UMONS
Université de Mons

Uncovering the economic tipping point between H_2-based gas turbines and CCS-enhanced gas turbines

In collaboration with ETN

Promotor: Ward De Paepe
Supervisor: Vincent Thielens

Jean Bériot
211514@umons.ac.be

ETN Global

POLYTECH MONS

Flexibility ?
Reliability ?
Dispatchability ?

CCGTs decarbonization: 2 Solutions

Carbon **C**apture, **U**tilization and **S**torage

CCUS-enhanced Gas Turbines

Burning hydrogen

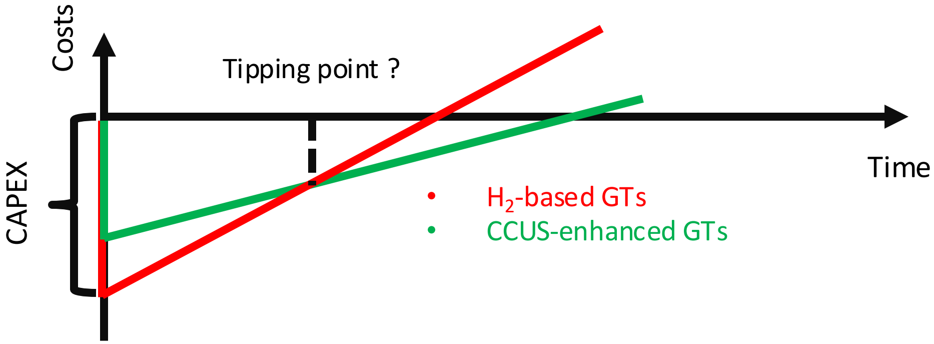
H_2-based Gas Turbines

FLEX4H2

H2med

Actual concern:

Uncovering the economic tipping point between CCUS-enhanced gas turbines And H_2-based gas turbines



Objectives

1: Techno-economic comparison of technologies in Combined-Cycle Gas Turbines (**CCGTs**)

→ **Determine Levelized Cost Of Electricity (LCOE) and Return On Investment (ROI)**

2: Online tool implementation

→**Results for industry with their own data**

How to do this ?

Get technical data
from literature
(Thermodynamic studies)

Implement a model
in Aspen Economics

Cross-validate the model
With industry data
and literature

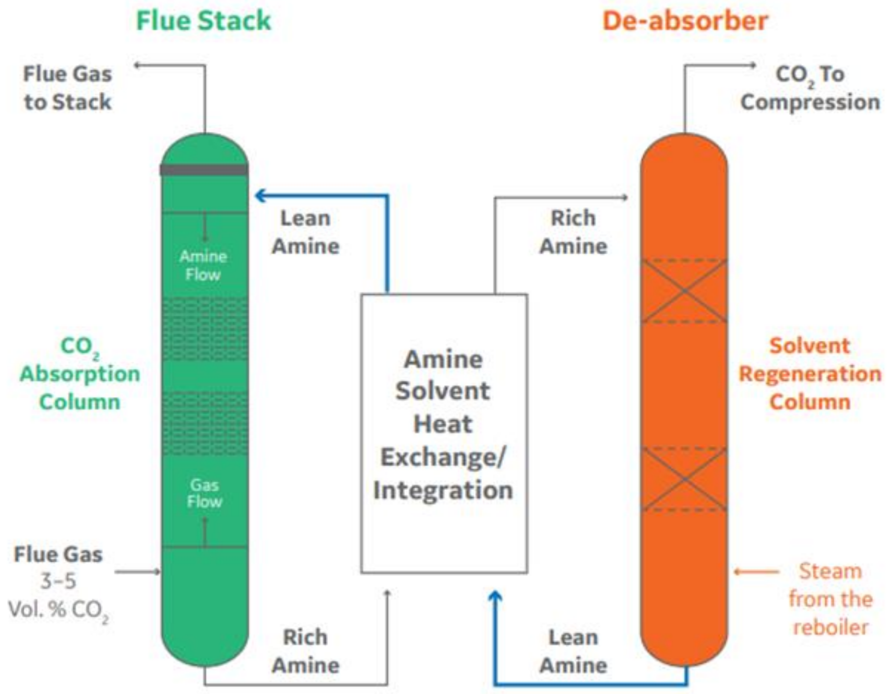
Implement an
economic model

Get
results

Outline

- **Technical comparison**
- CAPEX determination
- OPEX determination
- Results: LCOE and ROI comparison
- Tool presentation

Amine-based carbon capture



✓ Captures 90%-95% CO_2
➔ Carbon taxes ↘

✗ Consumes heat and power
➔ Net efficiency ↘

✗ High Investment costs

✗ Additionnal OPEX

Hydrogen gas turbines

GE VERNOVA

LM6000
$\eta_{CCGT} = 51{,}9\%$

SIEMENS energy

SGT-A35
$\eta_{CCGT} = 51{,}4\%$

In a near future…?

ansaldo energia

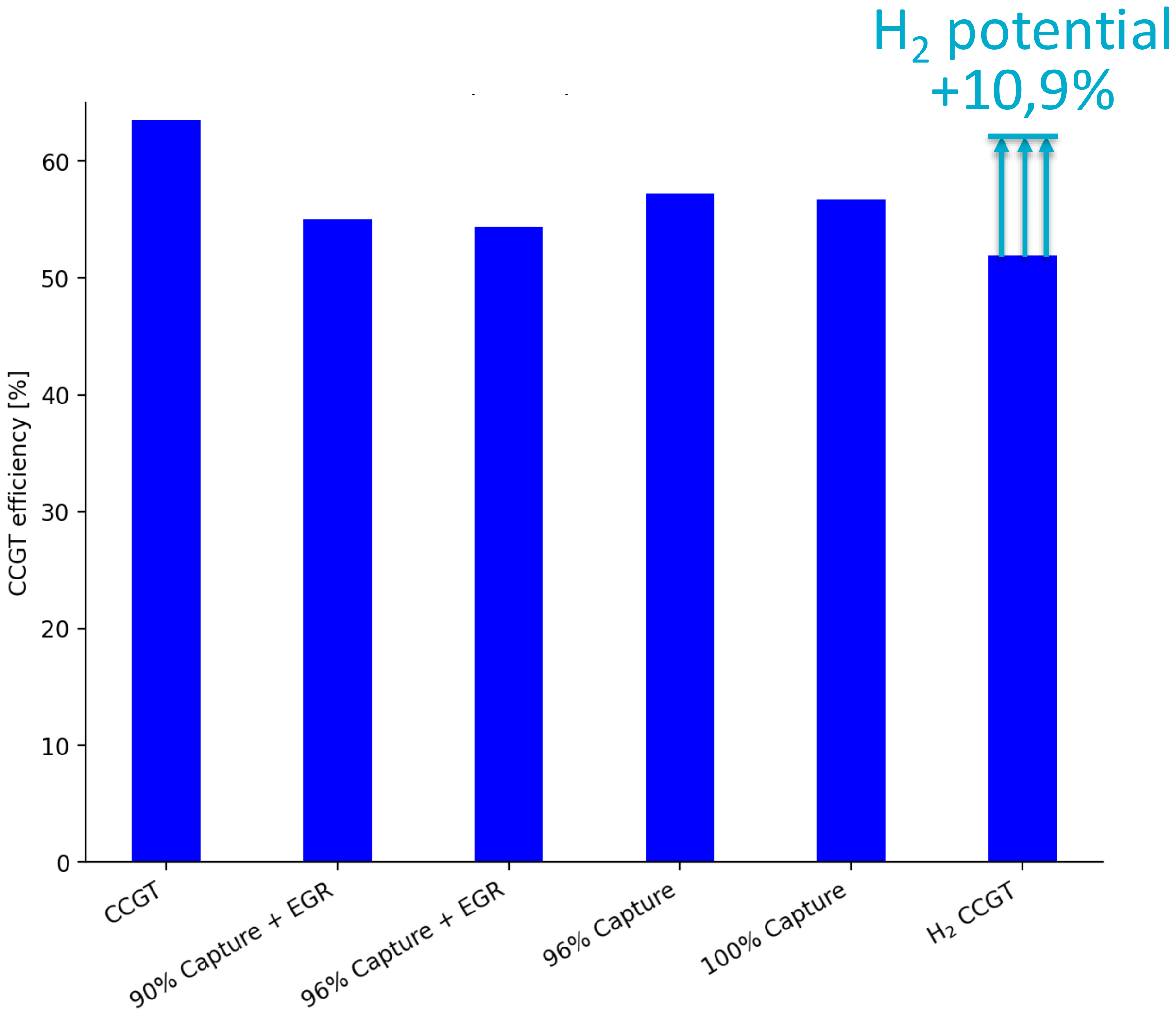
GT36 (70% H_2)
$\eta_{CCGT} = 62{,}8\%$

✓ 100% H_2 capable
➔ No CO_2 emissions

✗ Valid for Aeroderivative GTs
With WLE or DLE burners
➔ Net efficiency ↘

✗ More complex elements
➔ ~25 % increased CAPEX

CCGT efficiencies: hydrogen down



CO_2 ↘

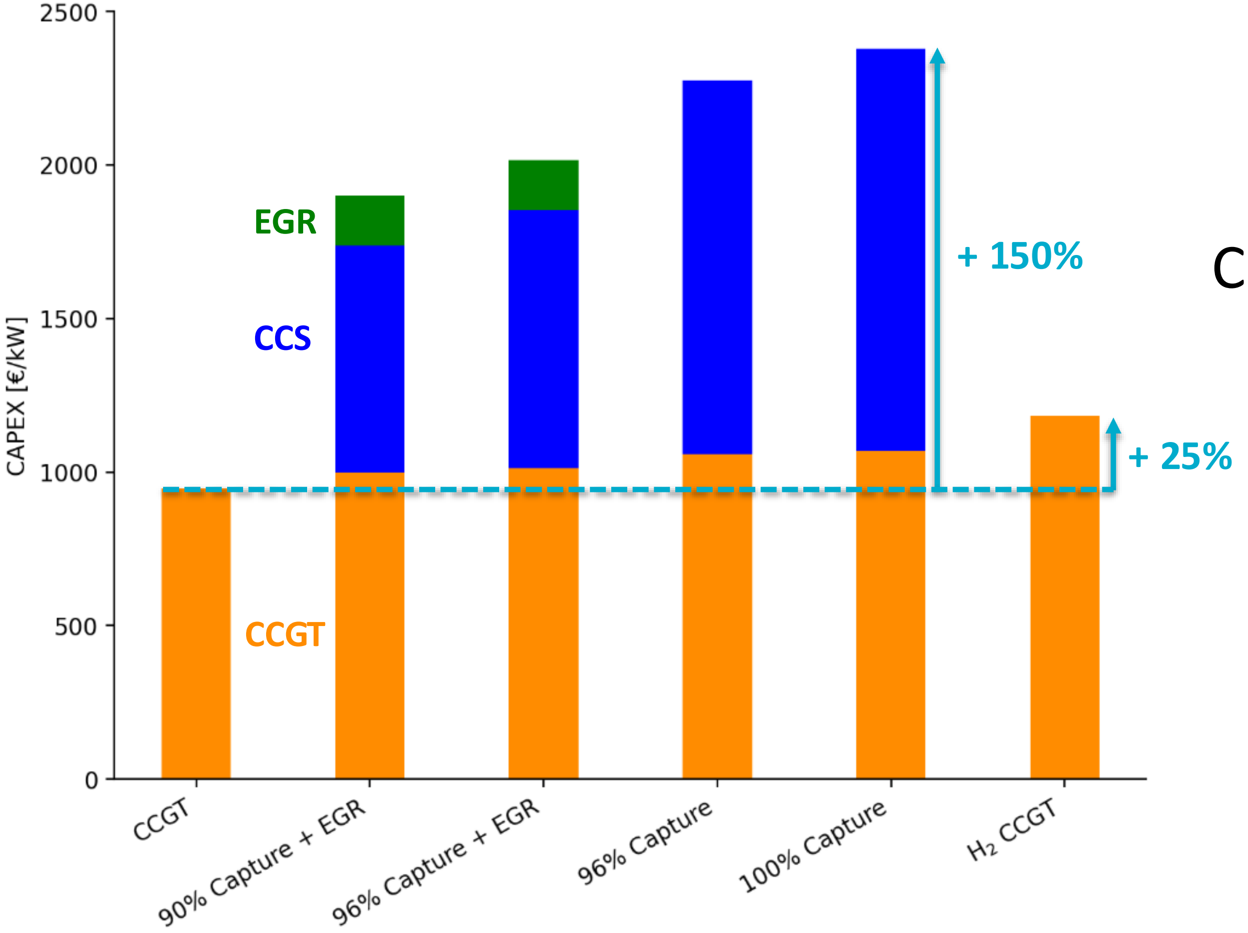
=

Efficiency ↘

Outline

- Technical comparison
- **CAPEX determination**
- OPEX determination
- Results: LCOE and ROI comparison
- Tool presentation

