Combined Cycle Gas Turbines as an Energy Storage Solution in a Hydrogen Economy

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ETN Global

flexnconfu

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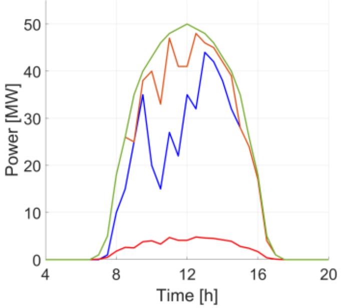
Background / Motivation

Increased share of renewables in the energy sector

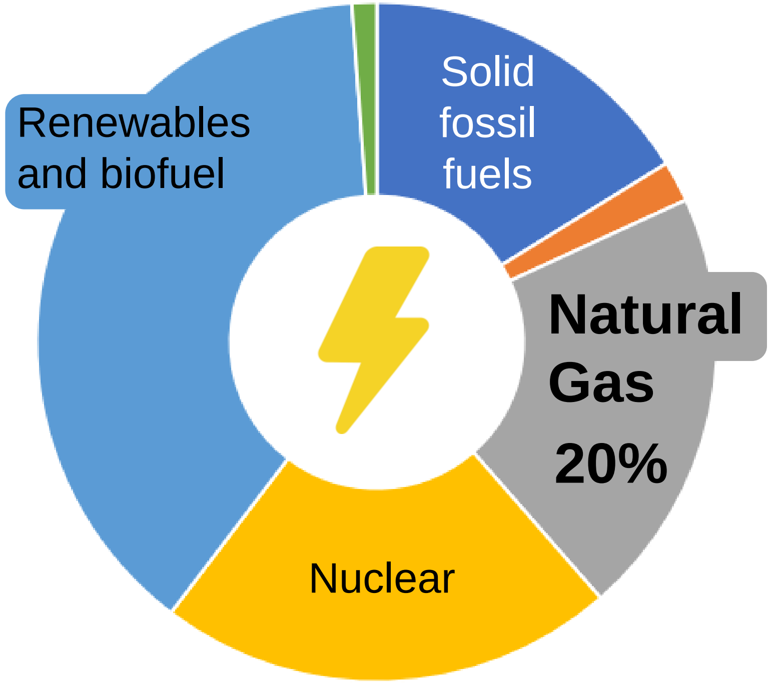
Wind and Solar

- No CO_2 emissions
- Competitive electricity prices
- Intermittent, non-dispatchable
- **Surplus electricity**



Fuel dependency / imports

Electricity production by fuel in EU 2022

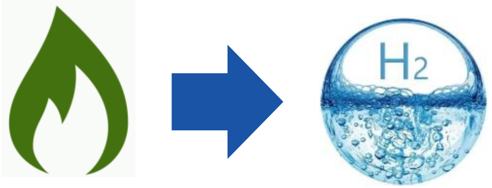


In 2021, the EU imported 83% of its natural gas consumption.

Need for:

- Energy storage

- Fuel transition

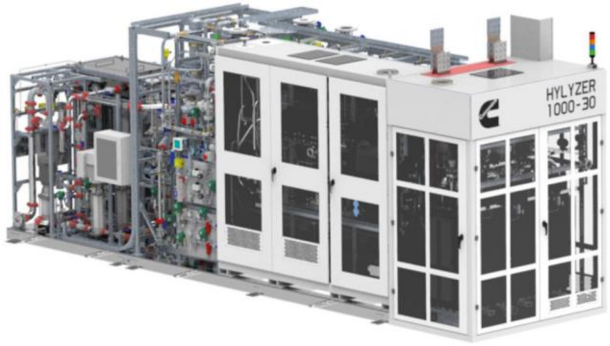


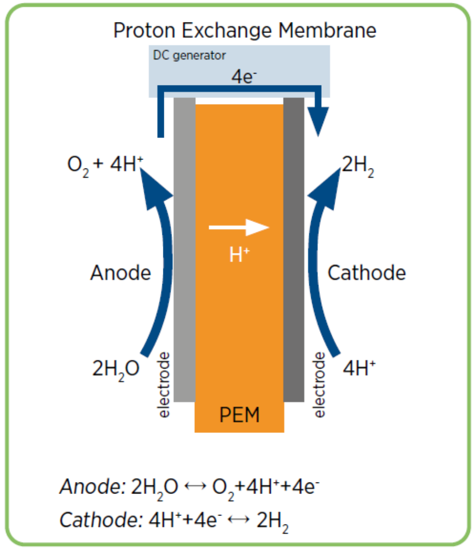
Power-H_2-Power

Power to Hydrogen to Power

- PEM Electrolysers:
  - $2H_2O + Energy \rightarrow 2H_2 + O_2$
  - < 70 bar – 50-80 °C
  - 51-55 kWh/Kg – ≈ 63% (LHV)
  - Stack lifetime 80.000 hours
  - Load levelling
  - Avoid shut-downs / start-ups

