Real-time modelling and validation of Distributed Energy Storage Systems and integration strategies

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ESR08

SmartGYsum

About me

20.11.2000
- Ravenna (Italy)

2014 - 2019
- High School Diploma in Urbino at Liceo Classico “Raffaello”

2019 – 2022
- B. Sc. in Mechatronics Engineering in **University of Bologna**

2022 – 2024
- M.Sc. Electrical Energy Engineering in **University of Bologna**
- Employed as electrical Designer in Imola

02.04.25 – …
- PhD candidate at **Karlsruhe Institute of Technologies**

Research field

Microgrid

- Interface solution to connect the new energy sources to the grid
- Composed by RES, storage and loads
- High efficiency: energy mostly locally produced and consumed
- Microgrids → Smart grid

DC

- Reduced number of conversions required
- Better integration with RES
- Reduced power quality issues
- Scalability and modularity

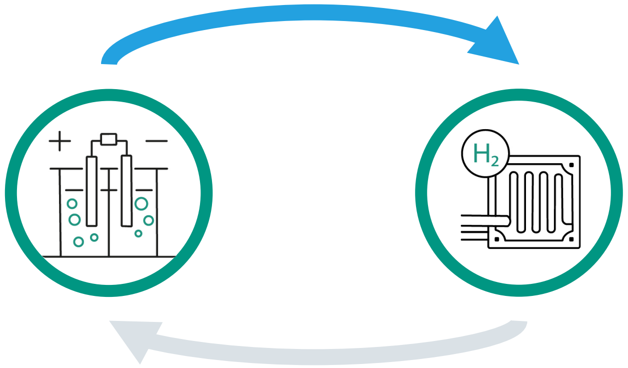
Hydrogen technologies

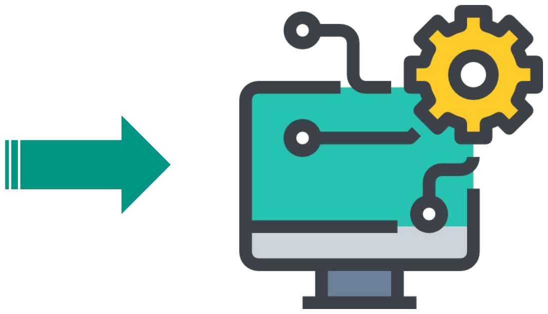
Hydrogen is one of the most promising energy vector for the future, because:

- It is currently largely used in chemical industrial processes.
- Water is the only byproduct of its consumption.
- It can be created from electricity and water and then converted back to electricity when needed.

Hydrogen technologies are already available but to fully realize its potential, it is first crucial to understand under which conditions in the DC microgrids hydrogen is economically viable or not.

The following step of the research aims to develop the optimal control strategies of DC microgrids which include a hydrogen system and validate them.





Work Plan
Techno-economic analysis of hydrogen energy storage plants

- **Energy scenario identification** – techno-economic feasibility of H_2 storage in different grid conditions (off-grid, weak grid, industrial networks)

- **Real-time modelling and control development** – novel control strategies for H_2 plants in simulative environment

- **Economic assessment of grid services** – integration of ancillary service revenues into the scenario analysis to improve plant profitability

- **Experimental validation** – real-time simulator and H_2-in-the-loop facility at KIT Energy Lab; results fed back into the economic analysis

- **Dissemination** – publications in international journals and IEEE conferences (PES, ECCE); SmartGysum project

Hydrogen In the Loop facility
Energy Lab at KIT

HIP aims to test hydrogen technologies under realistic grid conditions using a Power-Hardware-In-the-Loop (PHIL) approach