CAPEX Determination: high CCUS investments

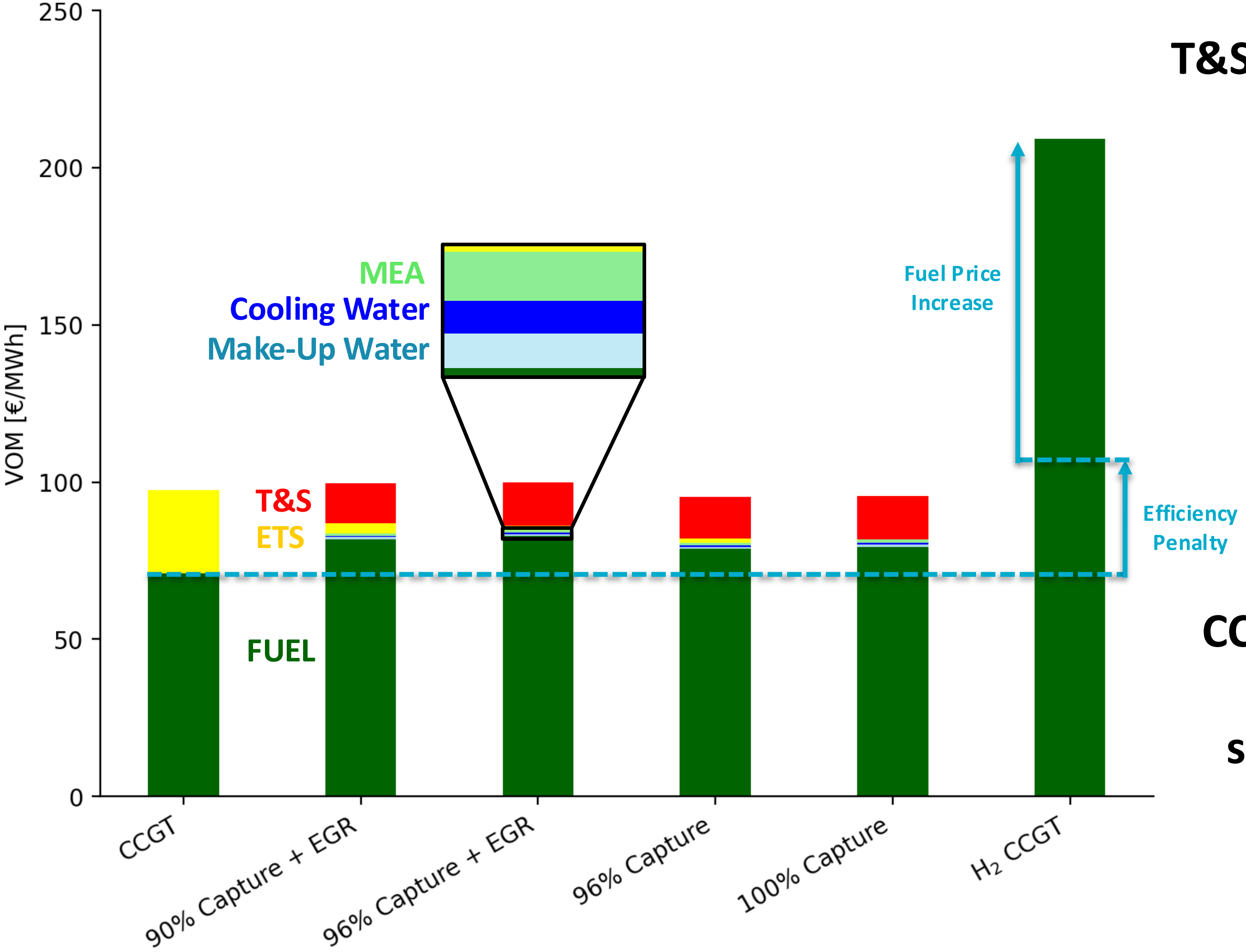


CCUS-enhanced CCGT is 2x more expensive than H_2-based CCGT

Outline

- Technical comparison
- CAPEX determination
- **OPEX determination**
- Results: LCOE and ROI comparison
- Tool presentation

VOM Computation: hydrogen apart



T&S and **efficiency penalty** are the most impacting for CCUS

H_2-based CCGT is impacted by the **price of hydrogen**

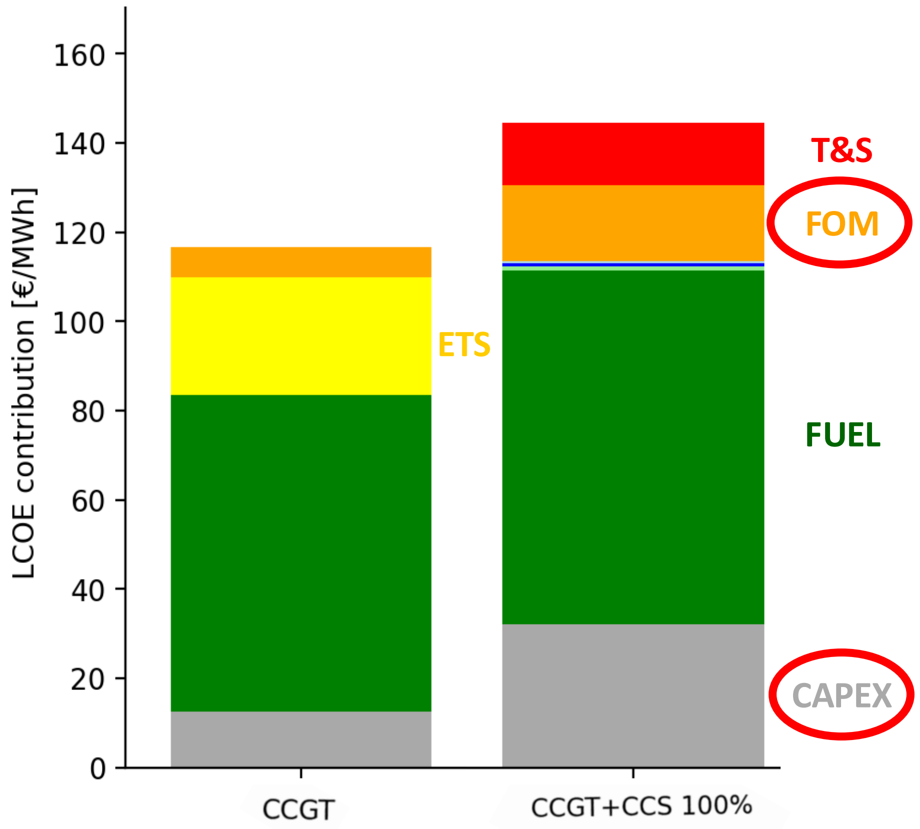
CCUS-enhanced CCGTs keep the **same range of VOM**

Outline

- Technical comparison
- CAPEX determination
- OPEX determination
- **Results: LCOE and ROI comparison**
- Tool presentation

LCOE

Simple CCGT VS 100% CCS-enhanced CCGT

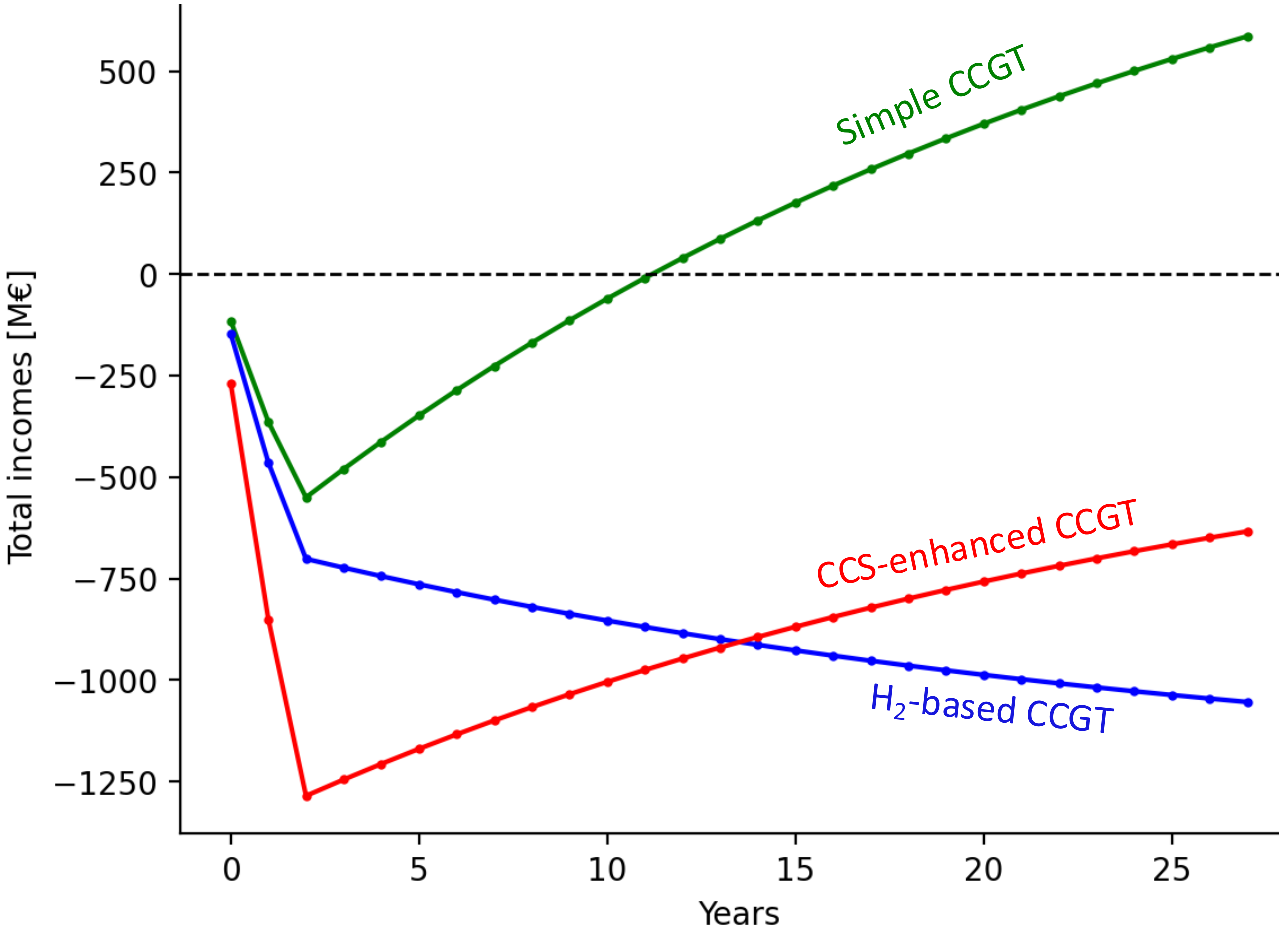


Same amount of electricity produced

CAPEX and **FOM** are responsible for the **LCOE increase**

H_2-based CCGT LCOE more than **10X higher**

ROI and Tipping point



Tipping point after 15 years

No ROI for both technologies

Final Thougts

Ensuring **hydrogen prices of ±2€/kg** is crucial **before deploying H_2-based CCGTS**
(**-45% for** H_2 and **-75% for** H_2)

For **CCUS-enhanced CCGTS:**

- Long run: **valorization of CO_2**
- Short run: **optimal AND reliable EGR**

Outline

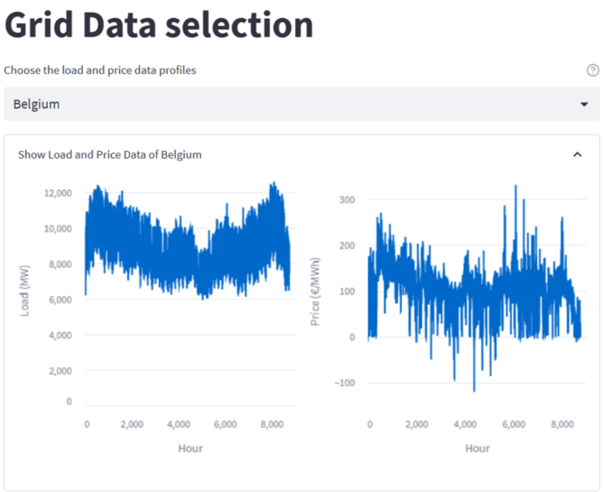
- Technical comparison
- CAPEX determination
- OPEX determination
- Results: LCOE and ROI comparison
- **Tool presentation**

The issue

- I am an industrial **interested in this study**
- This study does **not** reflect **my own parameters**, grid data, prices data, …
- **I can’t share** confidential **data** to a random student

The solution

Scan the QR code



Grid Data selection

Choose the load and price data profiles

Belgium

Show Load and Price Data of Belgium

Choose grid data between different countries

The solution

Scan the QR code

Prices specifications

Methane Price (Ct/kWh)
4.50
1.00 20.00

MEA price (€/kg)
1.20
0.50 3.00

Make-Up Water price (€/m^3)
3.15
2.00 8.00

Cooling Water price (Ct/m^3)
1.20
1.00 3.00

CO_2 Transport and Storage Price ($€/T_{CO_2}$)
40.00
10.00 100.00

Annual Fixed O&M Costs (% of total CAPEX)
3.50
1.00 10.00

ETS Price ($€/T_{CO_2}$)
85.00
50.00 150.00

Plant specifications

Capture efficiency (%)
100%

CCGT Capacity (MW)
587.00
100.00 1000.00

Load Factor Calcultation Method
Merit Order

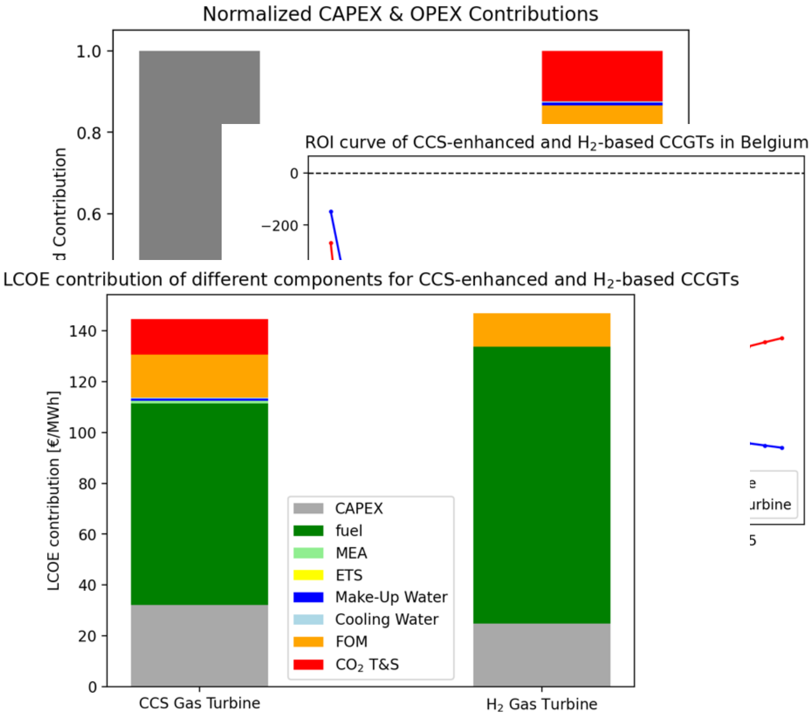
☐ Include Capacity Remuneration Mechanism (CRM) revenues

Inflation rate for ROI computation
4.00
0.00 8.00

Modify each parameter to user needs

The solution

Scan the QR code



Get your results
(ROI, LCOE breakdown, tipping point,…)

UMONS
Université de Mons

**Thank you
for listening !**

Feel free to try it !