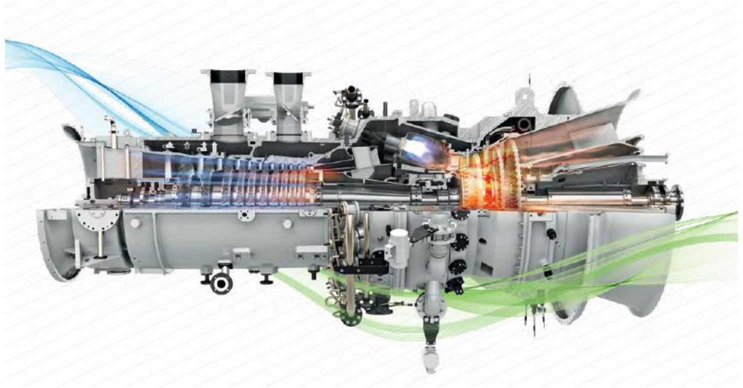
PEM Electrolysers



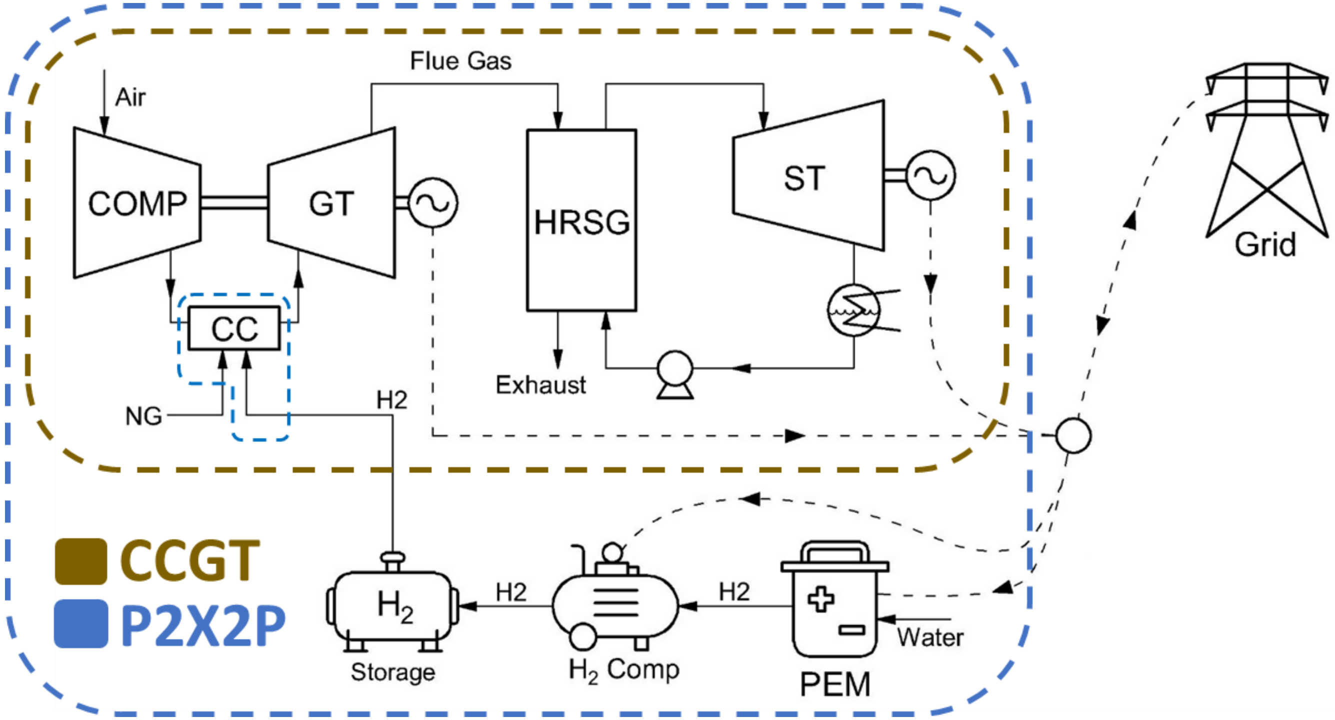


- Gas Turbines:
  - <10% H_2 vol → Control / software
  - 10-30% H_2 vol → Materials, comb chamber
  - >30% H_2 vol → Intervention in GT and ST

Hydrogen gas turbines



Proposed layout

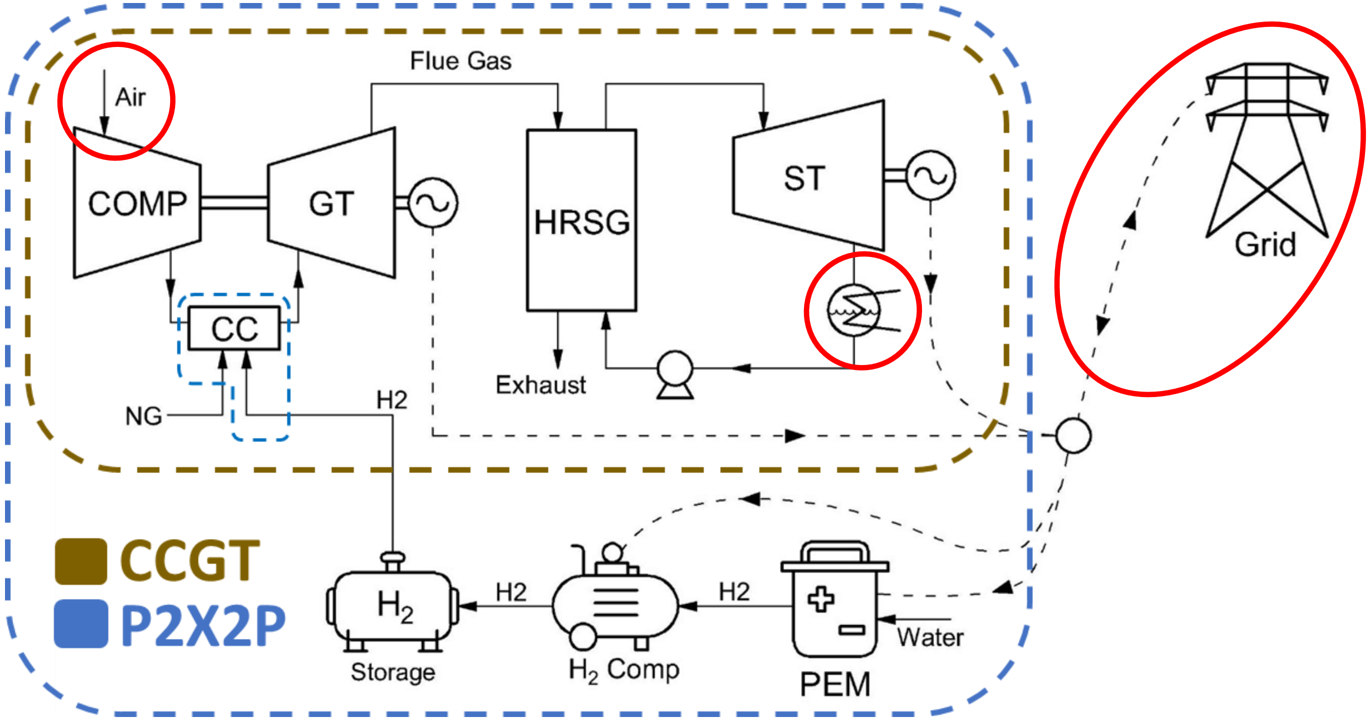


Integration of P2X2P for:

- Energy arbitrage:
  Producing H_2 during off-peak periods or high RES
- Less CO_2 emissions:
  Burning alternative fossil-free fuels
- Load levelling, avoid shut-down / start-up, increased efficiency

Techno-economic analysis

Conditions / assumptions – Boundary conditions



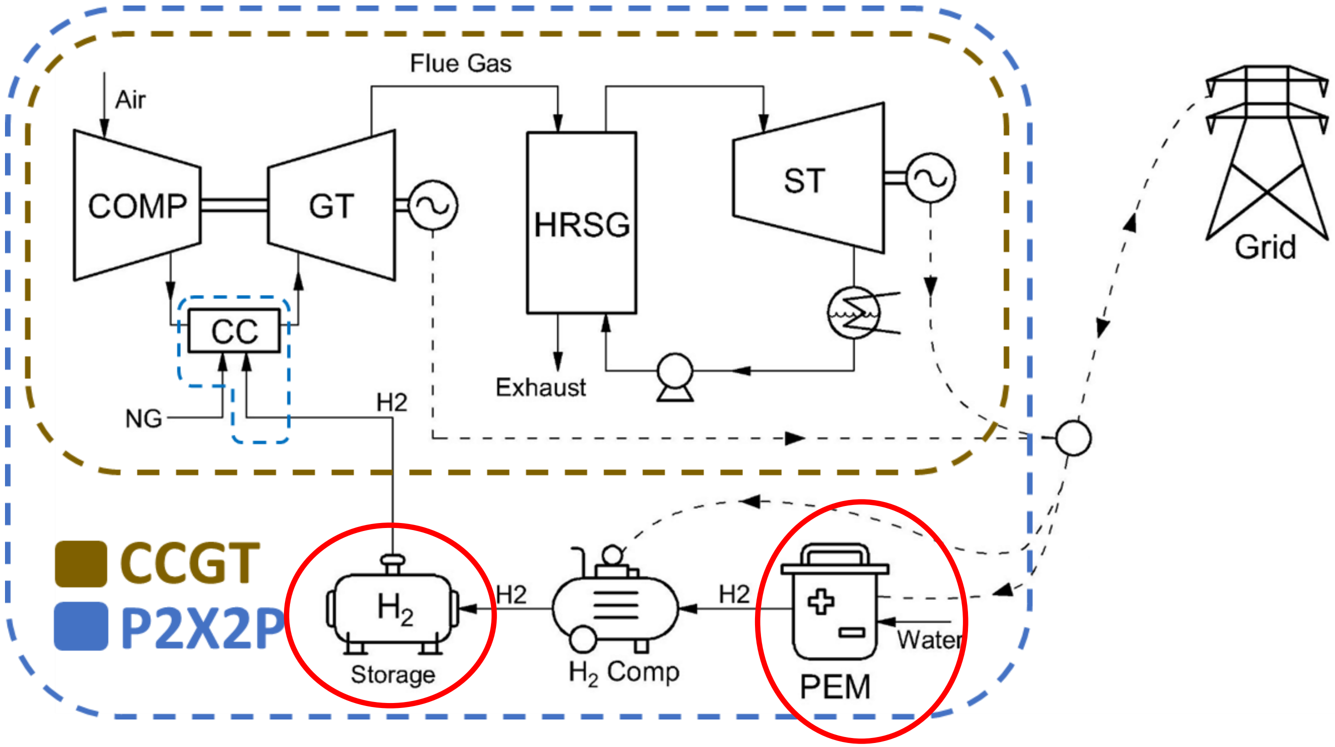
Electric power generation

- Mid-merit or peaker
- Maximum power transfer

Ambient conditions

- Lisbon, Portugal 2022
- Hourly values of:
  - Temperature
  - Pressure

Conditions / assumptions – Components sizes



Storage size

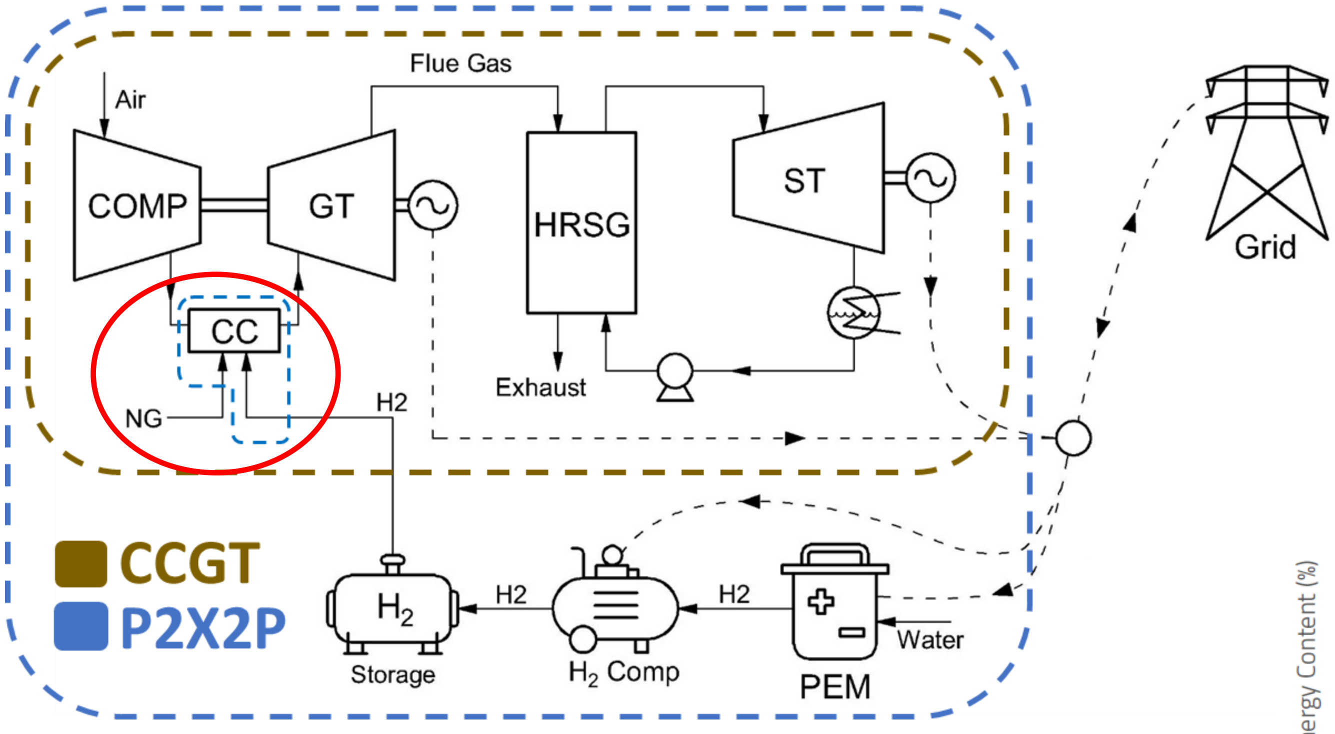
- From 0 to 24 hours of H_2 production

Electrolyser size

