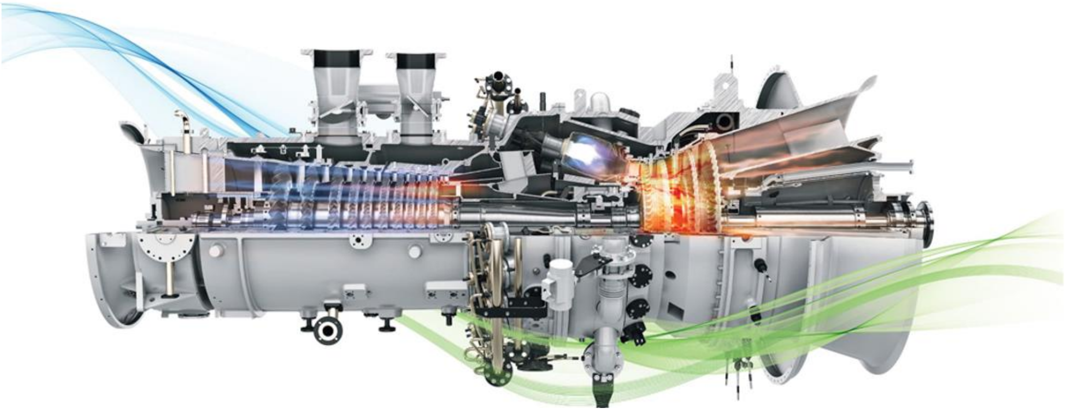
European Hydrogen Week Side Event

ETN Global



Hydrogen Deployment in Centralised Power Generation

A techno-economic case study

28 October 2022 | 12.00-13.00 CEST

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European Turbine Network (ETN) Young Engineers Committee (YEC)

The YEC recently published our first main report:

“Hydrogen Deployment in Centralised Power Generation – A techno-economic case study”

Download for free at:

https://etn.global/news-and-events/news/hydrogen-techno-economic-study/

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Agenda

1. Workshop Panel Introduction
2. Why Hydrogen (H_2)?
3. Techno-Economic Study
4. Levelized Cost of Electricity (LCOE)
5. Carbon Tax
6. Natural Gas and Hydrogen Price
7. Hydrogen GT Roadmap and Conclusions
8. Live Q&A

Workshop Panel

Moderator

Antonio Escamilla Perejón

EU Marie Sklodowska-Curie Early Stage Researcher
University of Seville

Panelists

Dr. Jon Runyon

GT Combustion Engineer
Uniper

Dr. Serena Gabriele

Hydrogen Business Development Manager
Baker Hughes

Dr. Daria Bellotti

Assistant Professor
University of Genoa

Alessandro Castelli

PhD Student
Polytechnic University of Milan

Lorenzo Pilotti

PhD Student
Polytechnic University of Milan

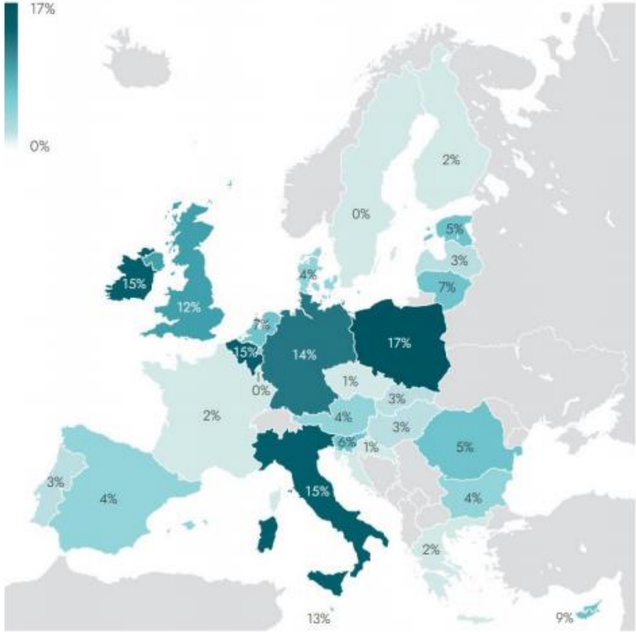
Why hydrogen (H_2)?

According to IEA Net Zero by 2050 report:

- **17%** of global H_2 will be used for power generation
- Requiring **~90 Mt H_2/year**
  - **Equivalent to today's global annual H_2 production!**
  - H_2 needs to be **low-carbon** or **zero-carbon**

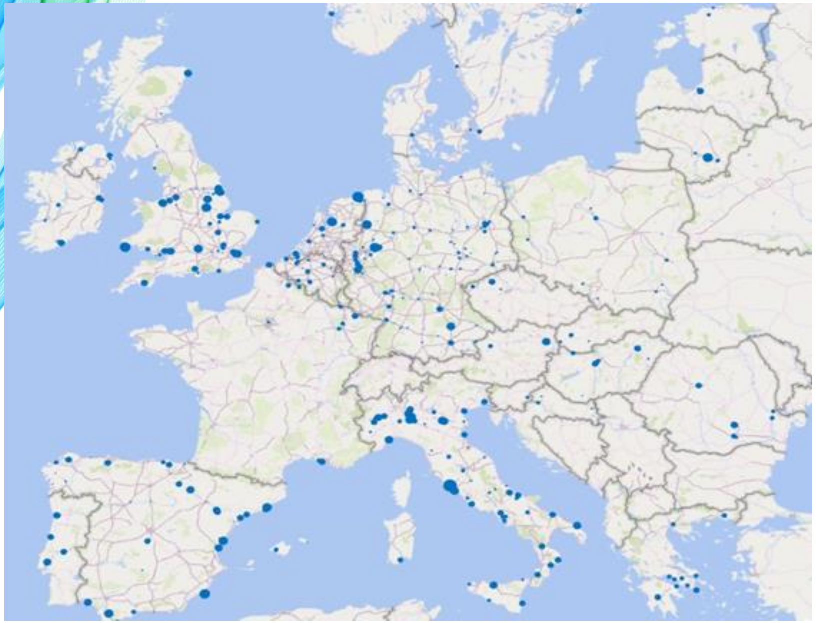
→ Study aim:

Identify the *economic* and *political* conditions under which H_2 firing in a GT could become viable.