Faculté Polytechnique

Uncovering the economic tipping point between H_2-based gas turbines and CCS-enhanced gas turbines

In collaboration with ETN

Promotor: Ward De Paepe
Co-Promotor: Vincent Thielens

Jean Bériot
211514@umons.ac.be

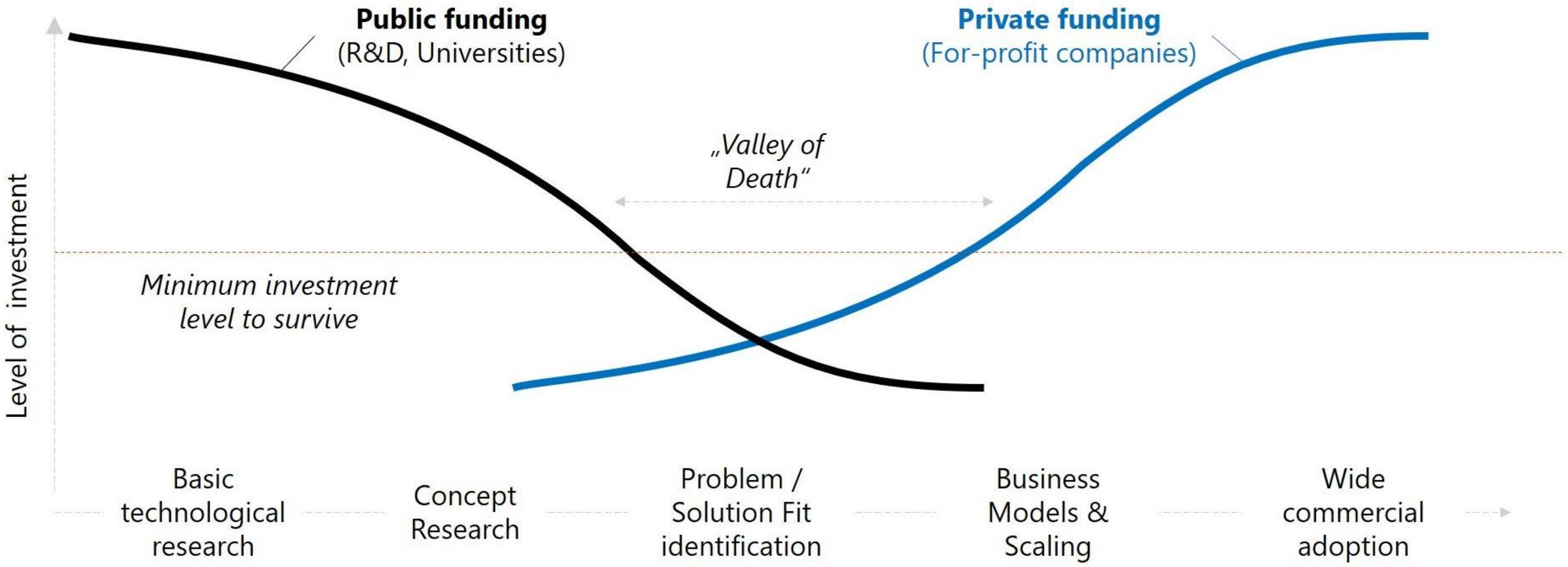
https://economical-comparison-h2-and-ccs.streamlit.app/

ETN Global

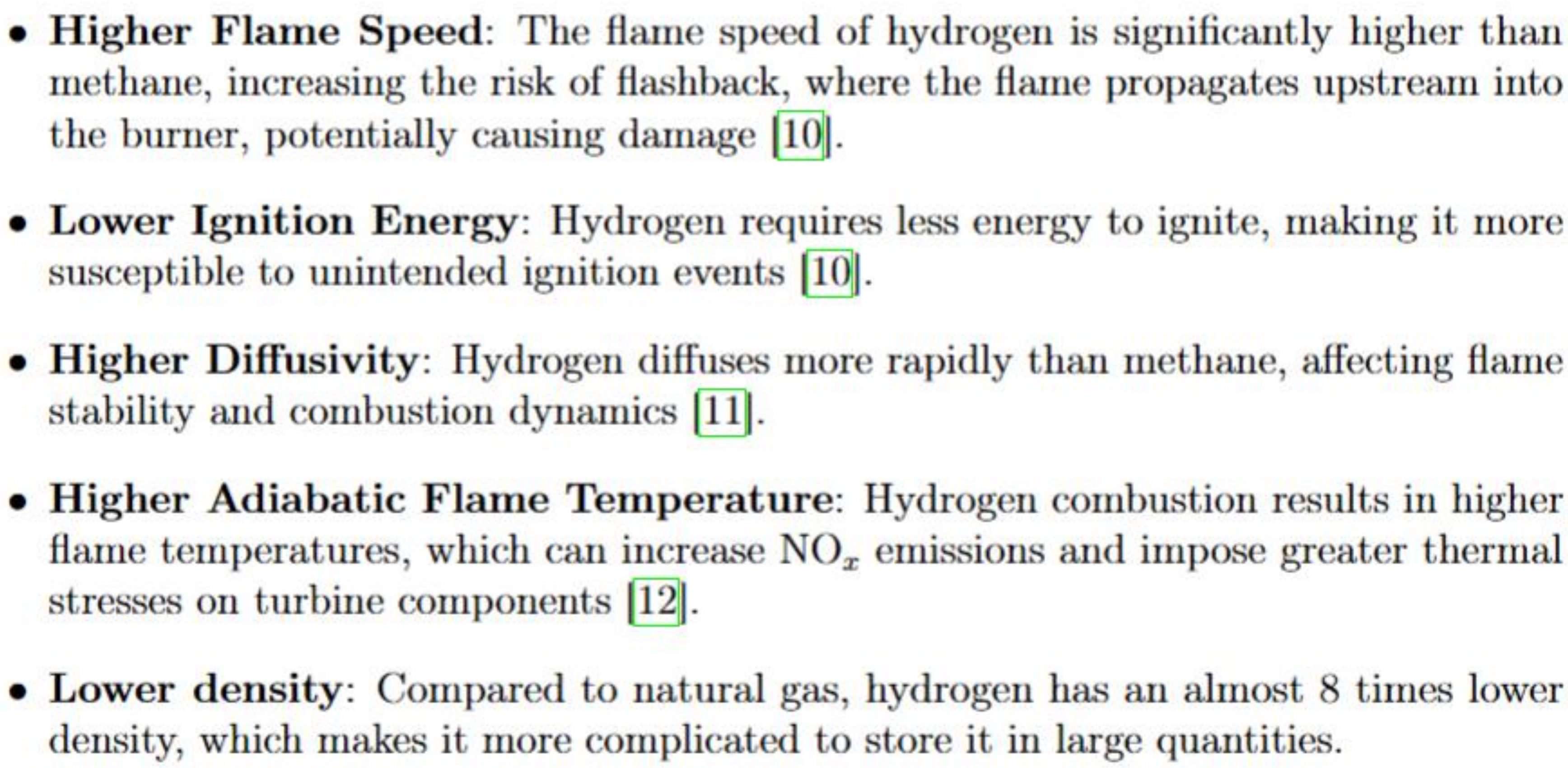
POLYTECH MONS

BACKUPS

Innovation Valley of Death

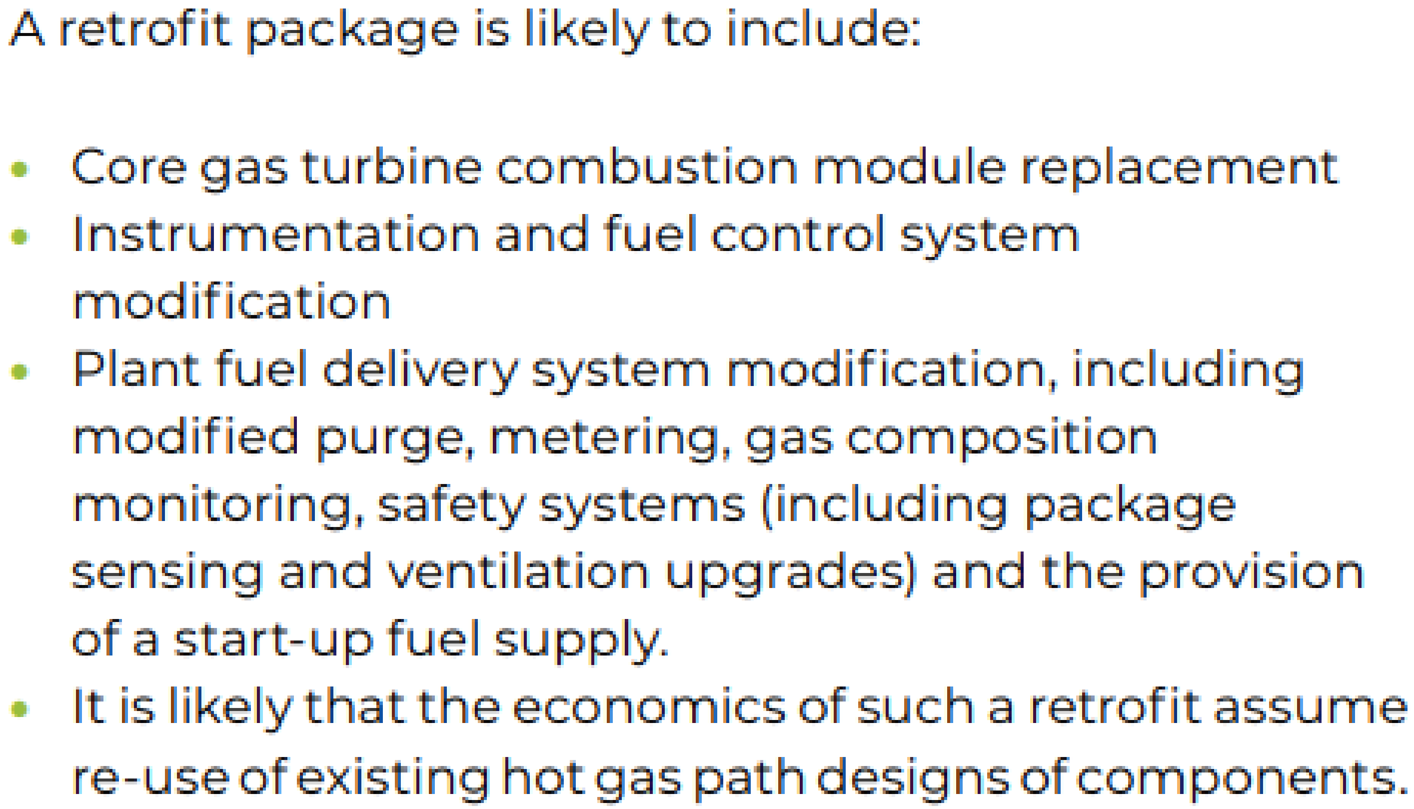


H2 technical issues



- **Higher Flame Speed**: The flame speed of hydrogen is significantly higher than methane, increasing the risk of flashback, where the flame propagates upstream into the burner, potentially causing damage [10].
- **Lower Ignition Energy**: Hydrogen requires less energy to ignite, making it more susceptible to unintended ignition events [10].
- **Higher Diffusivity**: Hydrogen diffuses more rapidly than methane, affecting flame stability and combustion dynamics [11].
- **Higher Adiabatic Flame Temperature**: Hydrogen combustion results in higher flame temperatures, which can increase NO_x emissions and impose greater thermal stresses on turbine components [12].
- **Lower density**: Compared to natural gas, hydrogen has an almost 8 times lower density, which makes it more complicated to store it in large quantities.