- Relative to CCGT installed capacity
- From 0 to 1

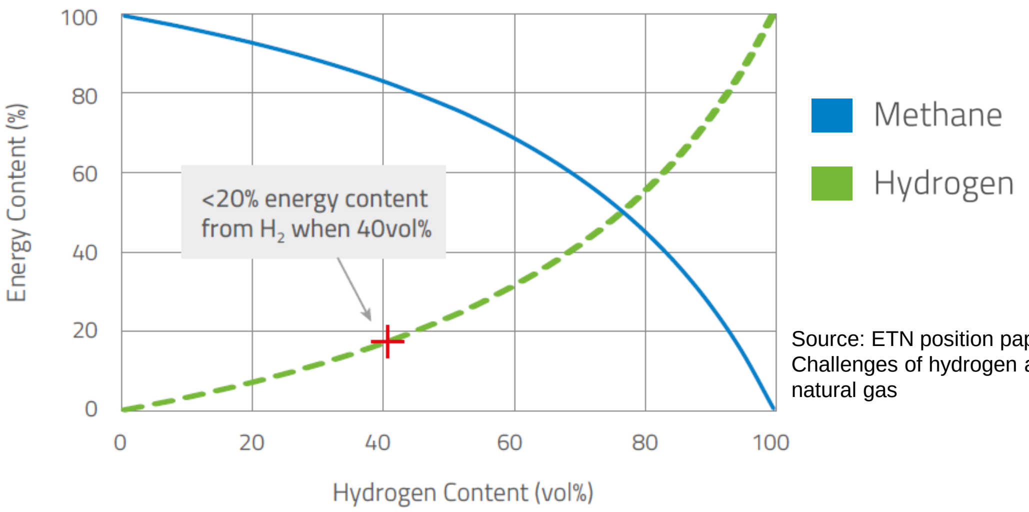
$$PEM_{size}^{rel} = \frac{PEM_{cap}[MW_e]}{CCGT_{cap}[MW_e]}$$

Conditions / assumptions – H_2 mix in fuel



Maximum H_2 mix in fuel

Volume	Energy	Investment
10 %	3 %	5 k€/MW_{el}
30 %	11 %	21 k€/MW_{el}
100 %	100 %	51 k€/MW_{el}

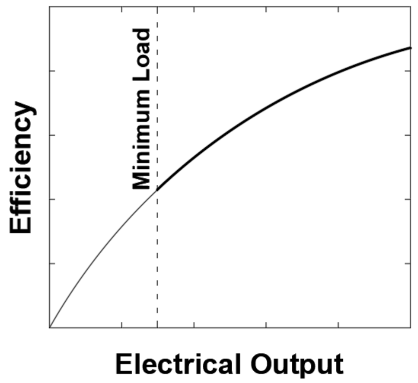


Source: ETN position paper 2022 Challenges of hydrogen addition to natural gas

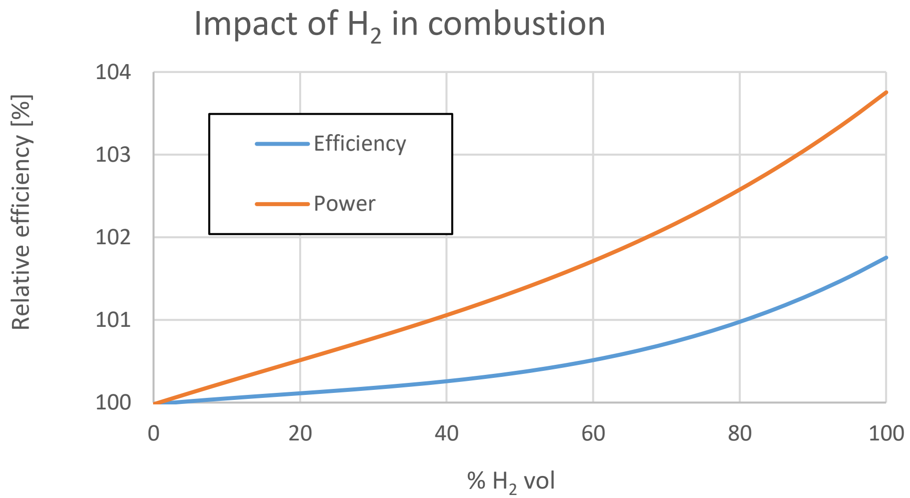
The Model: Components and costs

CCGT performance

- Fixed and variable heat rate model:
  - Efficiency at part load
  - Ambient temp. and pressure
  - Saves computational time



