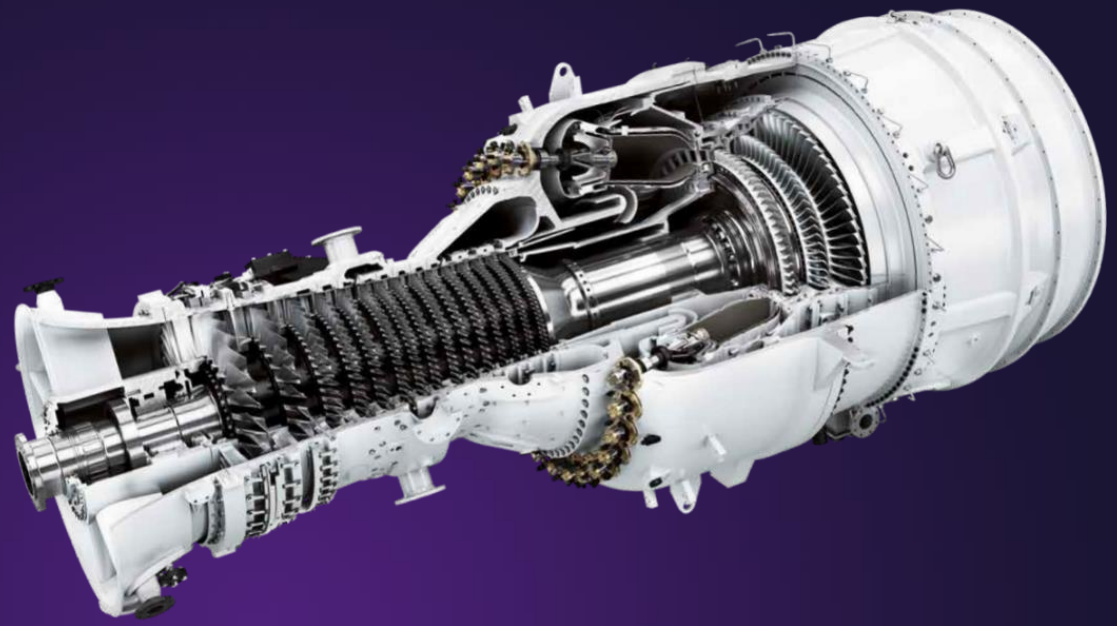


Thank you and stay energized!

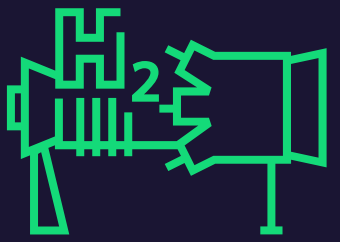


siemens-energy.com

Back-up slides



Chalmers University models competitiveness of hydrogen fueled gas turbines for a Zero Carbon Europe – Main conclusions



- Time-shifting of electricity generation using hydrogen provides a value to the system by reducing the average electricity cost by up to 16%

- Wind power dominated energy systems → Hydrogen fueled GTs are competitive to balance renewables since fluctuations are relatively few, irregular and longer in duration (less than 100 starts per year)
- Solar PV dominated systems → Batteries suitable since fluctuations are shorter and more frequent (daily). Hydrogen fueled GTs would take the role as back-up with fewer operational hours
- Demand side also important for flexibility e.g., smart EV charging, flexible operation of electrolyzers / heat pumps

- CCGTs operating around 2,000 hours per year is the most common GT application in the future
  More Open Cycle Gas turbines in the future energy system than today

- Flexible mixing of hydrogen with biogas strengthen the gas turbine competitiveness as it allows the installed gas turbines to operate also at times hydrogen is expensive. Blue hydrogen could supply up to 11-13 % of H2 demand

Combined Cycle GT on hydrogen / biogas operating ~ 2000 hours / year with a limited number of start / stops will be needed to balance renewables mainly in wind dominated energy systems

* Conclusions based on a fully optimized energy system and assumptions made in the model in Chalmers University report.

Bio-diesel in gas turbines
HVO100 & FAME (RME)