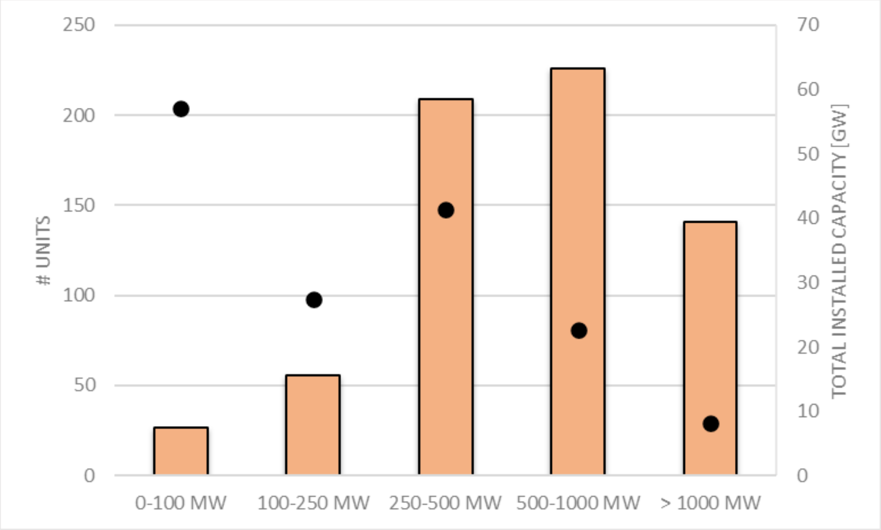
Fraction of total electricity generation attributed to H_2 generation in 2050
(from European Hydrogen Backbone)

Where do we start?



Map of European Natural Gas GT Plants
(from [Global Power Plant Database])

	World	EU27+UK	US
NG-based capacity:	1473 GW_e	173 GW_e	526 GW_e
NG-based share of total capacity:	26.4%	24.5%	44.0%

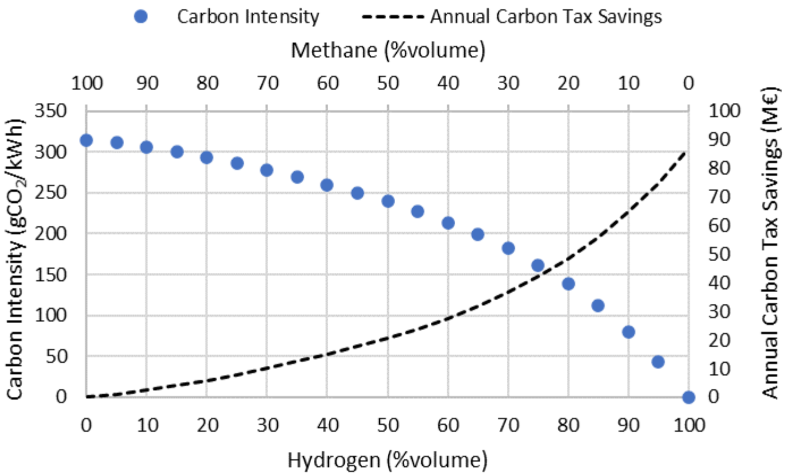


EU Natural Gas GT Units and Capacity by Size
 # Units = ●

H_2 blending in GT

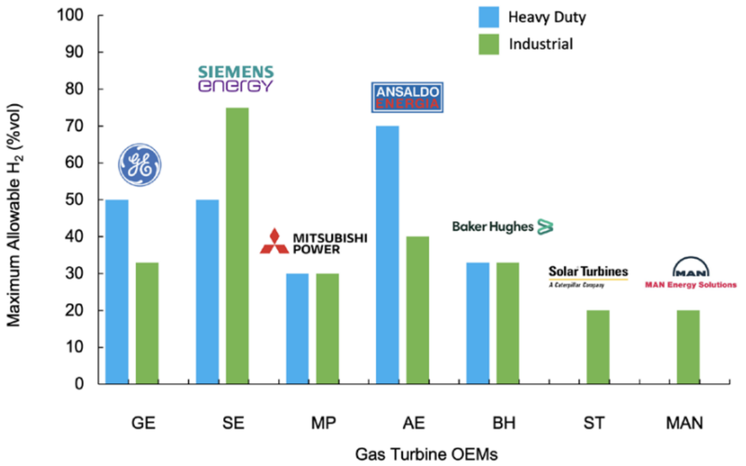
→ Hydrogen blending into natural gas in a high-efficiency CCGT will reduce the carbon intensity of the operations, resulting in an annual carbon cost savings*

→ Multiple OEMs have committed 100% H_2-capable DLN gas turbines commercially available by 2030



Carbon intensity (left) and annual carbon tax savings (right) with hydrogen blending (using GE Hydrogen Calculator)*

*GE 9HA.02 operating for 6000 hours and a carbon price of €50/tCO_2



Current DLN H_2 capability in a blend with natural gas

DLN: Dry Low NO_x

Techno-Economic Study

Levelized Cost of Electricity (LCOE)

$$\text{LCOE} = \frac{Sum\ of\ costs\ over\ lifetime}{Sum\ of\ electrical\ energy\ produced\ over\ lifetime}$$

LCOE has been used to compare costs of electricity production in centralized power generation plant by increasing %vol of H2 content in GT fuel blend

Blend NG-H_2 (vol%)					
Natural Gas	100%	70%	50%	30%	0%
Hydrogen	0%	30%	50%	70%	100%

Study Assumptions

Techno-economic study

Technical parameters

- GT configuration and size
- Operating regime
- Power and efficiency
- Derating
- H_2 blending

Sensitivity analysis

- H_2 price
- Natural gas price
- Carbon price
- Operating hours

Economical parameters

- Upgrading cost
- Operating costs
- Maintenance costs
- Fuel cost
- Carbon tax

Case Studies

To analyze the impact of hydrogen in centralized power generation, Levelized Cost of Electricity (LCOE) has been calculated for the retrofit/upgrade of **5 case studies** of thermal power plants

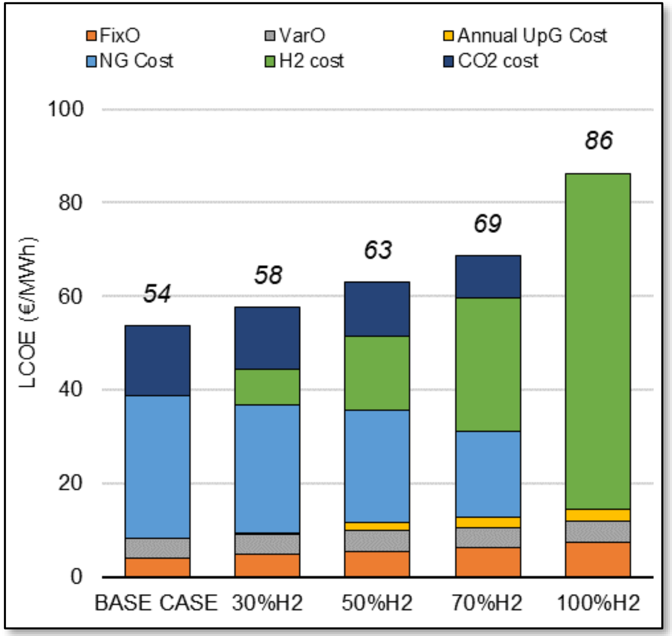
	GT Type	GT Output (MW_e) @ISO	Configuration	Annual equivalent operating hours	Annual start and stop cycles	Designation
1	Small	20	OCGT	800	150	S-OCGT
2	Small	20	CHP	6000	10	S-CHP
3	Medium	60	OCGT	800	150	M-OCGT
4	Large	450	OCGT	800	150	L-OCGT
5	Large	450*	CCGT	6000	10	L-CCGT