H_2 combustion in GT

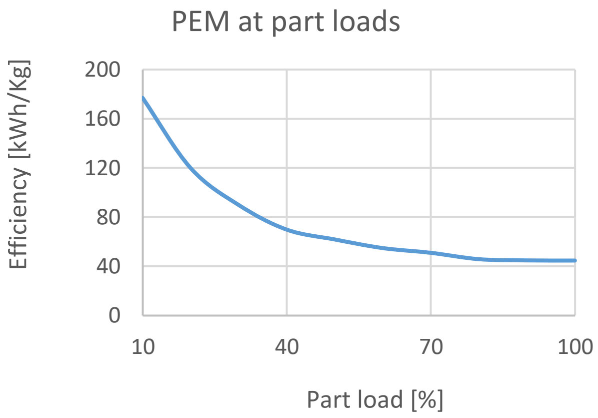


Costs functions

$$C_{PEM} = C_{PEM}^{Ref} \cdot \left(\frac{P_{PEM,Des}}{P_{PEM,Ref}}\right)^{\alpha_{PEM}}$$

PEM electrolyser

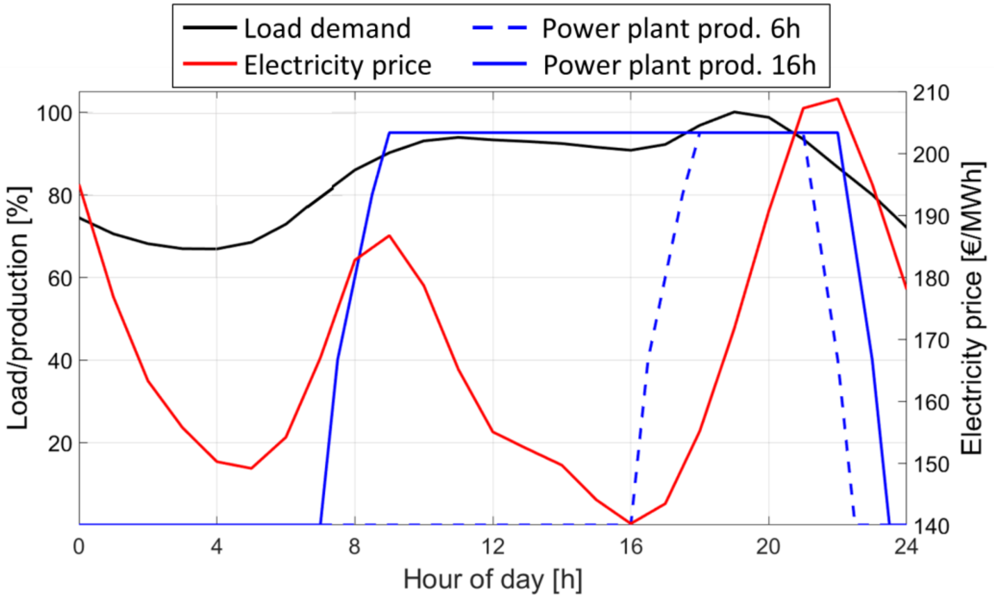
- Cell, stack, system level
- Validated with reference models and industrial partners
- Simplified to correlations