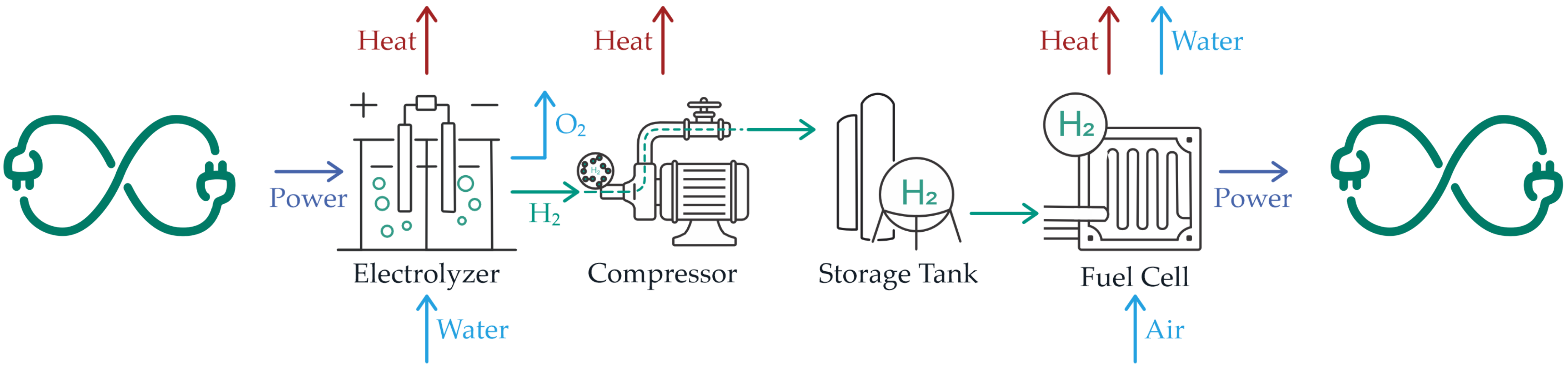
Electrolzyer	
$P_{N,EL}$	50 kW
U_{EL}	3x 400 V AC
$I_{EL,max}$	70 A
E_{H2}	19 kg / 1267 kWh

Fuel cell	
$P_{N,FC}$	10 kW
U_{FC}	41..57 V DC
$I_{FC,max}$	250 A
E_{H2}	19 kg / 317 kWh

Many otherprojects going on:

- LH2 liquefaction and storage plant (AppLHy! Project)
- High-Temperature Superconductor (HTS) power devices cooled by liquid hydrogen
- H2-Rail infrastructure (hydrogen-powered train)

H_2-in-the-Loop Plant Overview

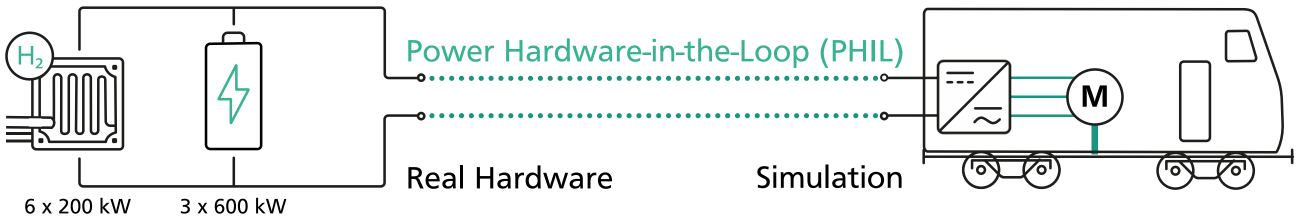


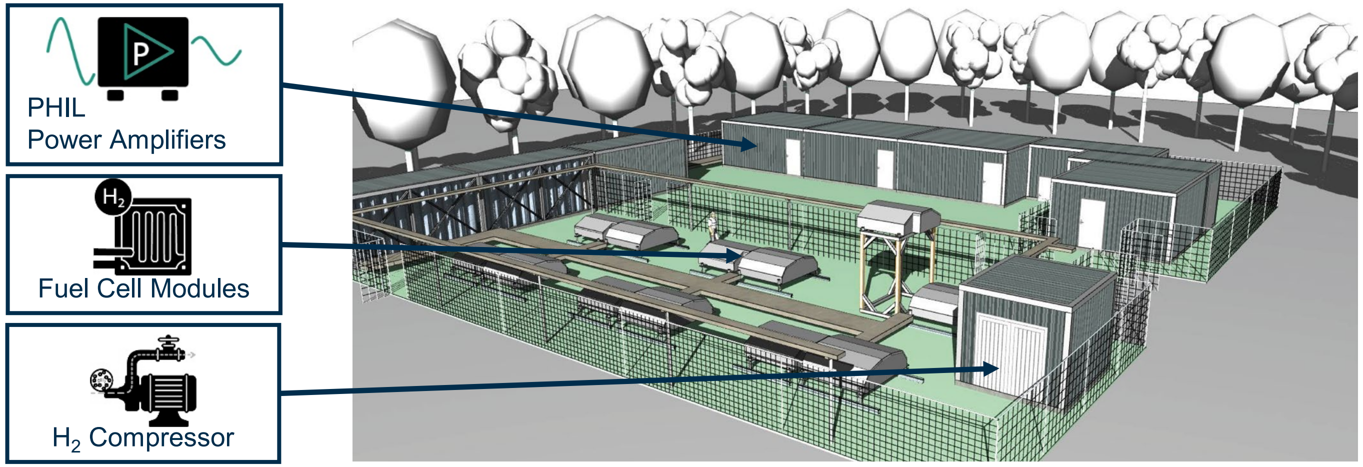
- Investigation of Electrolyzer systems as variable load
- Simulation of various grid support scenarios in Power Hardware-in-the-Loop