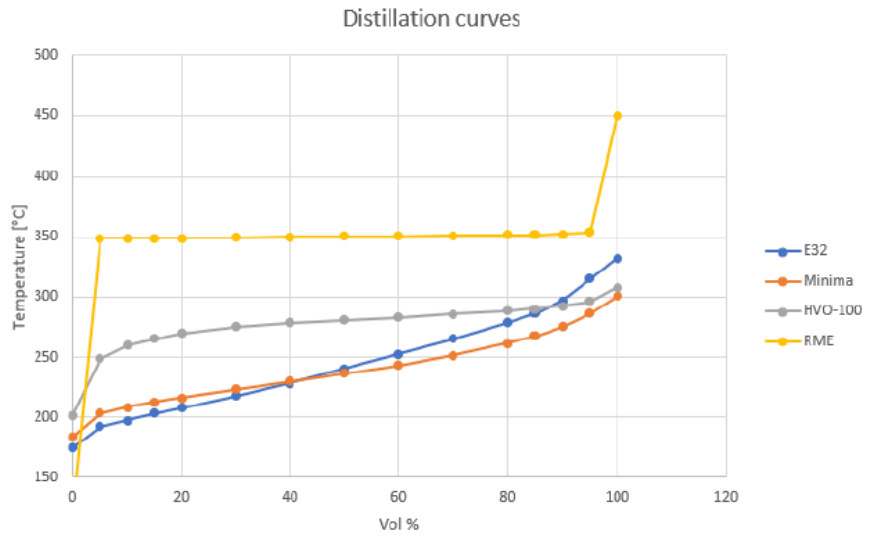
Testing

HVO100 was 2021 tested in SGT-800 at customer Göteborg Energi's site Rya CHP.

HVO100 has since been released as an approved gas turbine fuel

Characteristics

HVO100 behaves closer to an ordinary diesel fuel and is within our current fuel specification whereas FAME (RME) differs more, especially regarding the distillation curve and viscosity.



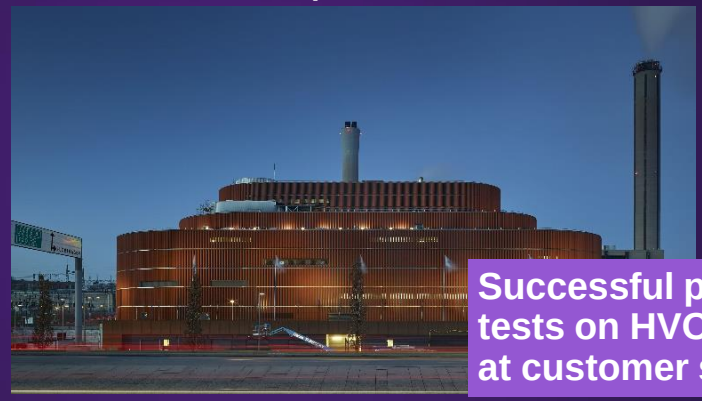
Cooperation

Göteborg Energi and Siemens Energy operated gas turbines 2021 on bio-diesel at Rya CHP co-funded testing from the Swedish Energy Agency