H2 technical issues

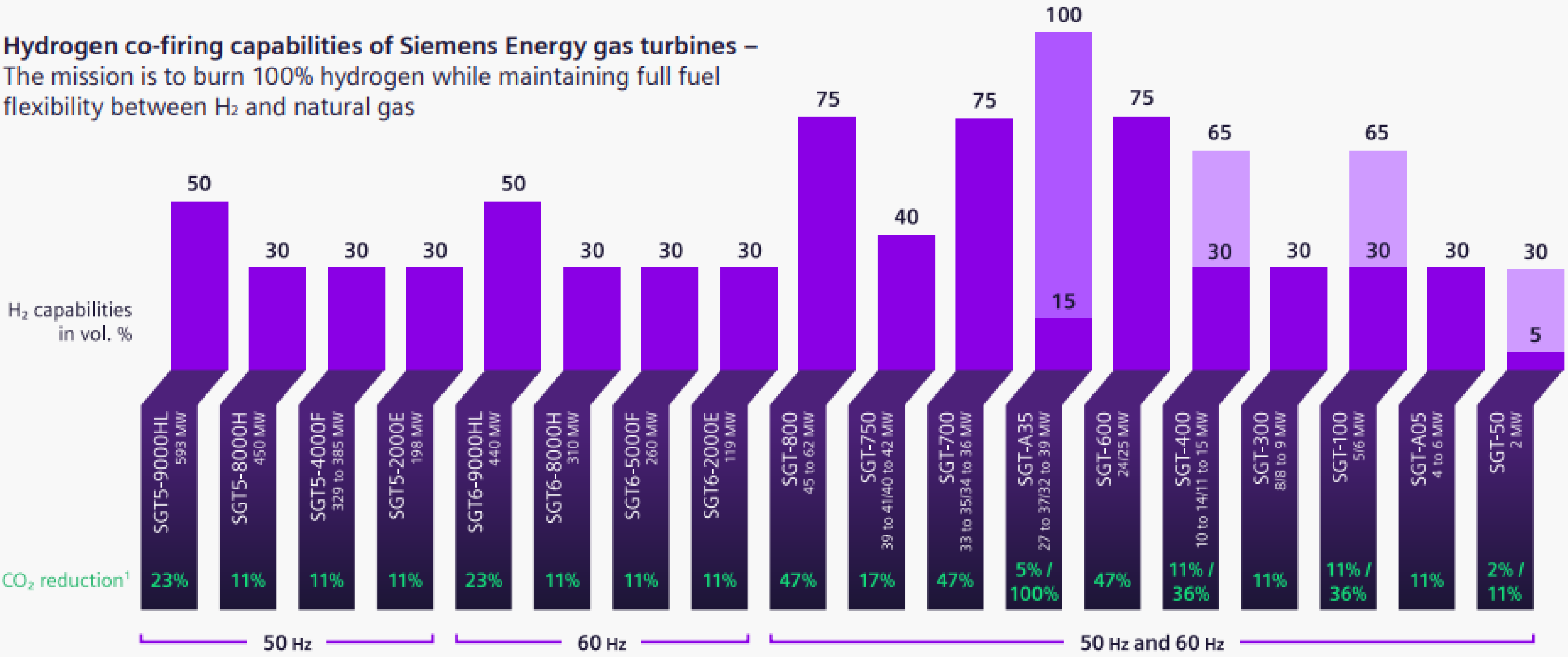


A retrofit package is likely to include:

- Core gas turbine combustion module replacement
- Instrumentation and fuel control system modification
- Plant fuel delivery system modification, including modified purge, metering, gas composition monitoring, safety systems (including package sensing and ventilation upgrades) and the provision of a start-up fuel supply.
- It is likely that the economics of such a retrofit assume re-use of existing hot gas path designs of components.

Siemens Energy Hydrogen Gas Turbines for our sustainable future

Hydrogen co-firing capabilities of Siemens Energy gas turbines – The mission is to burn 100% hydrogen while maintaining full fuel flexibility between H_2 and natural gas



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.

Hydrogen Gas Turbines: Power output in MW at ISO ambient conditions and natural gas
[1] Compared with 100% natural gas operation

■ DLE burner
■ WLE burner
■ Diffusion burner with unabated NO_x emissions

H2 Gas Turbines

https://www.gevernova.com/gas-power/products/gas-turbines/lm6000

https://www.ansaldoenergia.com/fileadmin/Brochure/Review_2024/AnsaldoEnergia-TheGasTurbine-GT36.pdf

https://etn.global/wp-content/uploads/2023/10/Decarbonisation-of-gas-turbines-with-the-H2R%C2%AE-hydrogen-retrofit-burner-Franklin-Genin-Crosstown-Power.pdf

https://etn.global/download-file/?file=2023/03/ETN-full-report-Addressing-combustion-challenges-of-hydrogen-addition-to-natural-gas-etnmembersonly.pdf

https://etn.global/wp-content/uploads/2024/11/ETN-Global-Hydrogen-Gas-Turbines-Report-10-2024.pdf

https://etn.global/wp-content/uploads/2022/11/ETN-Summary-Report-Combustion-challenges-of-hydrogen-addition-to-natural-gas-Nov2022.pdf

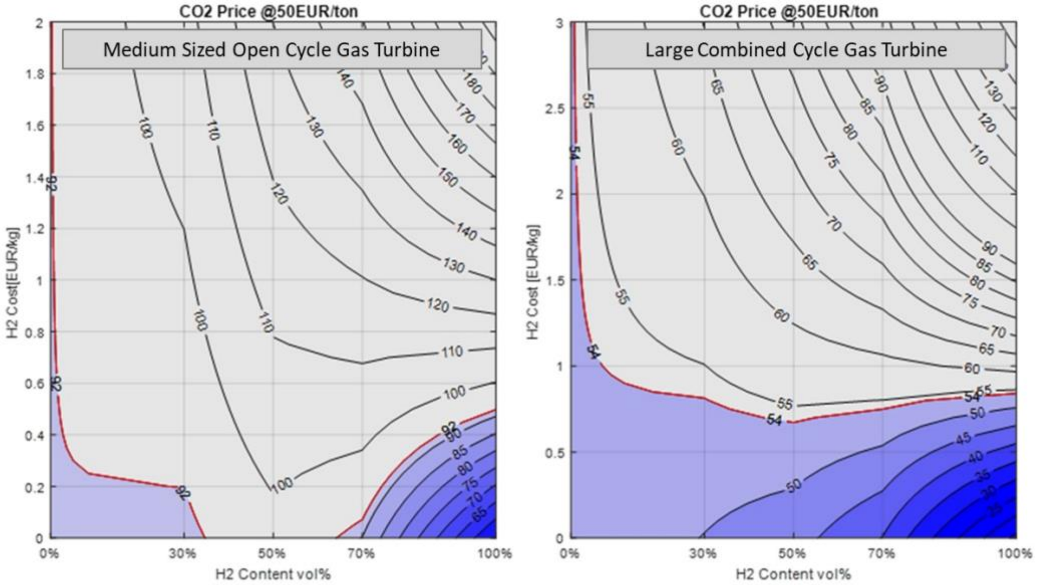


Figure 52. Contours of LCOE as function of H_2 price and H_2 content in fuel for open and combined cycle gas turbines. (From [90])