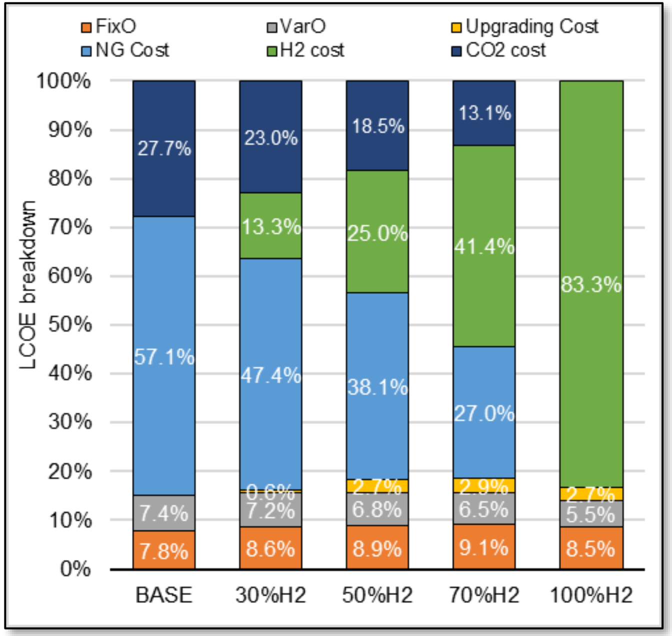
*CCGT output = 650 MW_e

CHP: Combined Heat and Power
OCGT: Open Cycle Gas Turbine
CCGT: Combined Cycle Gas Turbine