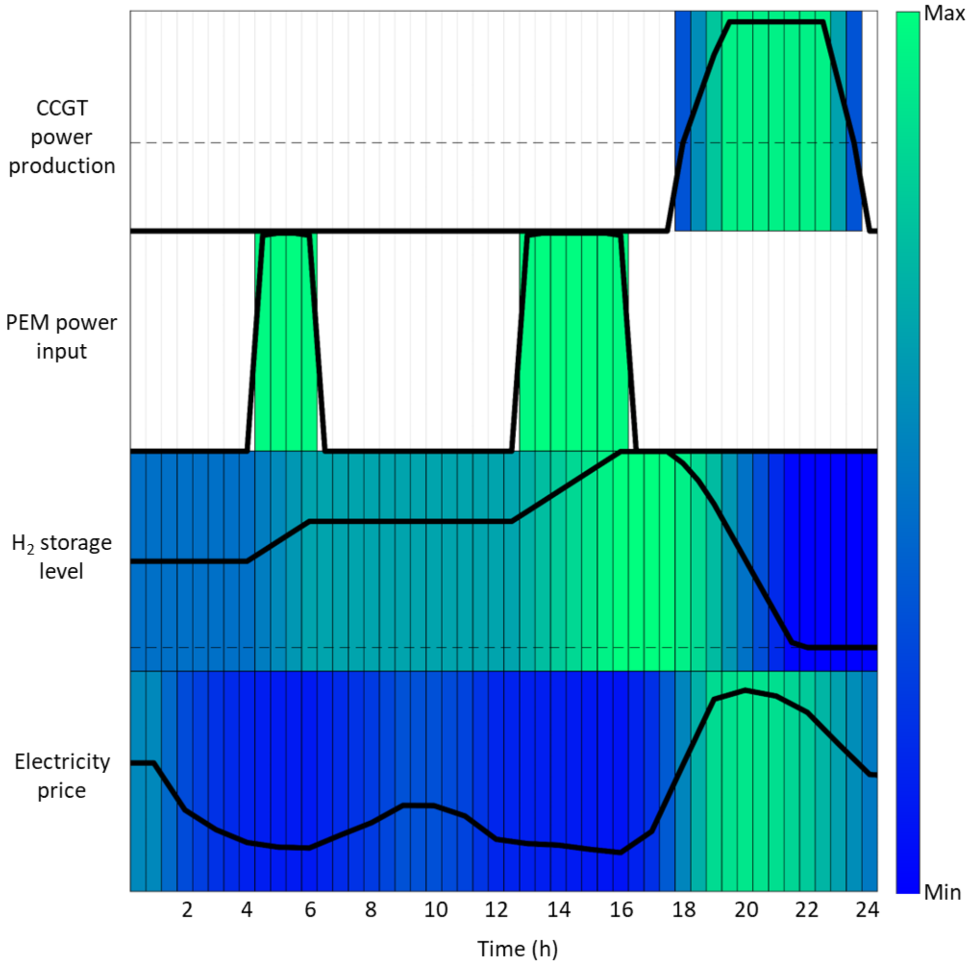
The Model: Dispatch / control

Electricity production

Pre-defined profiles



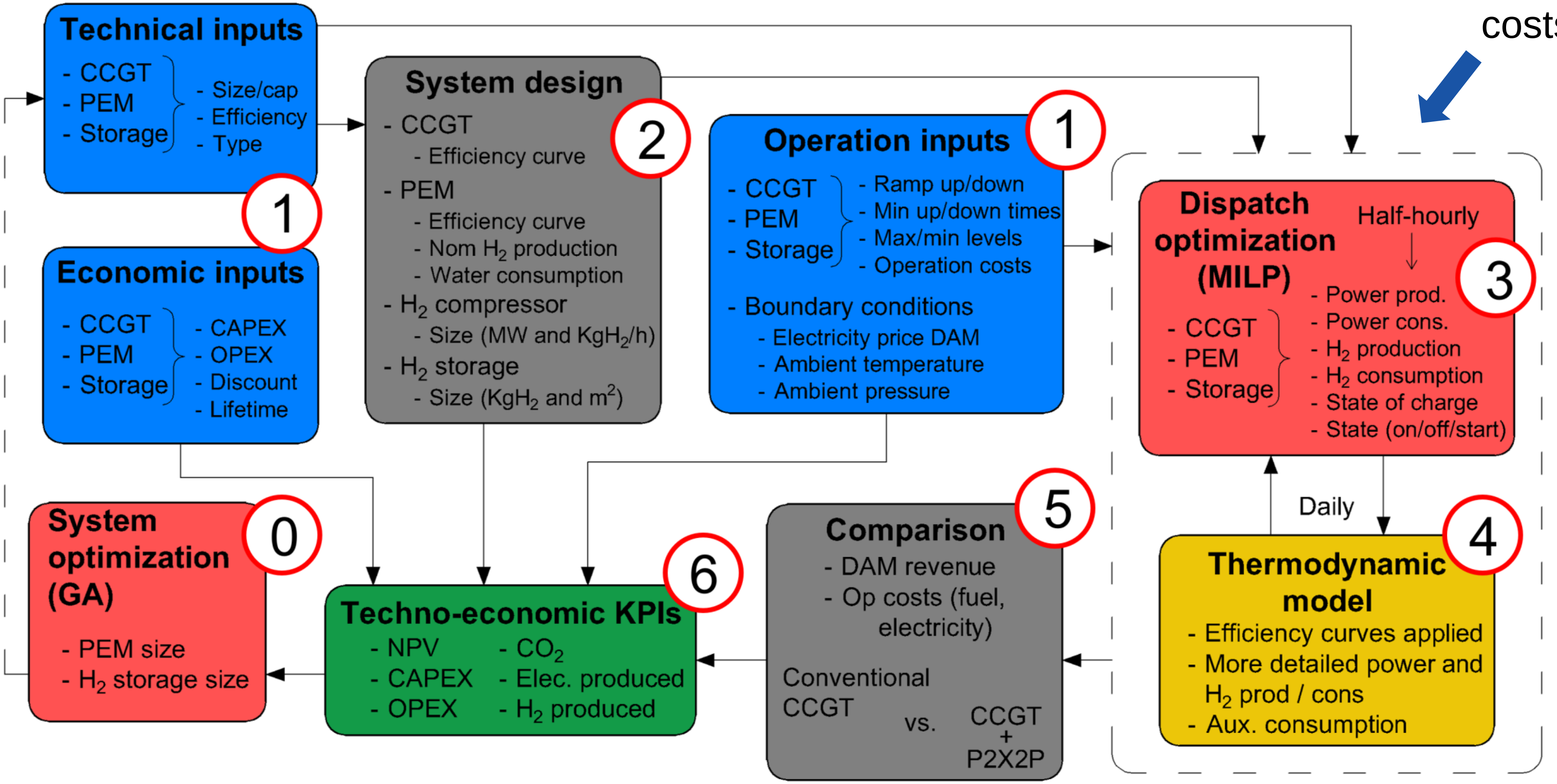
Hydrogen production - MILP



Simulation process

Minimize operational costs

Objectives:
- Max NPV
- Min CO_2



Scenarios - results

Fuel market scenarios

	Low	Medium	High
Natural gas [€/MWh]	50	130	210
CO_2 tax [€/ton]	40	80	120

Q1 2023
Prev. years

Average
2022

Projection
30 years

Results

- 12200 system configurations
- Only 100 → H_2 production
- Peaker plants perform better
- Less than 150 hours per year

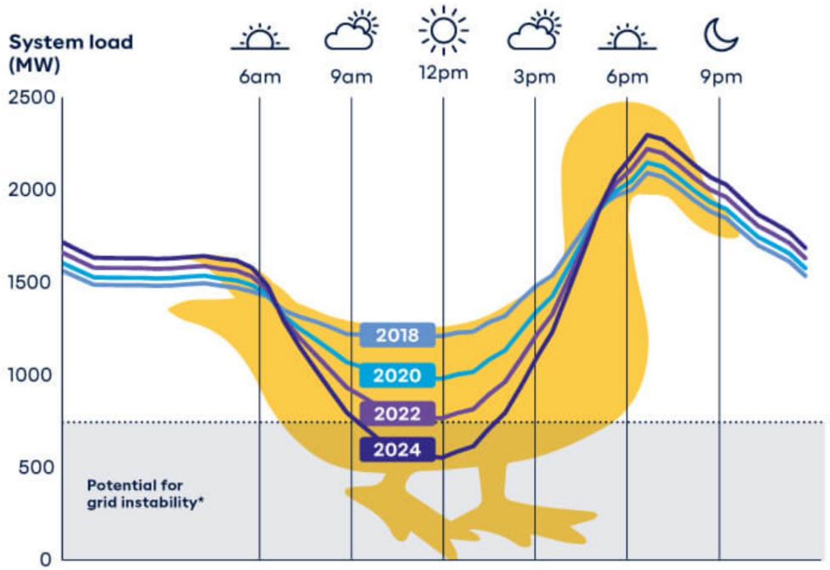
- Added complexity / risk
  - Project execution
  - Control / operation
  - Combustion
  - Environment