- Investigation of Fuel Cell systems as variable source
- Simulation of various grid support scenarios in Power Hardware-in-the-Loop

H_2Rail Plant Overview
and details

- 1.2 MW Fuel Cell power (6 x 200 kW)
- 1.8 MW Battery power (3 x 600 kW)
- DC coupling of Fuel Cells and Batteries
  - Flexible operation in PHIL system
- Local production of hydrogen (35 bar) and on-site compression (350 bar)
- Storage of up to 600 kg of hydrogen at high pressure (20 MWh)





Batteries	
$P_{N,Bat}$	3 x 600 kW
U_{Bat}	835 V
$I_{Bat,max}$	3 x 720 A
E_{Bat}	3 x 400 kWh

Fuel Cells	
$P_{N,FC}$	6 x 200 kW
U_{FC}	330..700 V
$I_{FC,max}$	305 A
E_{H2}	600 kg / 8300 kWh

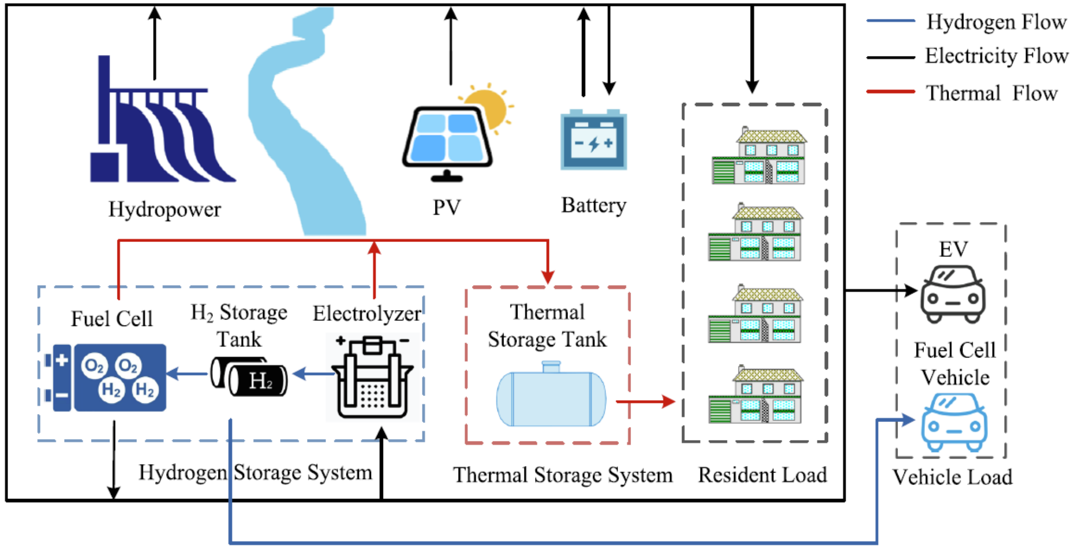
The research

An example

A hydrogen-based zero-carbon microgrid demonstration in renewable-rich remote areas: System design and economic feasibility,