Levelised Cost of Electricity

LCOE of Large CCGT case



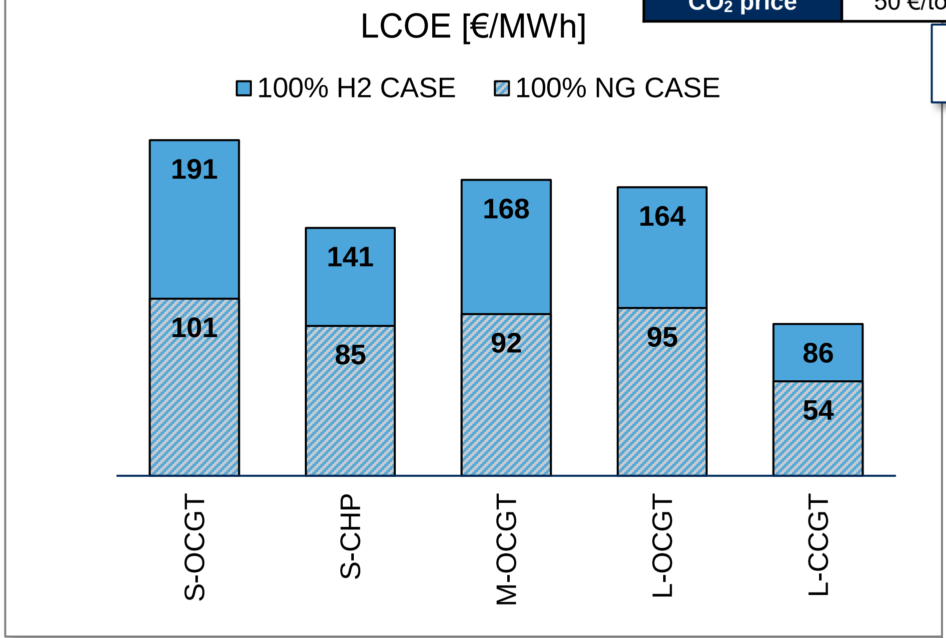


Hydrogen cost	Natural gas cost	CO_2 price
1.5€/kg	20€/MWh	50€/ton

Case study update for 100% Hydrogen GTs

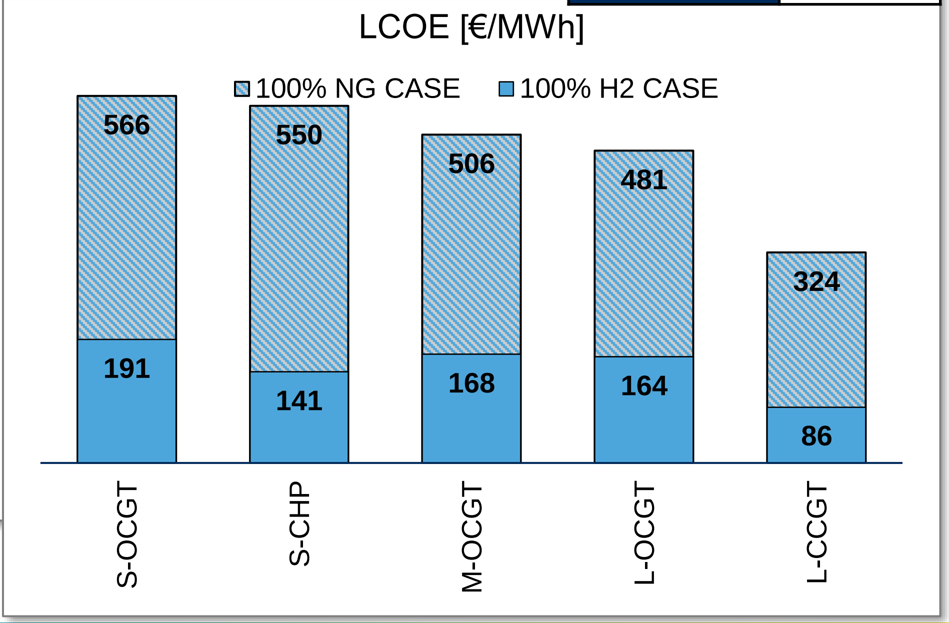
Reference Scenario

Hydrogen cost	1.5 €/kg
Natural gas cost	20 €/MWh
CO_2 price	50 €/ton



1st October scenario

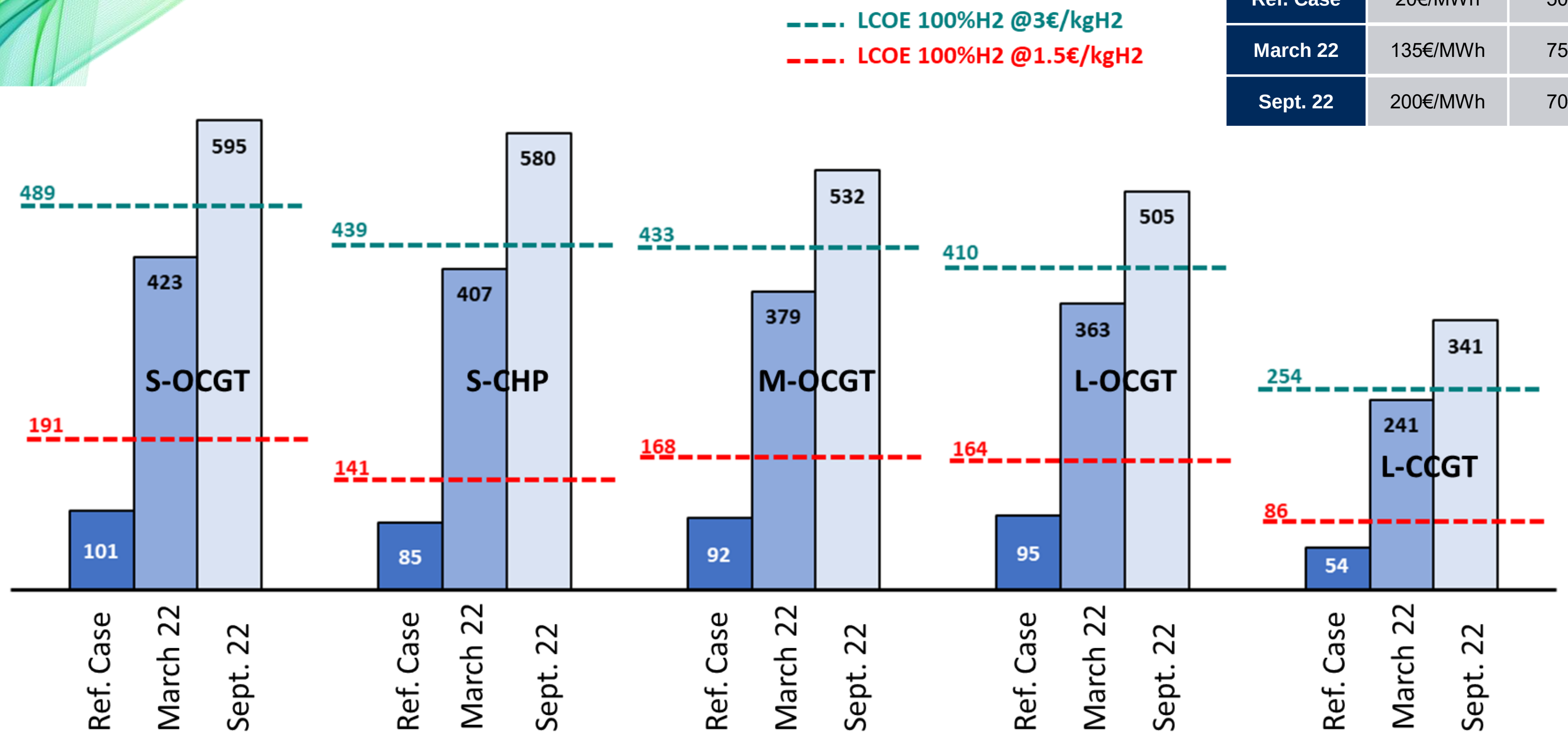
Hydrogen cost	1.5 €/kg
Natural gas cost	190 €/MWh
CO_2 price	65 €/ton



LCOE: Levelised Cost of Electricity

LCOE of 100%H2 GTs vs 100%NG GTs

	Natural gas cost	CO_2 price
Ref. Case	20€/MWh	50€/ton
March 22	135€/MWh	75€/ton
Sept. 22	200€/MWh	70€/ton



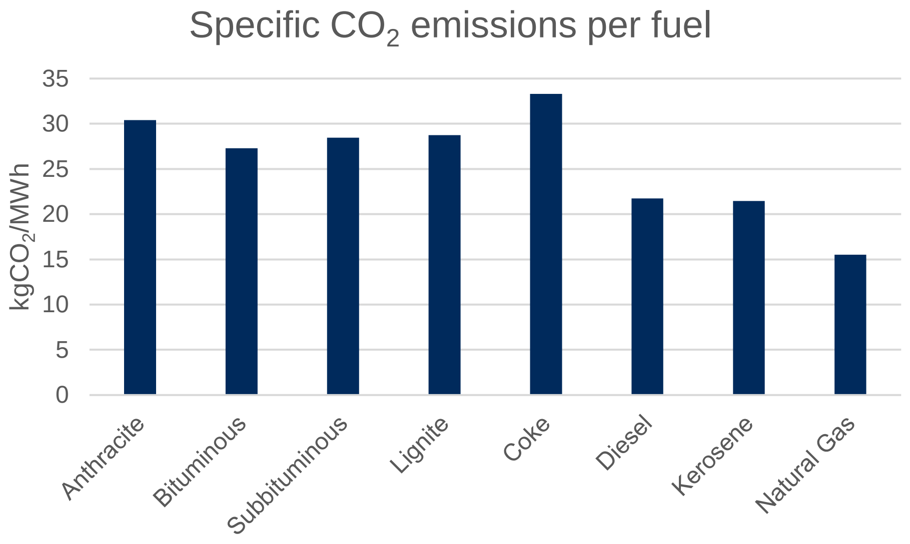
Carbon Tax

Carbon tax

"A carbon tax is a fee imposed on the burning of carbon-based fuels".

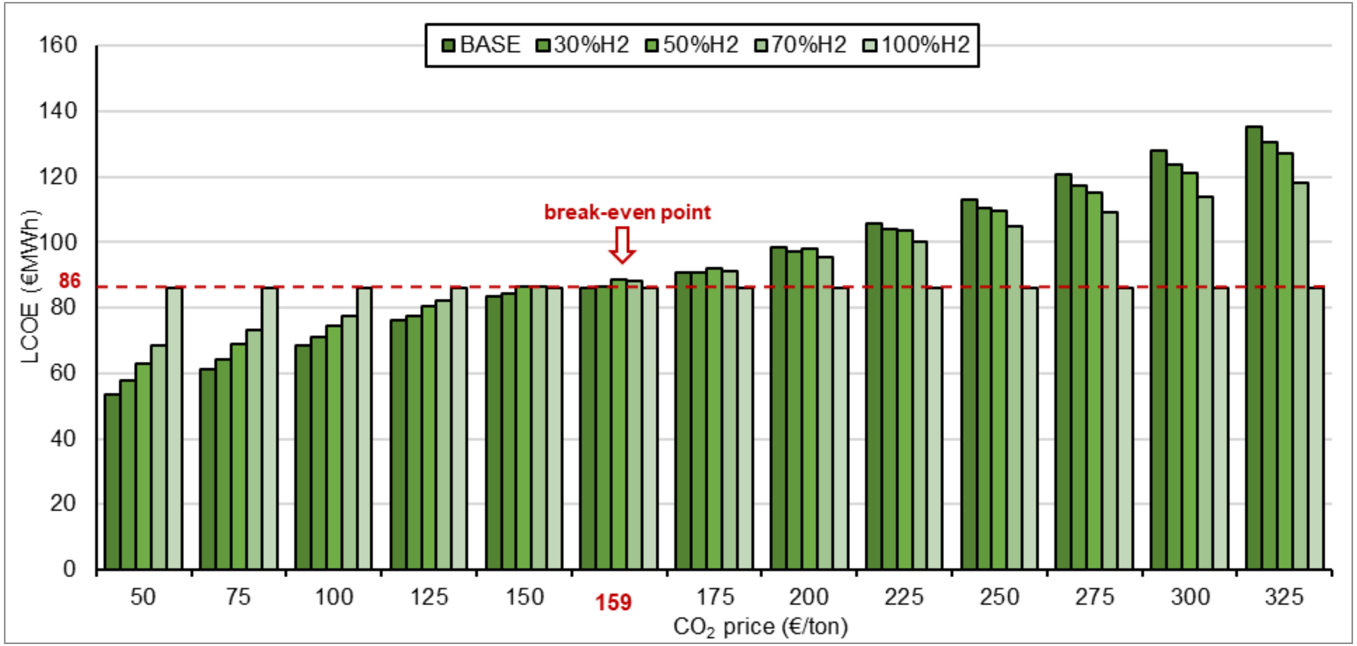
- European Union: 20 €/ton$_{CO2}$ – May 2020
  80 €/ton$_{CO2}$ – 28/10/2022
- United States: not implemented
- China: not implemented