→ **Not feasible**

Additional scenarios

Electricity demand

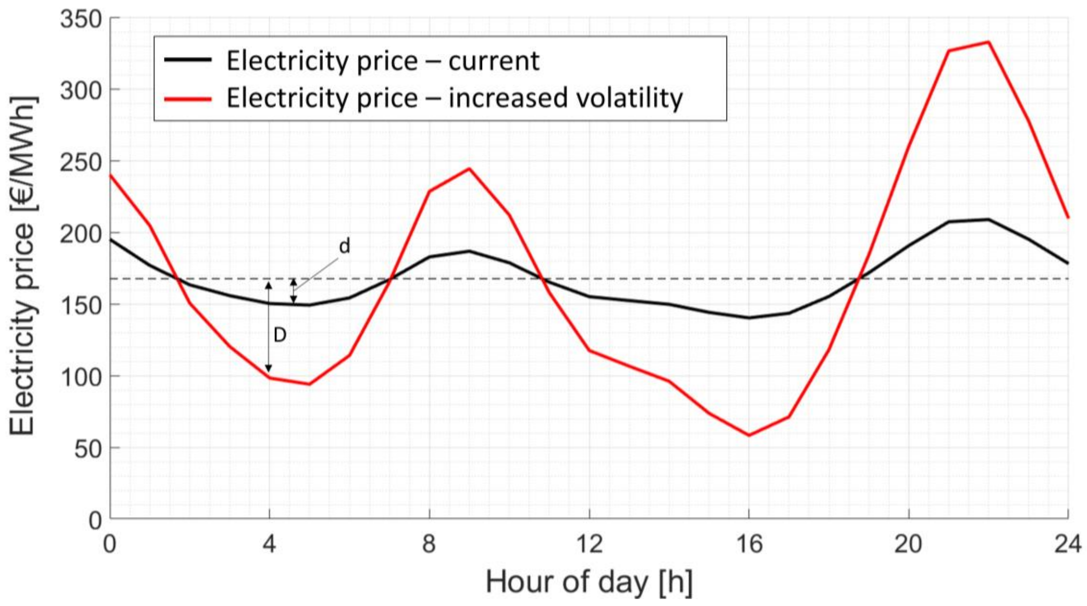
Duck curve



Source: www.synergy.net.au

Electricity Price

Increased price volatility



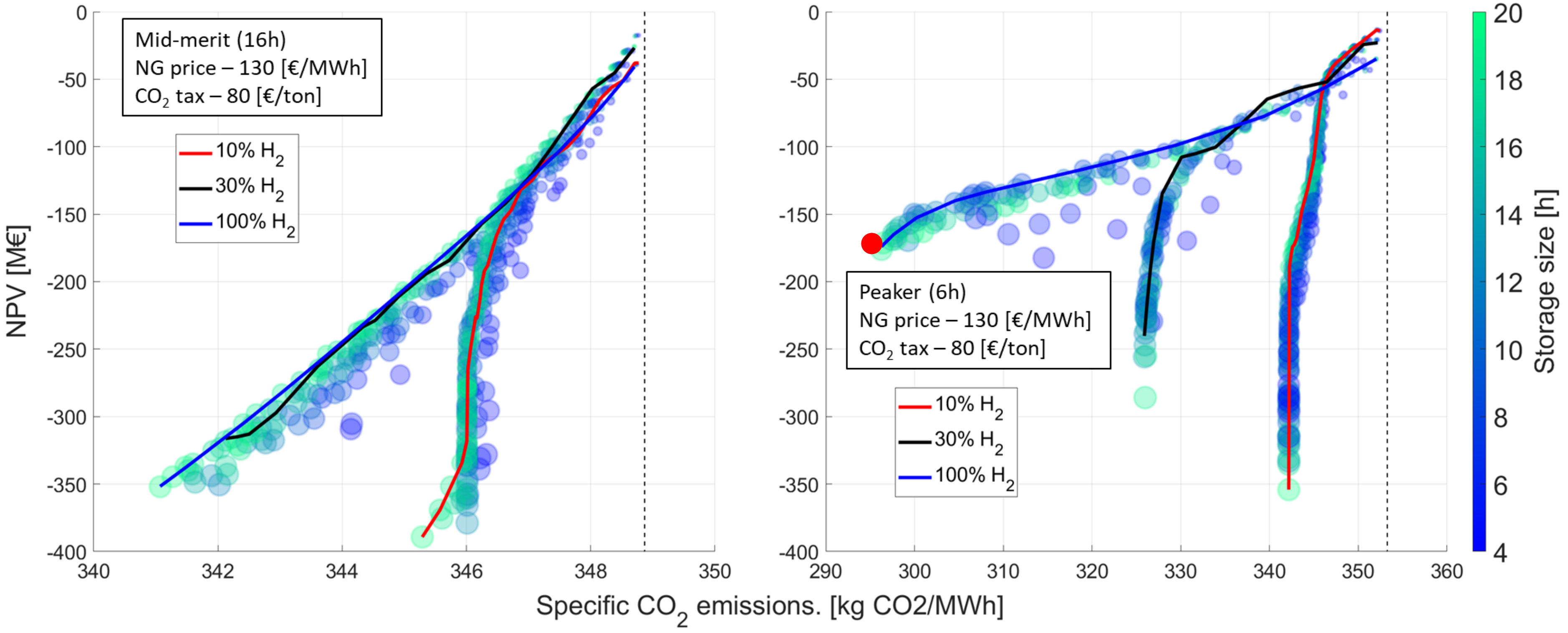
Additional scenarios – medium fuel price