H2 : Best Case

- H2 price: 2,1 €/kg
- $\eta_{\mathrm{CCGT}} = 63\%$
- No CAPEX increase

Marginal cost = `100.01` €/MWh

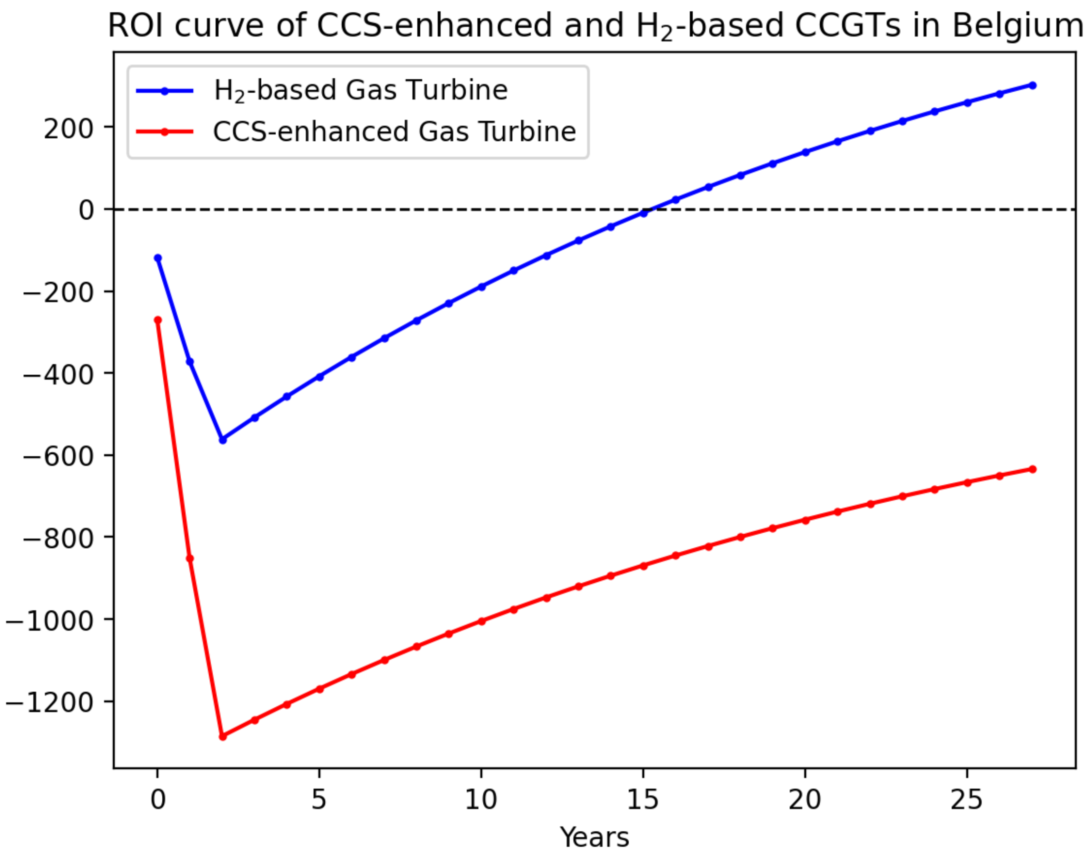
Load Factor = `47.95` %

Yearly OPEX = `267.1` M€/year

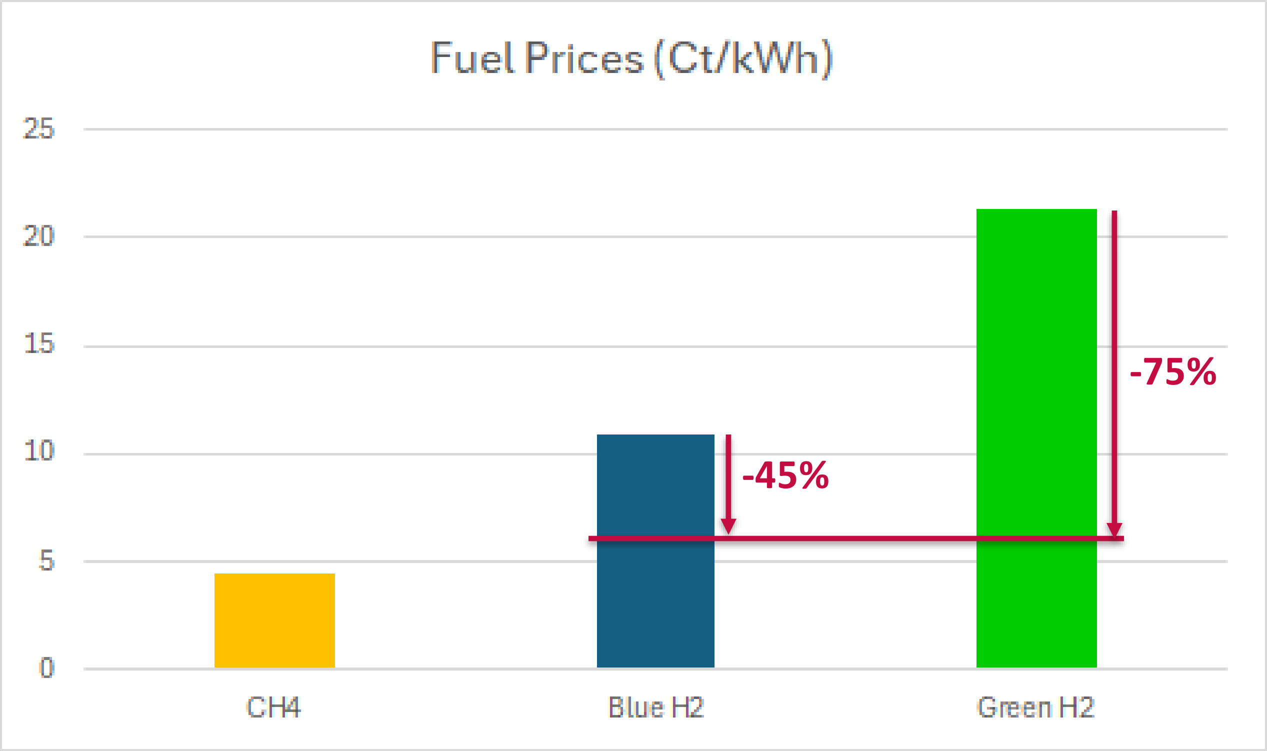
CAPEX = `587.0` M€

LCOE = `124.1` €/MWh

ROI = `16` years, `100` days



Fuel Prices



H2 Price: Two opinions

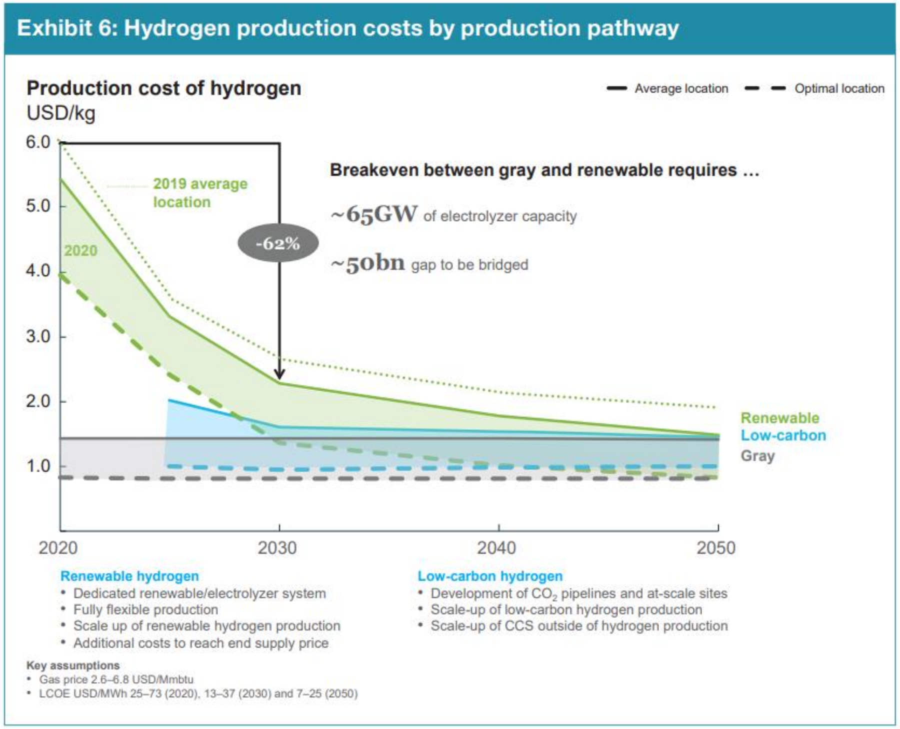


Exhibit 6: Hydrogen production costs by production pathway

Breakeven between gray and renewable requires …

~65GW of electrolyzer capacity

~50bn gap to be bridged

Renewable hydrogen
- Dedicated renewable/electrolyzer system
- Fully flexible production
- Scale up of renewable hydrogen production
- Additional costs to reach end supply price

Low-carbon hydrogen
- Development of CO_2 pipelines and at-scale sites
- Scale-up of low-carbon hydrogen production
- Scale-up of CCS outside of hydrogen production

Key assumptions
- Gas price 2.6–6.8 USD/Mmbtu
- LCOE USD/MWh 25–73 (2020), 13–37 (2030) and 7–25 (2050)

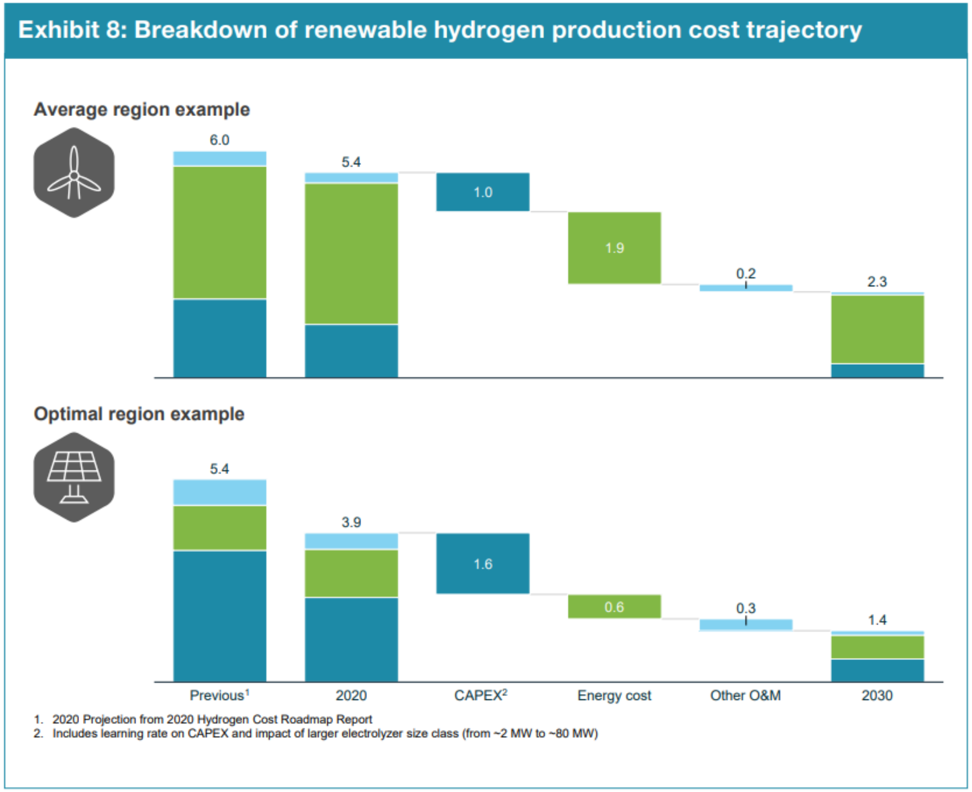


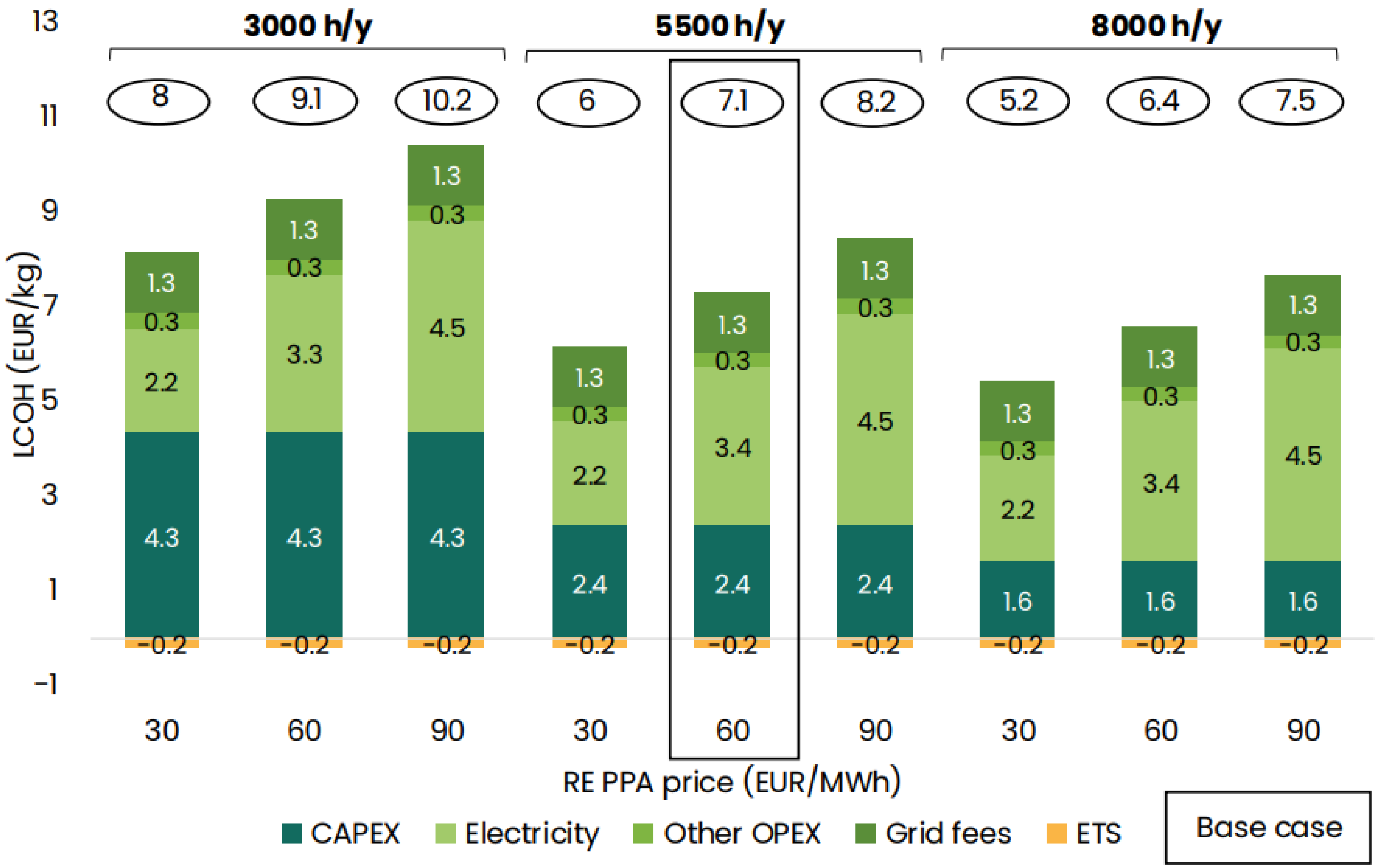
Exhibit 8: Breakdown of renewable hydrogen production cost trajectory

1. 2020 Projection from 2020 Hydrogen Cost Roadmap Report
2. Includes learning rate on CAPEX and impact of larger electrolyzer size class (from ~2 MW to ~80 MW)

https://hydrogencouncil.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021.pdf

H2 Price: Two opinions

Figure 1.4: 2024 LCOH of low-temperature electrolysis depending on RE PPA price and utilisation

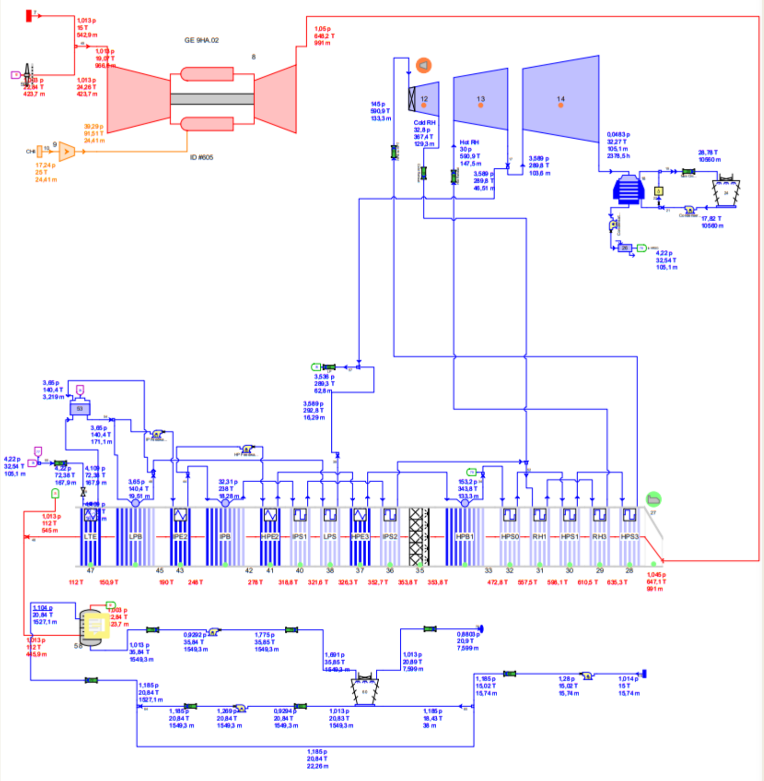


https://hydrogeneurope.eu/wp-content/uploads/2024/06/2024_H2E_CleanH2ProductionPathwaysReport.pdf

CCGT Model

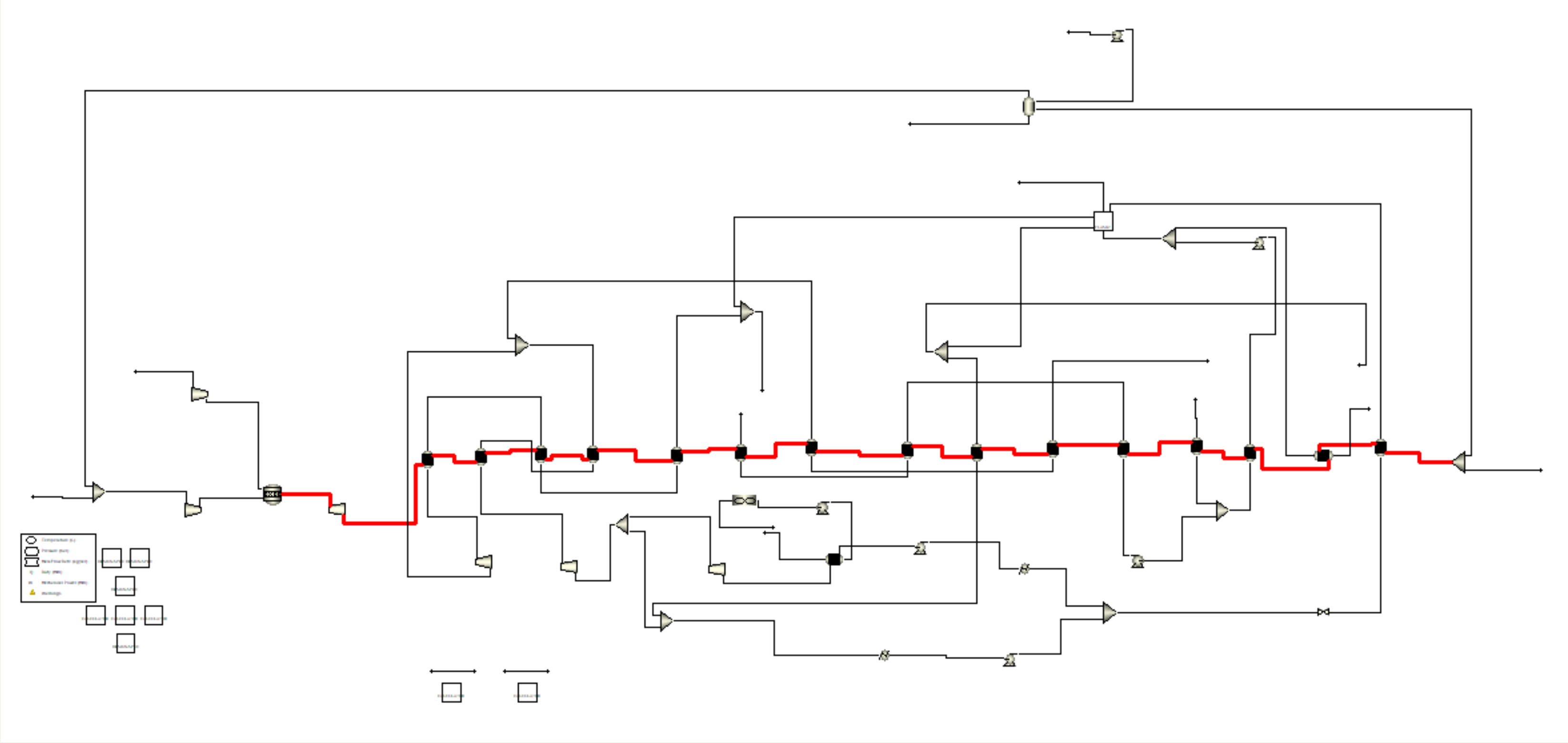
Based the **CCGT+CCUS** model on a previous study made on **Thermoflow** using a **GE9HA** …

$$P_{OCGT} = 506{,}6\ MW$$
$$P_{CCGT} = 672{,}2\ MW$$
$$\eta_{OCGT} = 41{,}47\%$$
$$\eta_{CCGT} = 55{,}03\%$$