- Shifting to NG implies a huge reduction in CO_2 emissions
- Competing against NG is more challenging for H_2



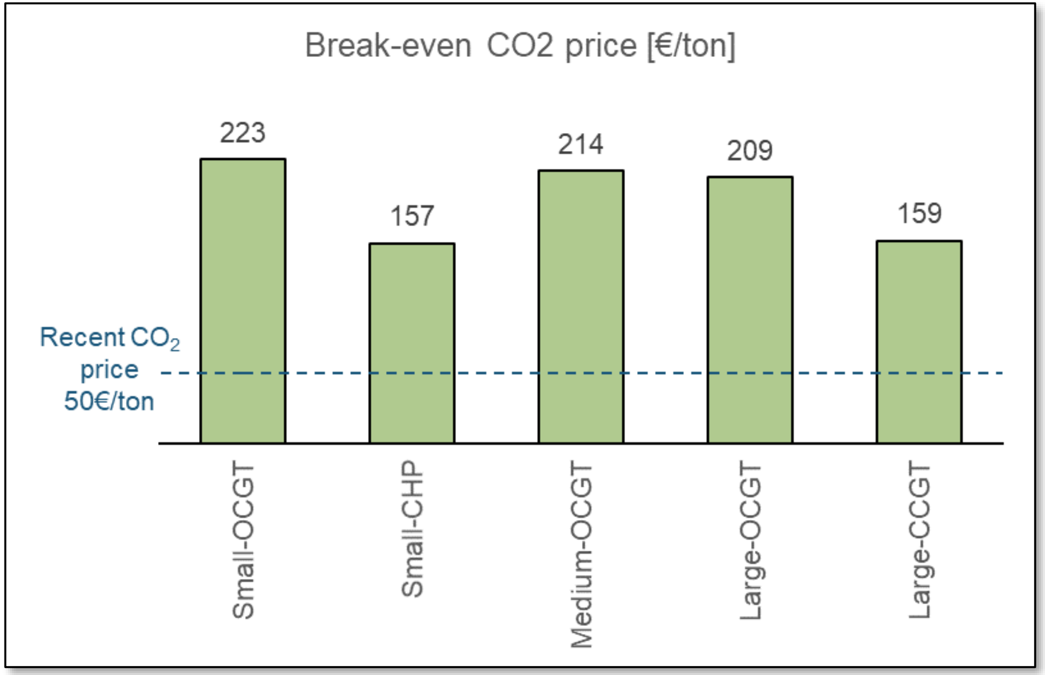
LCOE Break-Even for Large CCGT case

Break-even: NG LCOE = 100% H_2 LCOE



Hydrogen cost	Natural gas cost	CO_2 price
1.5€/kg	20€/MWh	Variable (X-axis)

LCOE Break-even for all 5 case studies



- Break-even carbon tax value higher than current by ~2x
- More efficient plants have lower break-even
  - Small-CHP does not account for the value of the heat production
- **Increased natural gas price** or **reduced hydrogen price** will improve break-even point.

Hydrogen cost	Natural gas cost	CO_2 price
1.5€/kg	20€/MWh	As shown

Natural Gas and Hydrogen Prices

What changed?

- Natural Gas Price (Dutch TTF)

€13/MWh ➡ €190/MWh

Today NG is **near 100 €/MWh**!

Grey and blue H_2 price is strongly affected by NG price

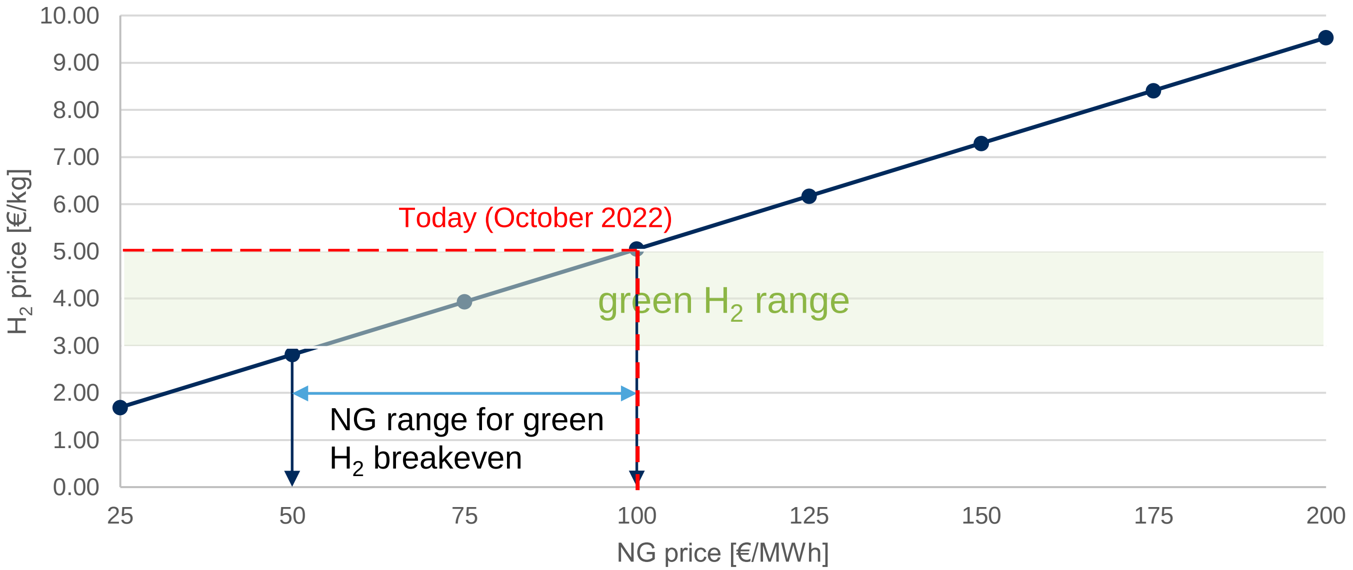
Most of the hydrogen today is produced from natural gas via the reaction of steam methane reforming