- Negative NPV
- Environmental impact
- Example configuration:
  - Peaker
  - PEM 390 MW_e
  - Storage 19 h
  - 100% H_2

Parameter	Units	Reference	Example config
NG cons.	[kton NG]	87.54	73.41
NG price	[€/MWh]	130	
Cost NG	[M€]	158.14	132.62
Elec prod.	[GWh]	681.42	
Elec purch.	[GWh]	0	267.70
Cost Elec	[M€]	0	1.24
PEM OH	[h]	0	696.00
H2 prod.	[kton H_2]	0	5.03
NPV	[M€]	0	-176.13
spf. CO_2	[kg/MWh]	353.27	296.26

Specific CO_2 emissions [$kgCO_2$/MWh]			
BAU	10% H_2	30% H_2	100% H_2
348.9	345.3	342.1	341.1
	-1.0 %	-1.9 %	-2.2 %

Specific CO_2 emissions [$kgCO_2$/MWh]			
BAU	10% H_2	30% H_2	100% H_2
353.2	342.2	325.9	296.3
	-1.9 %	-6.6 %	-15.1 %



Additional scenarios – high fuel price

- Example configuration:
  - Peaker
  - PEM 380 MW_e
  - Storage 11 h
  - 100% H_2

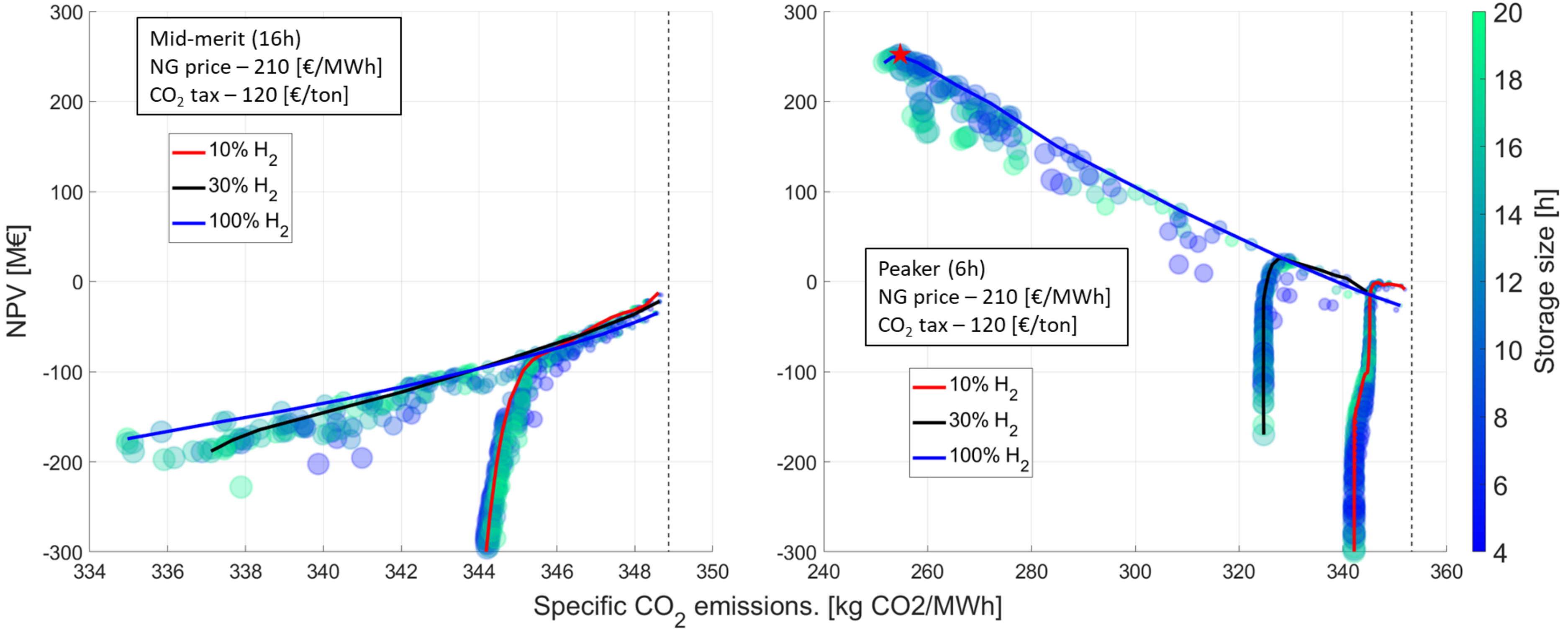
Parameter	Units	Reference	Example config
NG cons.	[kton NG]	87.5	63.1
NG price	[€/MWh]	210	
Cost NG	[M€]	255.5	184.2
Elec prod.	[GWh]	681.4	
Elec purch.	[GWh]	0	511.0
Cost Elec	[M€]	0	15.7
PEM OH	[h]	0	1338
H2 prod.	[kton H2]	0	9.6
NPV	[M€]	0	251.9
spf. CO_2	[kg/MWh]	353.3	254.7
PEM area	[m2]	0	5651
Storage area	[m2]	0	3152.8
Storage cap.	[ton H2]	0	79.2
Water cons.	[m3]	0	143986

PEM OH: 500 h

CO_2: 349 → 335 [Kg/MWh] -4%

PEM OH: 1340 h

CO_2: 353 → 255 [Kg/MWh] -30%



Conclusions

Layout proposed: CCGT + electrolyser with storage – P2X2P

Not feasible under current fuel and electricity markets

Challenges

Technology readiness

Large investment

Footprint

Water consumption

Potential in a scenario with greater electricity price volatility

→ Technical

→ Environmental

→ Economic