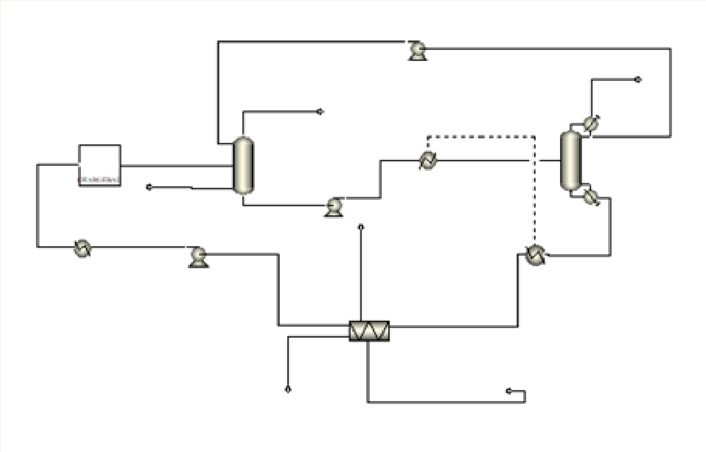


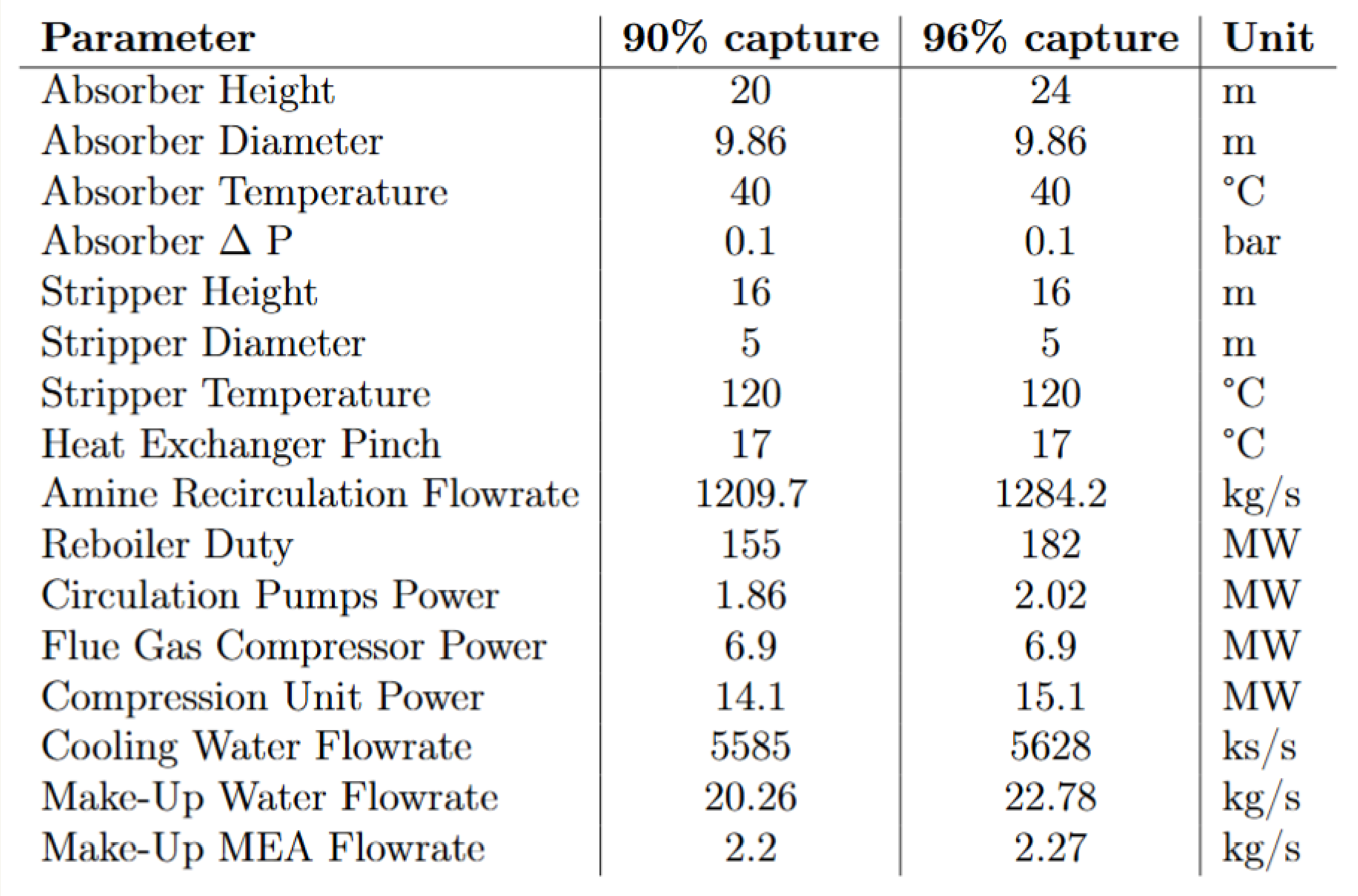
CCGT Model

… and modeled the CCGT part in Aspen



CCUS Model





Parameter	**90% capture**	**96% capture**	**Unit**
Absorber Height	20	24	m
Absorber Diameter	9.86	9.86	m
Absorber Temperature	40	40	°C
Absorber Δ P	0.1	0.1	bar
Stripper Height	16	16	m
Stripper Diameter	5	5	m
Stripper Temperature	120	120	°C
Heat Exchanger Pinch	17	17	°C
Amine Recirculation Flowrate	1209.7	1284.2	kg/s
Reboiler Duty	155	182	MW
Circulation Pumps Power	1.86	2.02	MW
Flue Gas Compressor Power	6.9	6.9	MW
Compression Unit Power	14.1	15.1	MW
Cooling Water Flowrate	5585	5628	ks/s
Make-Up Water Flowrate	20.26	22.78	kg/s
Make-Up MEA Flowrate	2.2	2.27	kg/s

Variable Operation and Maintenance (VOM) costs: the price to run

VOM type	**Price**	
Methane	4.5 Ct/kWh	**Fuels**
Hydrogen	10.86 Ct/kWh	
Cooling Water	0.05 €/m^3	**Negligibles**
Make-Up Water	3.15 €/m^3	
MEA	1.2 €/kg	
CO_2 T&S	40 €/Ton	**CO_2 Transport and Storage**
ETS	85 €/Ton	**Carbon Tax**

4 base cases in this study

Own computations

90%+EGR **96%+EGR**

From thermodynamic study

With Exhaust Gas Recirculation (EGR)
➔ 8% Vol. CO_2

Implementation on Aspen Economics
➔ Get CCGT efficiencies and CAPEX

Crossvalidation by literature
and ETN members

Turbine: GE 9HA0.2

Ref: Antoine Verhaeghe et al.

Reference study

96% **100%**

From technoeconomic study

4,9% Vol. CO_2

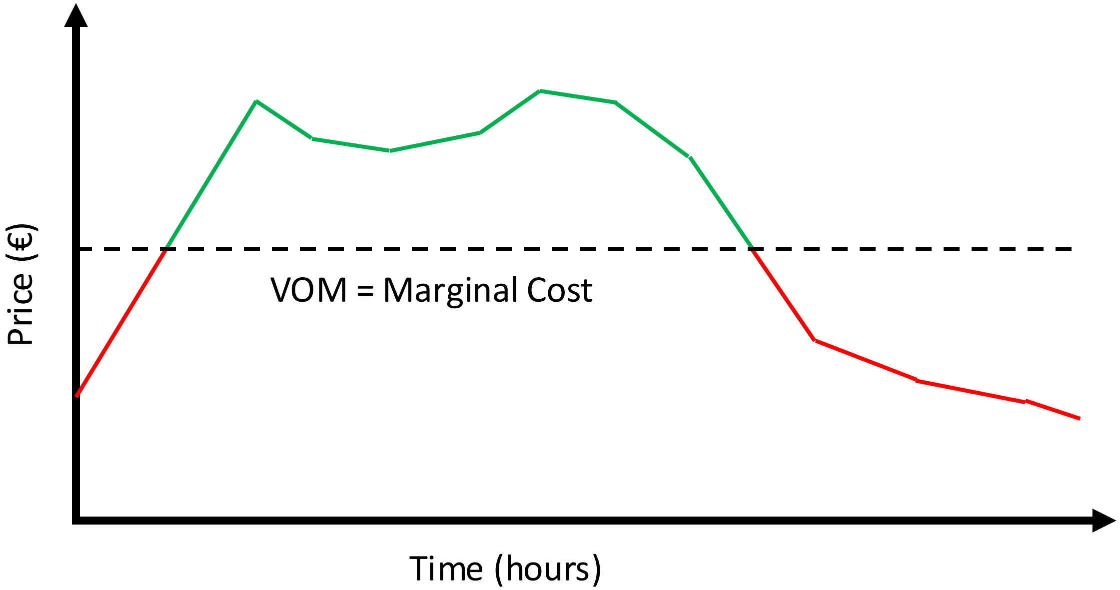
CAPEX already computed

Turbine: GE 9HA0.1

Ref: Daniel Mullen et al.