$$CH_4(g) + H_2O(g) \longrightarrow 3H_2(g) + CO(g)$$

Impact of natural gas price on H_2 price

For NG price above 100 €/MWh → **blue H_2** price reaches > 5€/kg

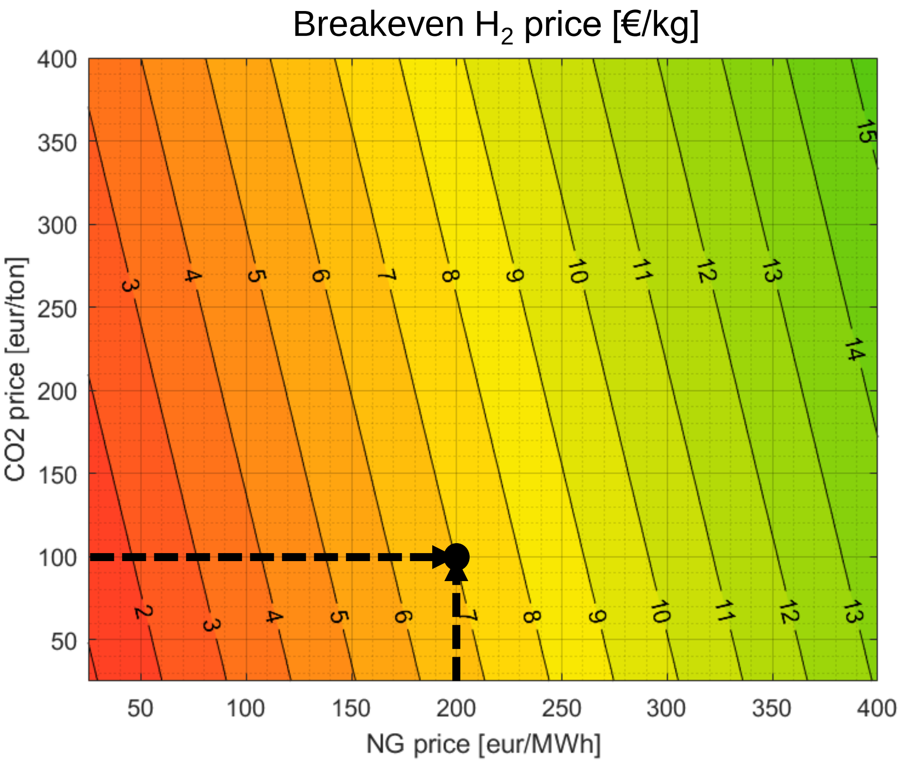
→ **green H_2** could become **competitive with blue**



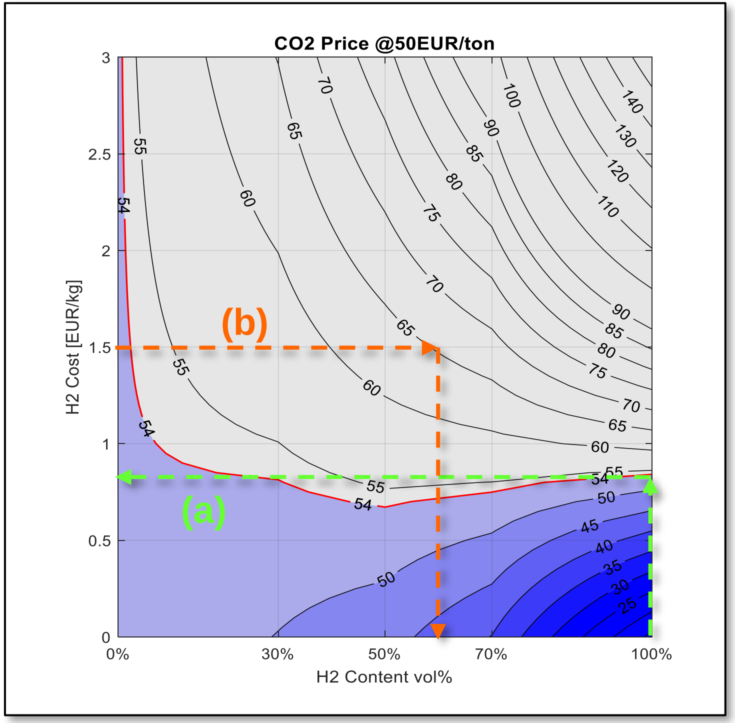
*assuming FTR technology operating for 8760 h @ 75% constant conversion efficiency (LHV basis) with a CCR of 80%

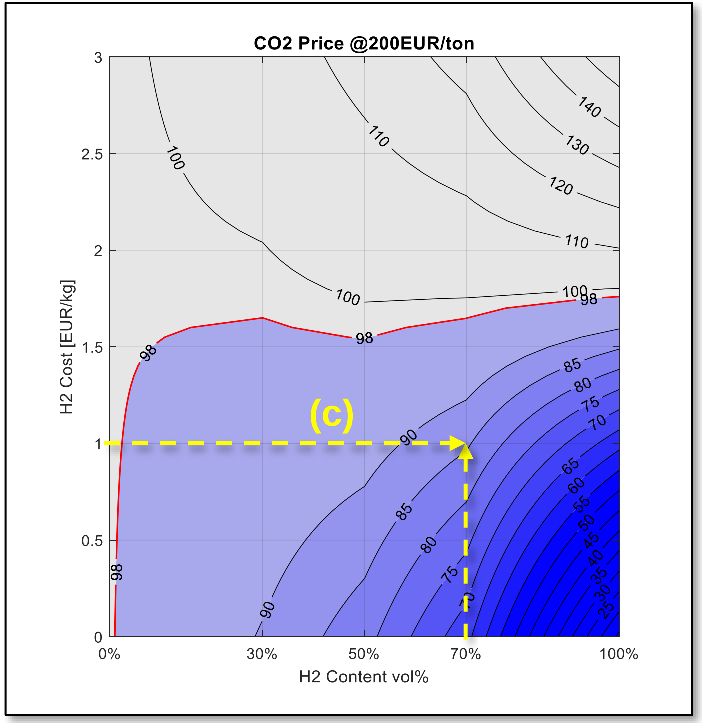
Case study update – Large CCGT

- 650 MW_e output
- 64% efficiency
- Example:
  - Natural gas = 200 €/MWh
  - CO_2 = 100 €/ton
  - H_2 < 7 €/kg to justify use in large CCGT (i.e., lower LCOE than 100% natural gas)