Portfolio Elements
3 x SGT-800 gas turbine

Reference

Stockholm Exergi power plant on HVO100
Commercial operation 2023



Portfolio Elements
1 x SGT-800 gas turbine

Successful performance tests on HVO100 performed at customer site

Hydrogen reference
Braskem, Brazil

60% Hydrogen at 25ppm NO_x

Customer: Braskem

Country: Brazil

Commercial operation: 2023

Challenge

- Low cost for O&M
- 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

Technology

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

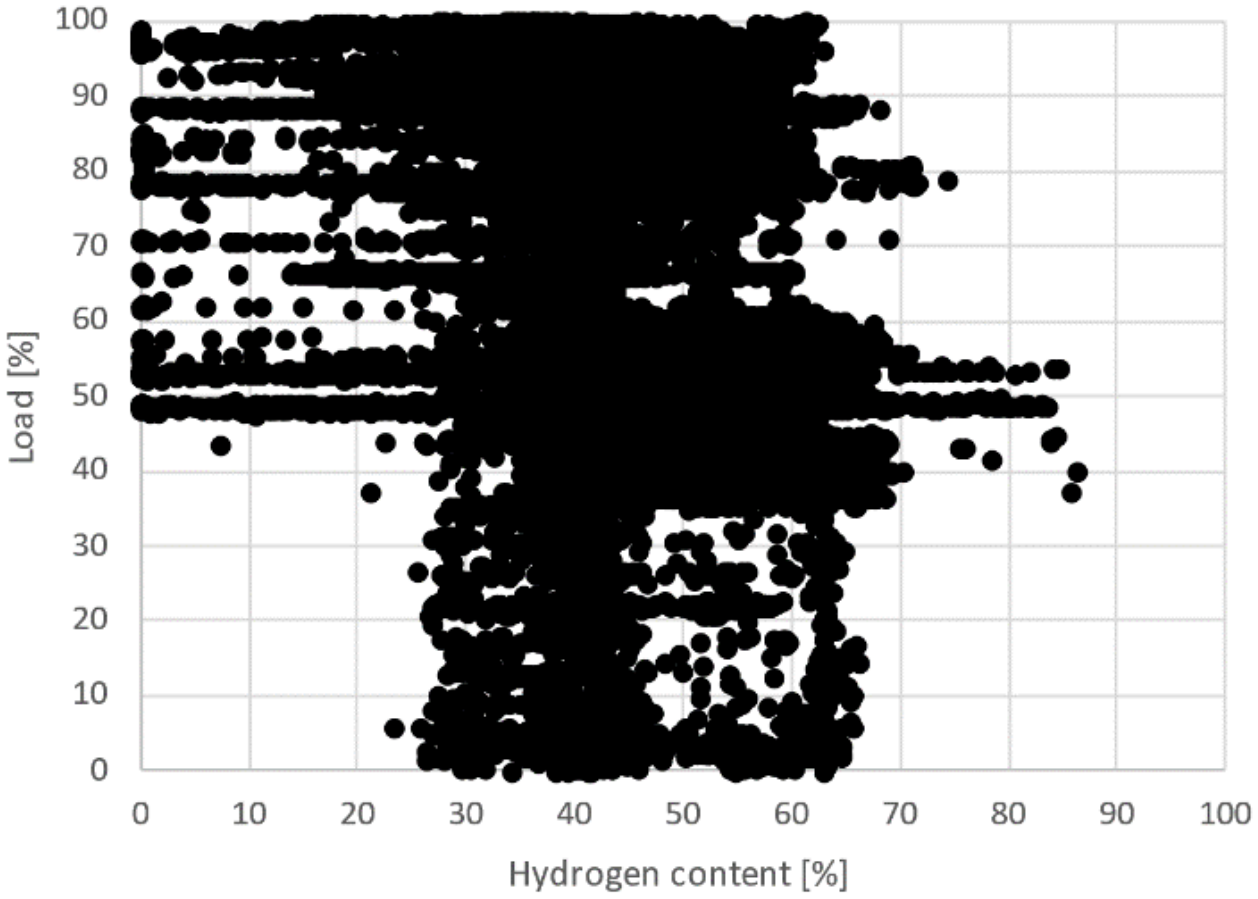
Solution

- 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

Operational Statistics



- The units have collected over 10,000 operational hours on varying amounts of hydrogen
- There is significant experience of operating with up to 60% H_2 at any load.
- At around 50% load the engines have been operated without any issue with close to 90% H_2

Hydrogen reference
HKW Leipzig Süd, Germany

Combined heat and power plant

Customer: Stadtwerke Leipzig GmbH
Country: Germany

Commercial operation: 2023

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

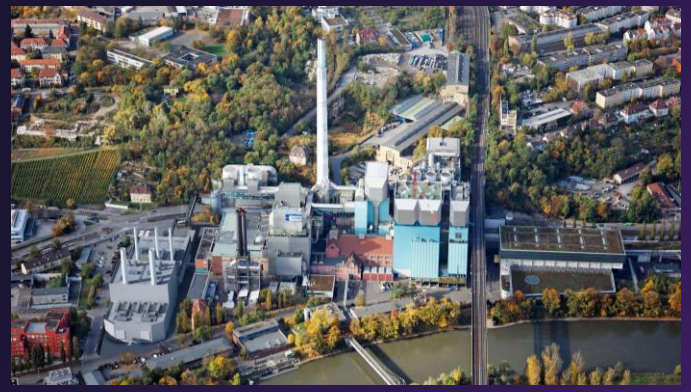
Solution

- 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 2023

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

Reference
HKW Stuttgart-Münster, Germany



Combined heat and power plant

Customer: EnBW AG

Country: Germany

Commercial operation: 2025

Challenge

- Make power and district heating independent from coal according to the climate goals of the city of Stuttgart and EnBW – to be CO_2 neutral by year 2035
- Decarbonize parts of the district heating generation with affordable and dispatchable technology
- Choose a sustainable technology which can “grow” with the H_2 availability

Technology

- 2 x SGT-800 62 MW gas turbines
- 2 x SGen-100A generators
- Long term service contract over a period of 13 years with optional extension to 19 years

Solution

- Two cutting-edge gas turbine packages to supply 125 MW electrical and 155 MW thermal capacity
- The GT’s exhaust heat will generate steam in two auxiliary fired HRSGs to supply existing steam turbines and district heating condensers
- 100% H_2-ready gas turbine package incl. 75% vol. H_2 capability for the core engine right from the start
- Evolution path to 100% H_2 included in service contract

Benefits

- Reduce CO_2 emissions via fuel switch;
  Step 1: 60% with coal to gas transition
  Step 2: complete 100% reduction with green hydrogen fuel
- Affordable, dispatchable and green supply of district heating and power for the city of Stuttgart
- Avoid stranded asset by assuring H_2 readiness of the gas turbine package
- Support strategic goal of Stuttgart city and EnBW to get CO_2 neutral by 2035

Further information

- Siemens Energy H_2 web page
- H_2 whitepaper Hydrogen power with Siemens Energy gas turbines | 2023
- H_2 retrofit capability for installed units
- Hydrogen Decarbonization Calculator
- Hydrogen Power Plants
- Zero Emission Hydrogen Turbine Center (ZEHTC)
- Brownfield Exchange (BEX)