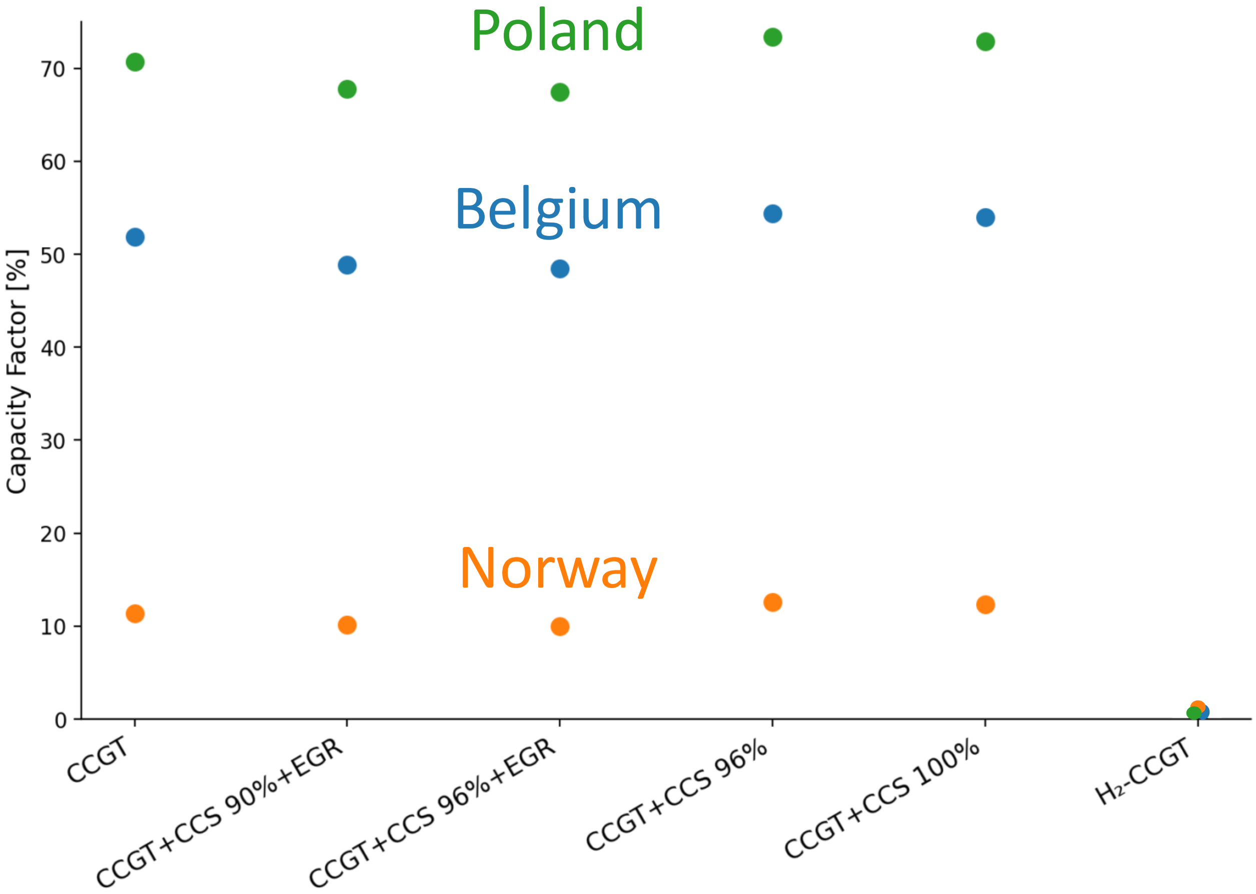
Capacity factor determination

Compare VOM with hourly electricity price data



➔ Determine the number of hours per year it will run

Capacity factor determination



CCS-enhanced CCGTs keep the **same range of Capacity Factor**

Capacity Factor of H_2-based CCGT **close to zero**

Results depend heavily on the country

Power plant data

Construction time = 3 years

Lifespan = 25 years

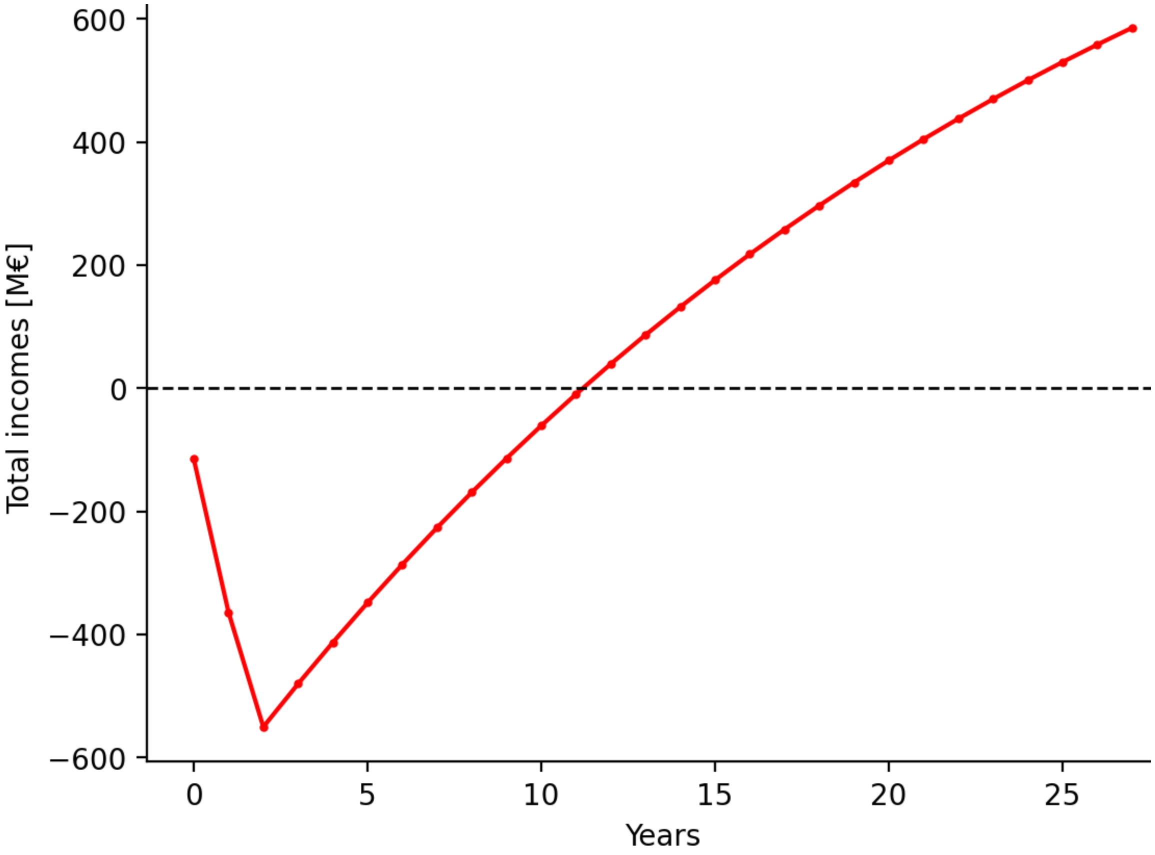
Inflation rate = 4%

Fixed O&Ms = 3,5% of CAPEX

$$\text{LCOE} = \frac{\text{Sum of yearly annualized } \mathbf{costs}}{\text{Sum of yearly annualized } \mathbf{electricity\ produced}}$$