The impact of H_2 blending and price

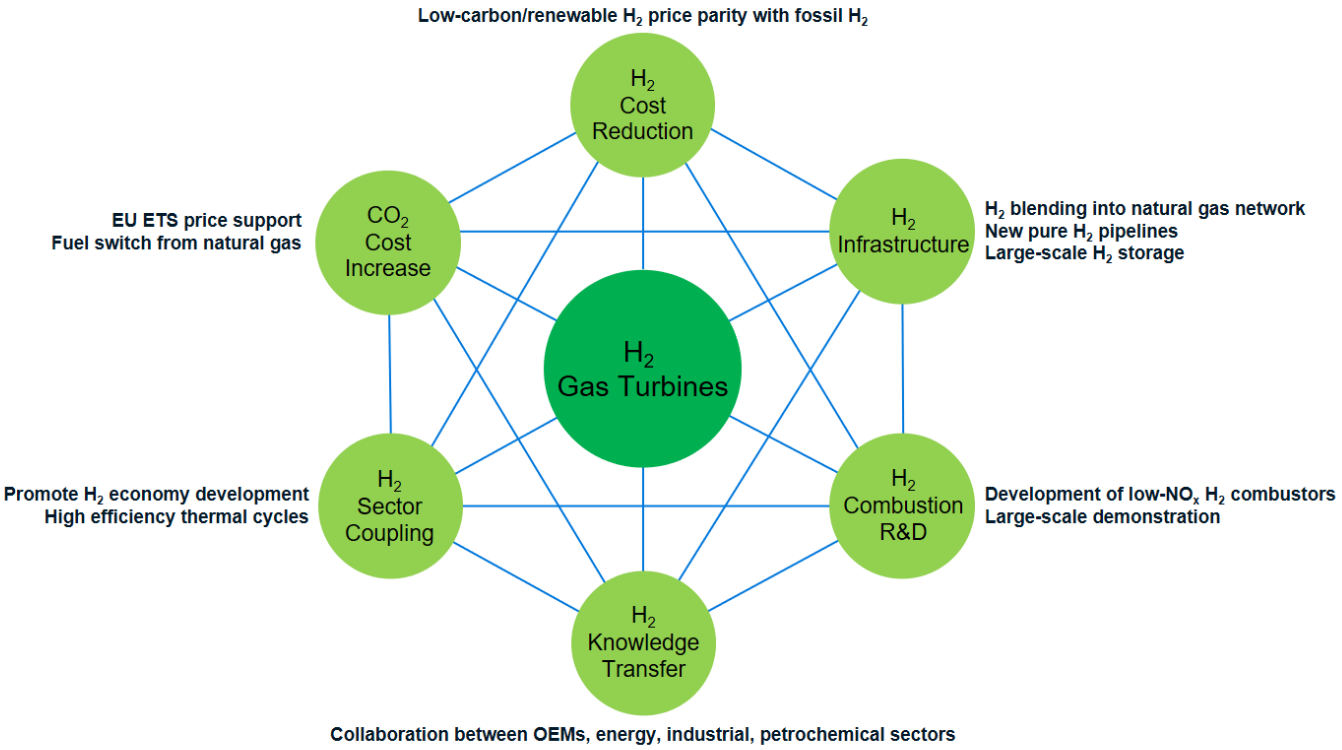




Large CCGT Case

Natural gas cost	20 €/MWh

Hydrogen GT Roadmap

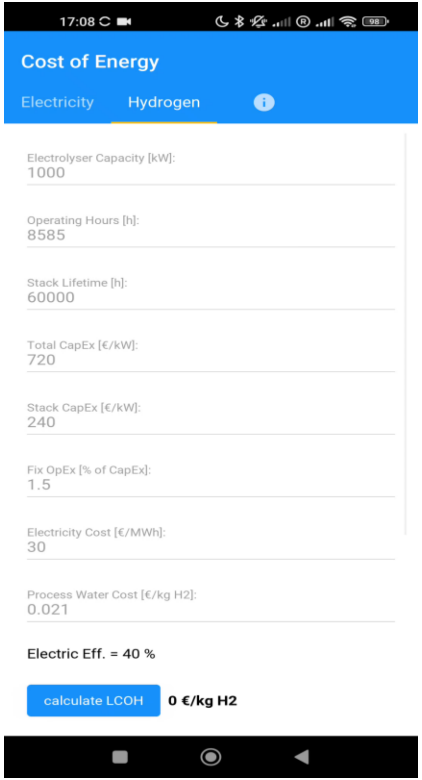


Respond to changing market conditions

- An Android app for calculating LCOE and LCOH

Scan QR code

ANDROID APP ON Google play



ETN Hydrogen Working Group

Chair: Peter Kutne, DLR
Co-Chair: Geert Laagland, Vattenfall

Objectives:
Accelerating the development and use of hydrogen-based gas turbine technology by:

- Identifying potential barriers, and exploring:

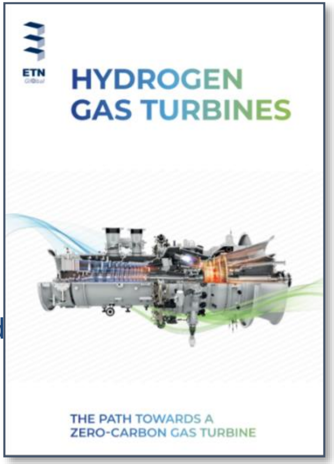
Economic aspects & business cases	**Demonstration projects**	**Operational issues/ effects on GT components**
Retrofit solutions for high hydrogen-content fuel	**Safety aspects**	**Research needs**

- Exploring cooperation opportunities to ensure safe, reliable and cost-efficient solutions for existing and

Activities:

- Taskforce *"GT Enclosure standard for hydrogen fuel"* with the objective to develop an ISO safety standard
- Techno-economic study (Young Engineers Committee) – accomplished & published
- Review paper "Addressing the combustion challenges of Hydrogen addition to Natural Gas" – finalised