ROI and LCOE

Simple CCGT

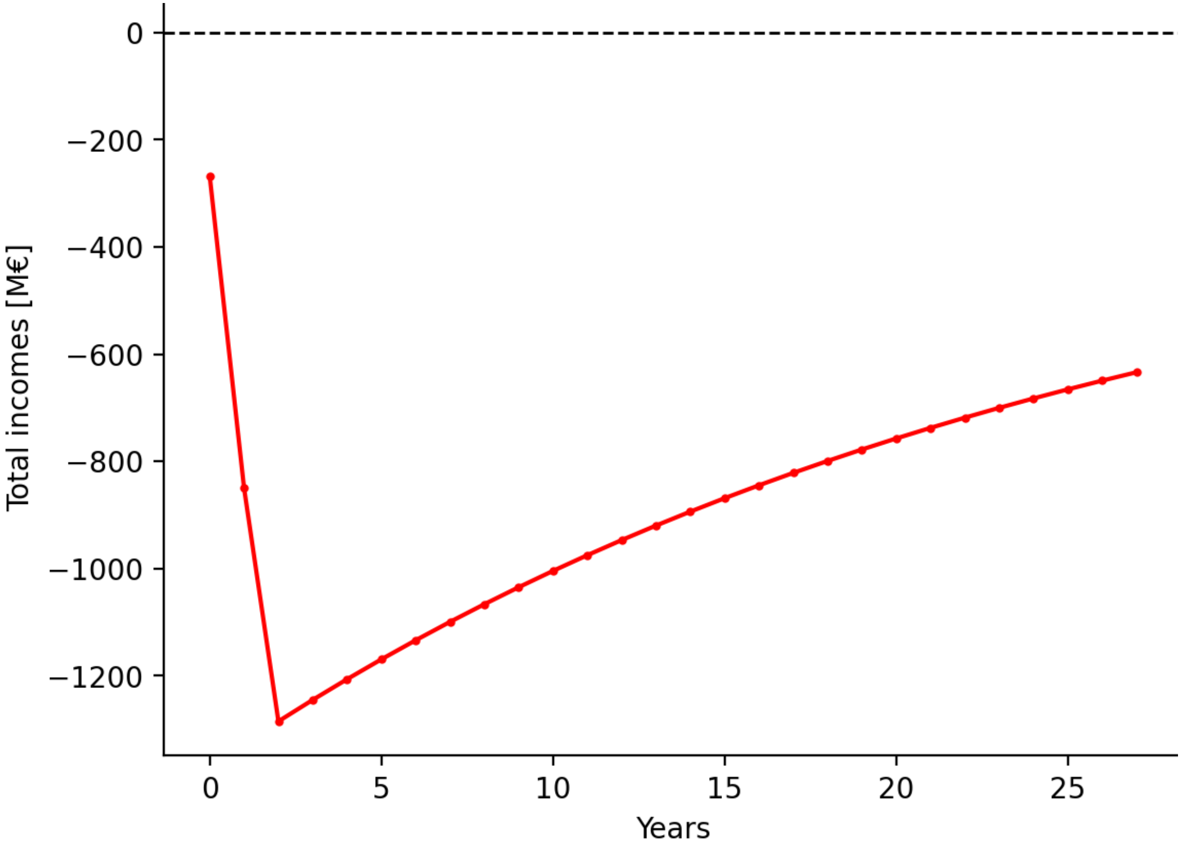


ROI = 12 years

LCOE = 116.6 €/MWh

ROI and LCOE

100% CCUS-enhanced CCGT



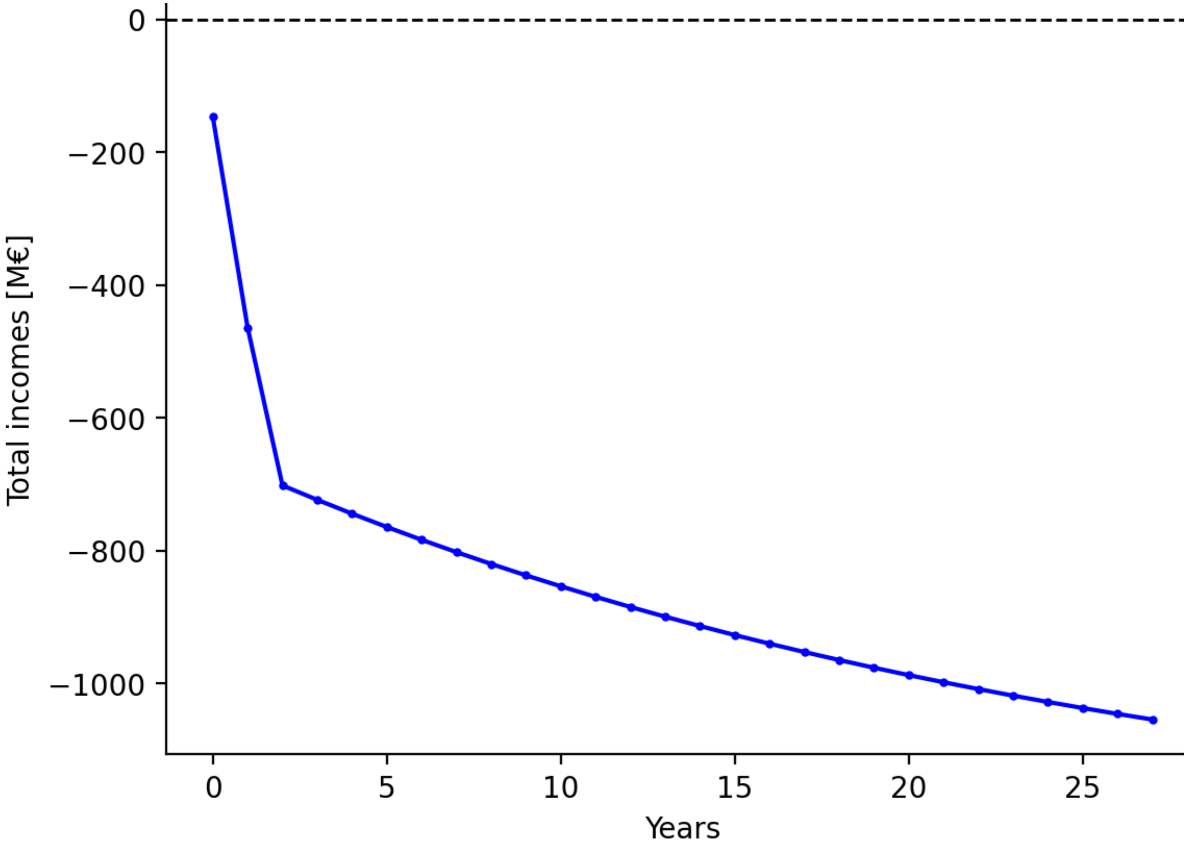
Negative ROI

LCOE = 144.6 €/MWh

Only +24%

ROI and LCOE

H_2-based CCGT



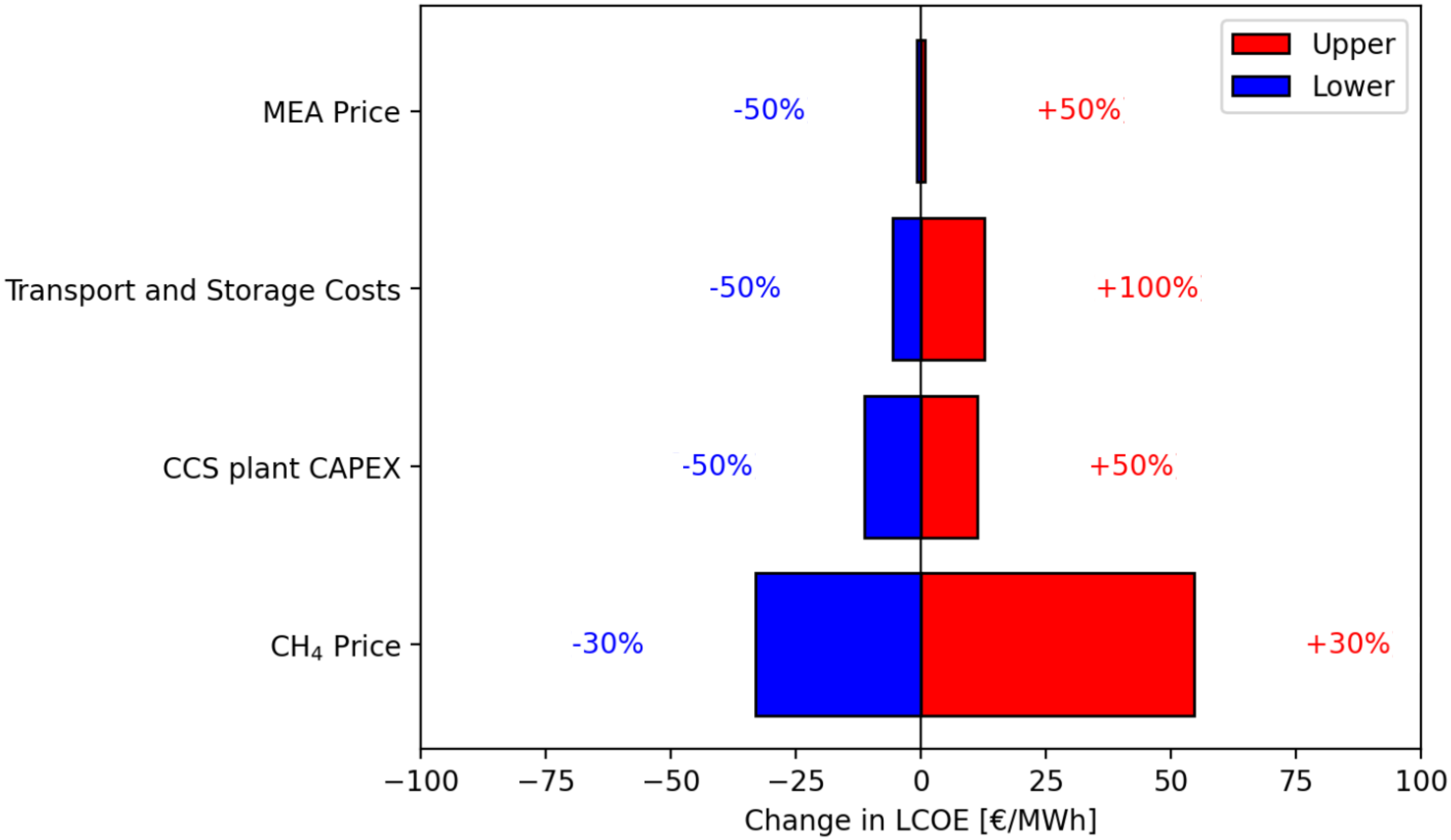
Negative ROI

LCOE = 1664,2 €/MWh

+1300%

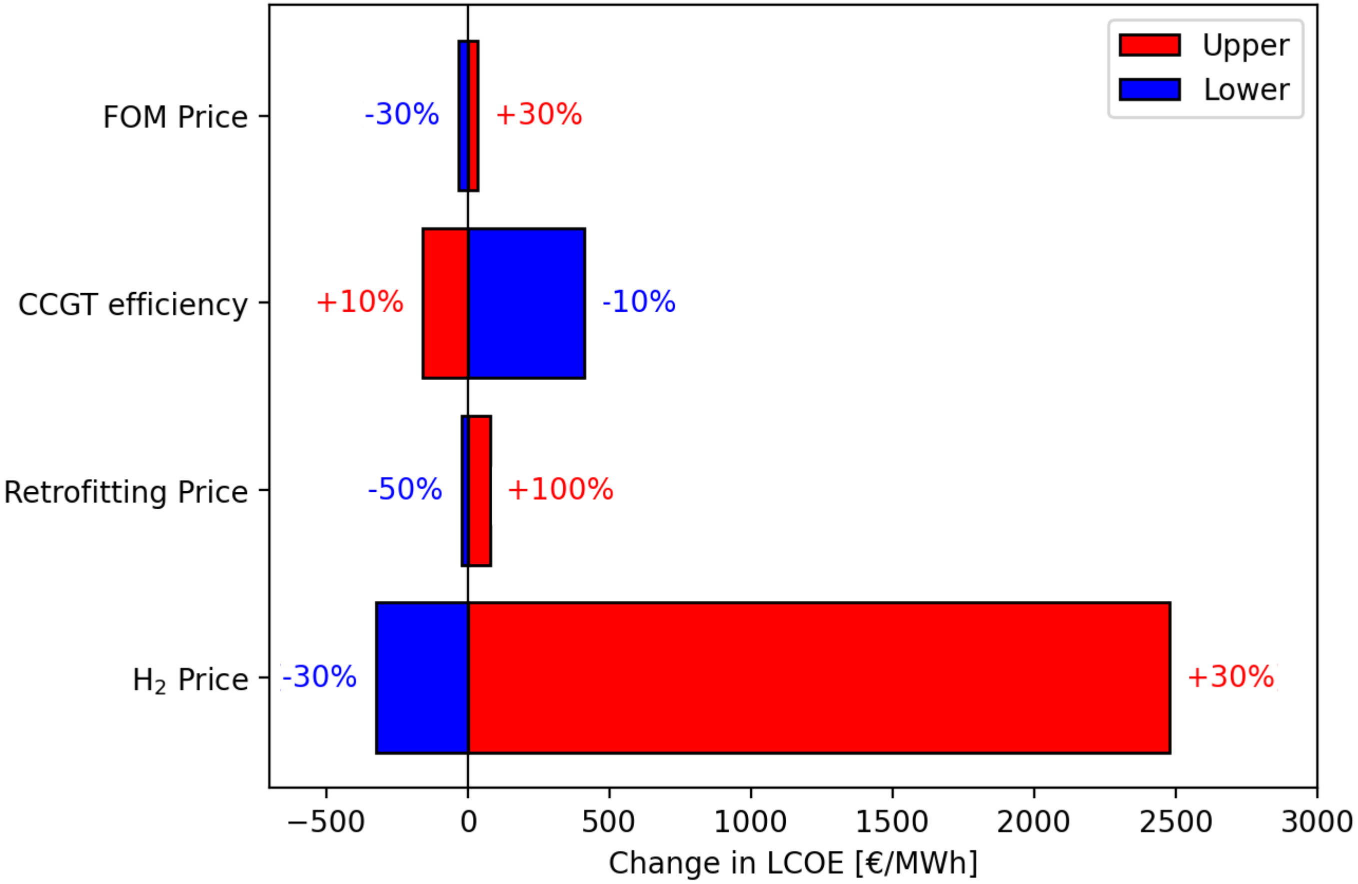
Sensitivity analysis on LCOE

100% CCS-enhanced CCGT

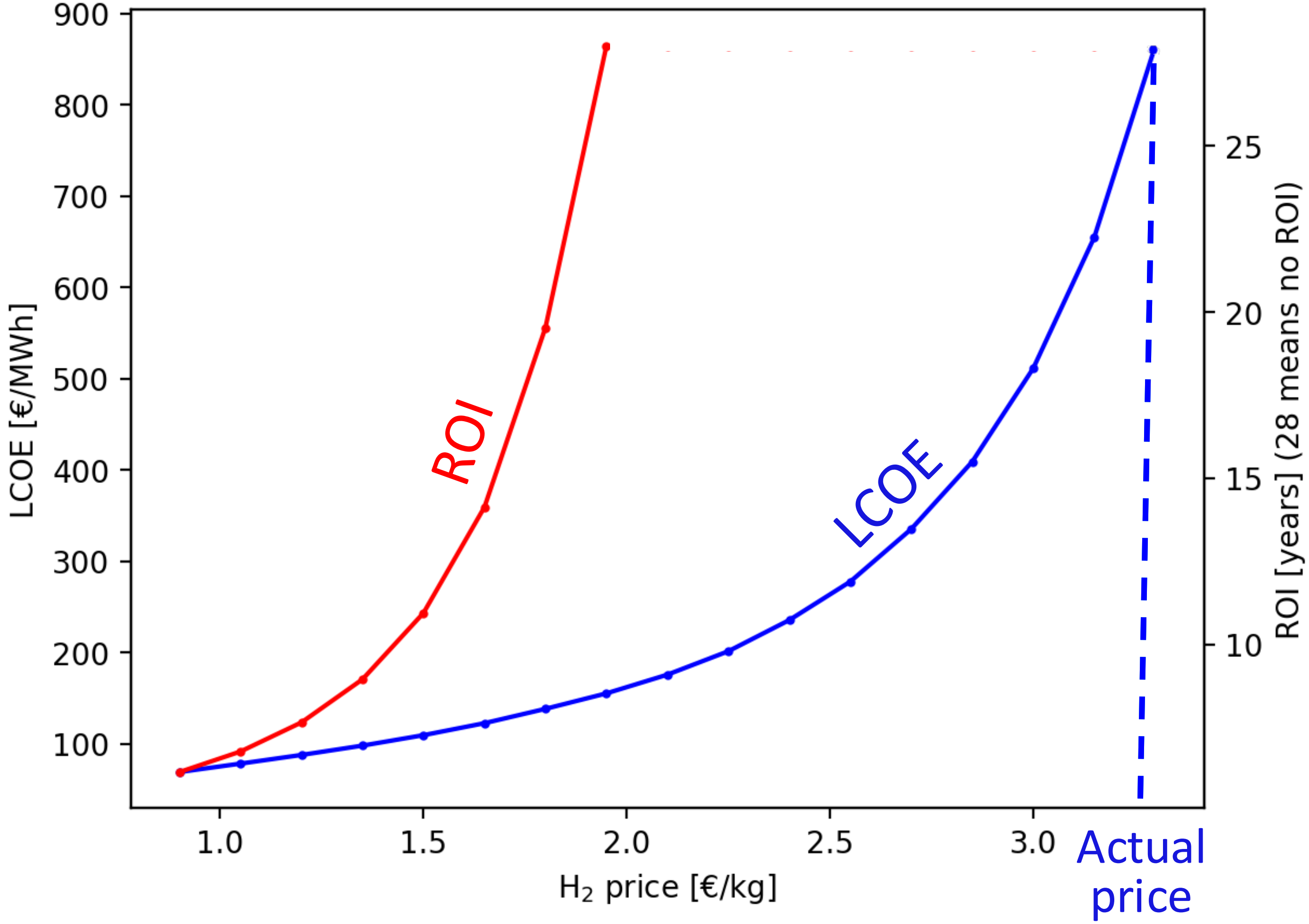


Sensitivity analysis on LCOE

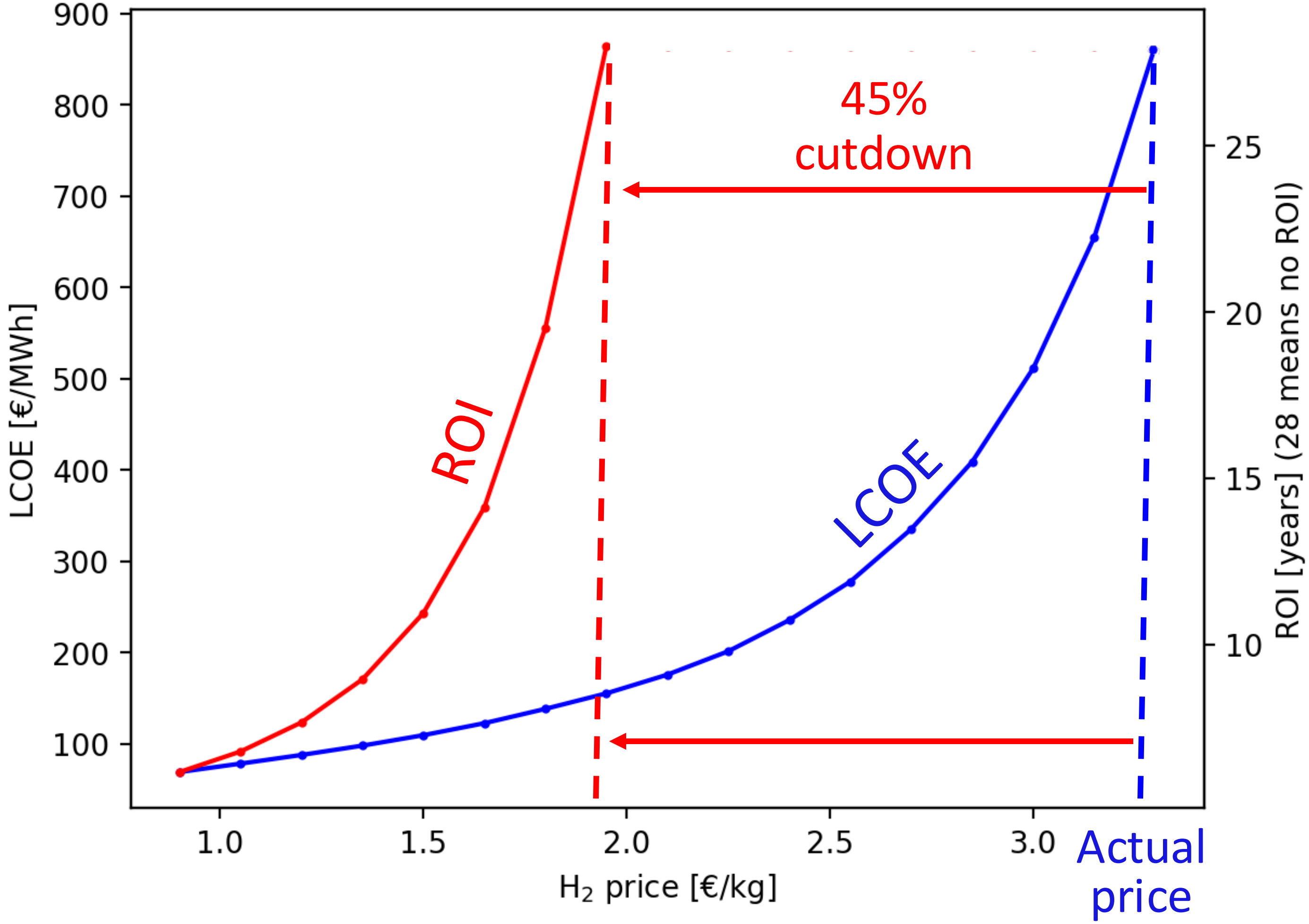
H_2-based CCGT



Sensitivity analysis on hydrogen price



Sensitivity analysis on hydrogen price



What if…
it is not the right way ?