The path towards a
Zero-Carbon Gas Turbine
Published in January 2020



Download at
etn.global/hydrogen-report

ETN Key Topics, Working Groups and Projects

Air filtration WG

Energy efficiency
Part-load efficiency
New cycles

Hydrogen WG

sCO_2 WG

Operational optimization SGT-A35 & LM-2500 User groups

Fuel Flexibility
Low-carbon/carbon-free fuels

Security of supply

Afford-ability & Access

Net-zero

Decentralised energy system solutions

Additive 3D Manufacturing WG

AM Machine Evaluation Project

Decentralised Energy solutions WG

CCS/CCUS solutions

CCS Taskforce

Live Q&A

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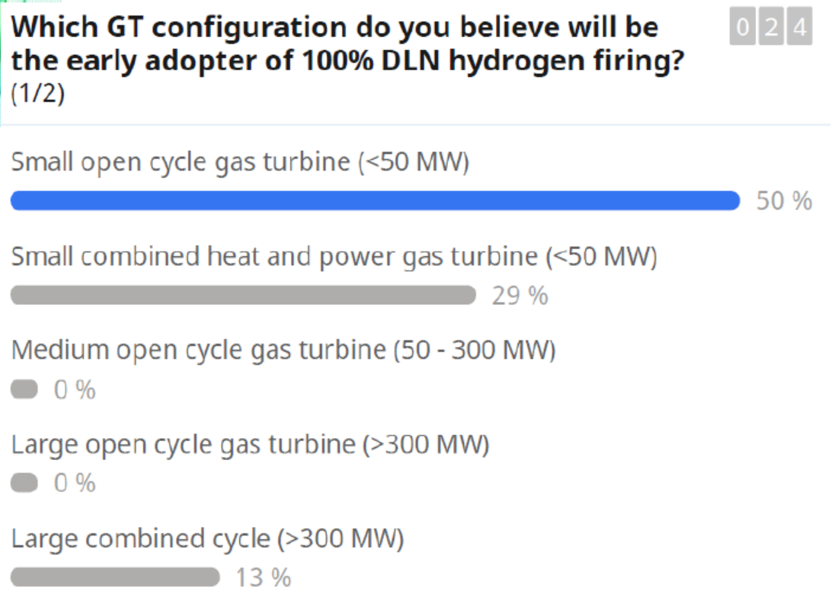
Poll Question

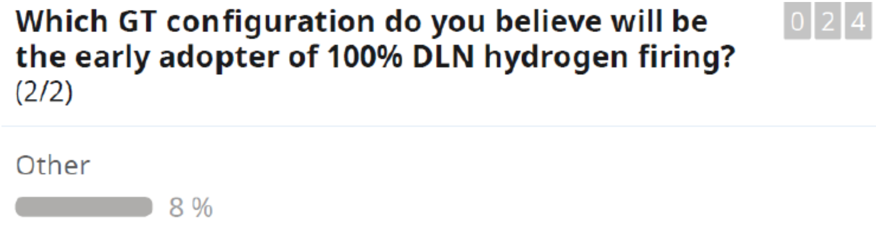
Which GT configuration do you believe will be the early adopter of 100% DLN hydrogen firing?

1. Small open cycle gas turbine (< 50 MW)
2. Small combined heat and power gas turbine (< 50 MW)
3. Medium open cycle gas turbine (50 – 300 MW)
4. Large open cycle gas turbine (> 300 MW)
5. Large combined cycle (> 300 MW)
6. Other

Results



Which GT configuration do you believe will be the early adopter of 100% DLN hydrogen firing? (1/2)
0 2 4
Small open cycle gas turbine (<50 MW)
50 %
Small combined heat and power gas turbine (<50 MW)
29 %
Medium open cycle gas turbine (50 - 300 MW)
0 %
Large open cycle gas turbine (>300 MW)
0 %
Large combined cycle (>300 MW)
13 %

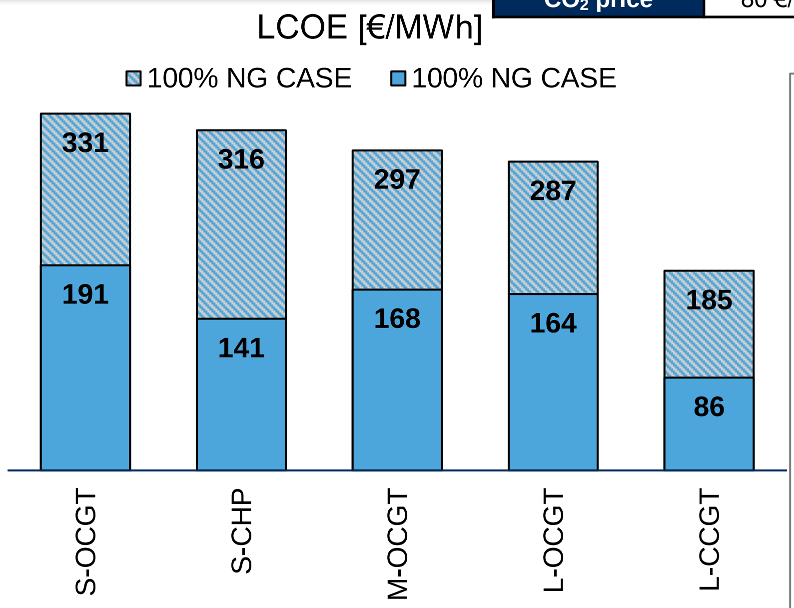


Which GT configuration do you believe will be the early adopter of 100% DLN hydrogen firing? (2/2)
0 2 4
Other
8 %

LCOE of 100% Hydrogen GTs

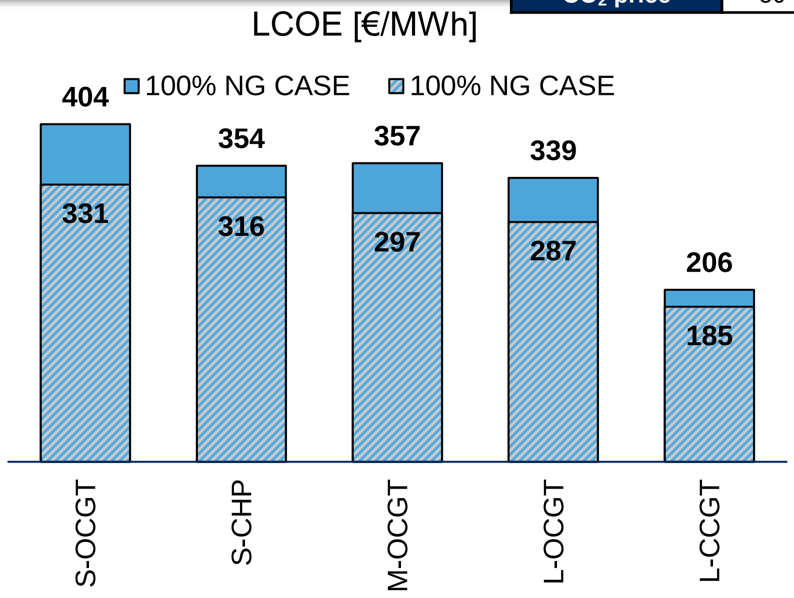
Today picture

Hydrogen cost	1.5 €/kg
Natural gas cost	100 €/MWh
CO_2 price	80 €/ton



Today picture

Hydrogen cost	4 €/kg
Natural gas cost	100 €/MWh
CO_2 price	80 €/ton



The impact of H_2 blending and price

Small OCGT Case – 20 MW