Xiaojun Shen, Xingyi Li, Jiahai Yuan,Yu Jin

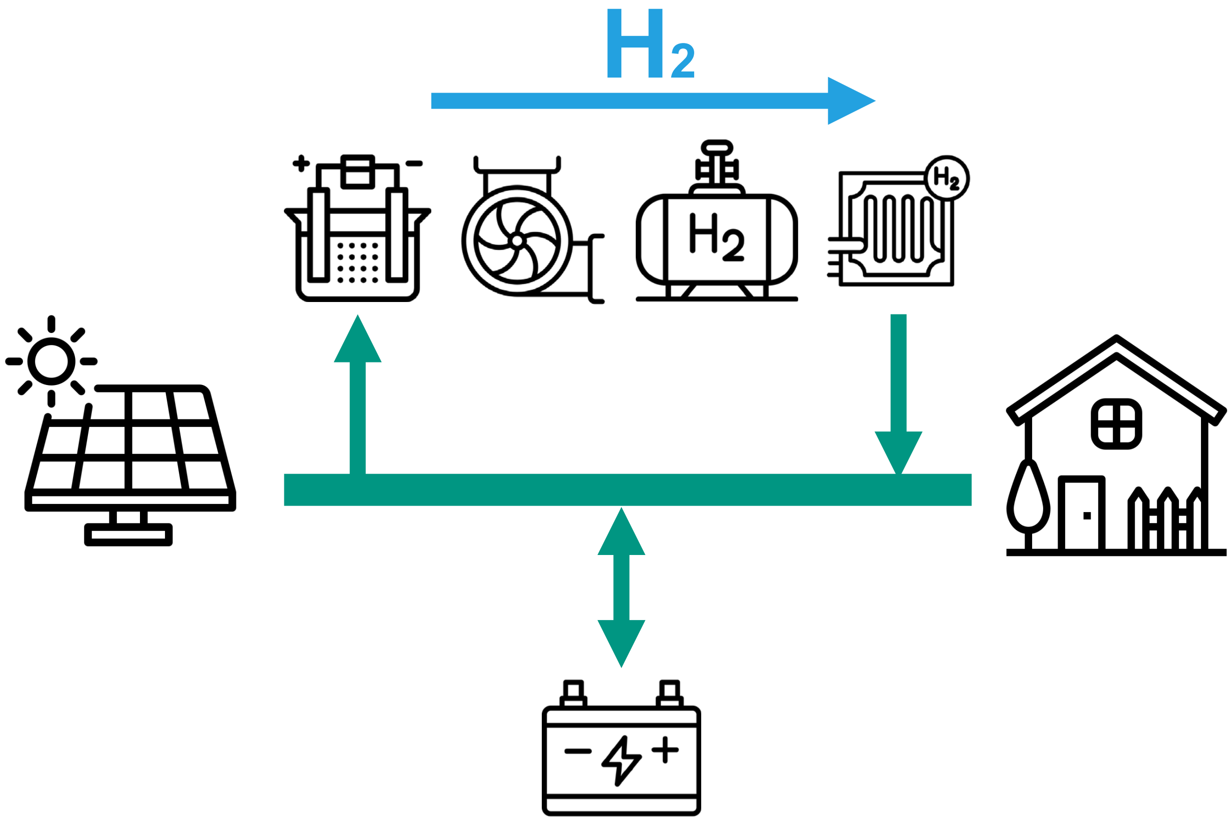
This article explores the possibility to realize a microgrid with a seasonal hydrogen storage system.



Item	Scale [unit]	Min. Unit Price (€/unit)	CAPEX Price [€]	OPEX [%CAPEX/y]	OPEX [€/y]	Total cost in 20 years [€]
Alkaline Electrolyzer [kW]	5000	250	1250000	0.02	25000	1750000
Compressor [kg/d]	1827	400	730779	0.04	29231	1315402
Compressed hydrogen storage 350 bar [kg]	217814	200	43562800	0.02	871256	60987920
Fuel Cell System [kW]	6000	1000	6000000	0.04	240000	10800000
Battery [kWh]	198000	100	19800000	0.01	198000	23760000
Total cost						**98,613,322**

LCOE [€/kWh]	Payback time [years]
0.77	**4.27**

Developed scenario
German case study example



Component	CAPEX [€]	% of total	OPEX [€/y]
PV	73,886	12.1%	961
Battery	67,950	11.1%	1,359
Electrolyzer	149,640	24.5%	4,489
Compressor	45,904	7.5%	918
H_2 Tank	170,880	28.0%	3,418
Fuel Cell	102,100	16.7%	3,063
Total	**610,350**	**100%**	**14,207**

Parameter	Value
PV peak power	131.1 kW
Annual energy produced	159,820 kWh/y
Battery size	340.3 kWh
H_2 tank capacity (LHV)	43,082 kWh
H_2 tank mass	1,293 kg
H_2 tank volume	114.4 m^3

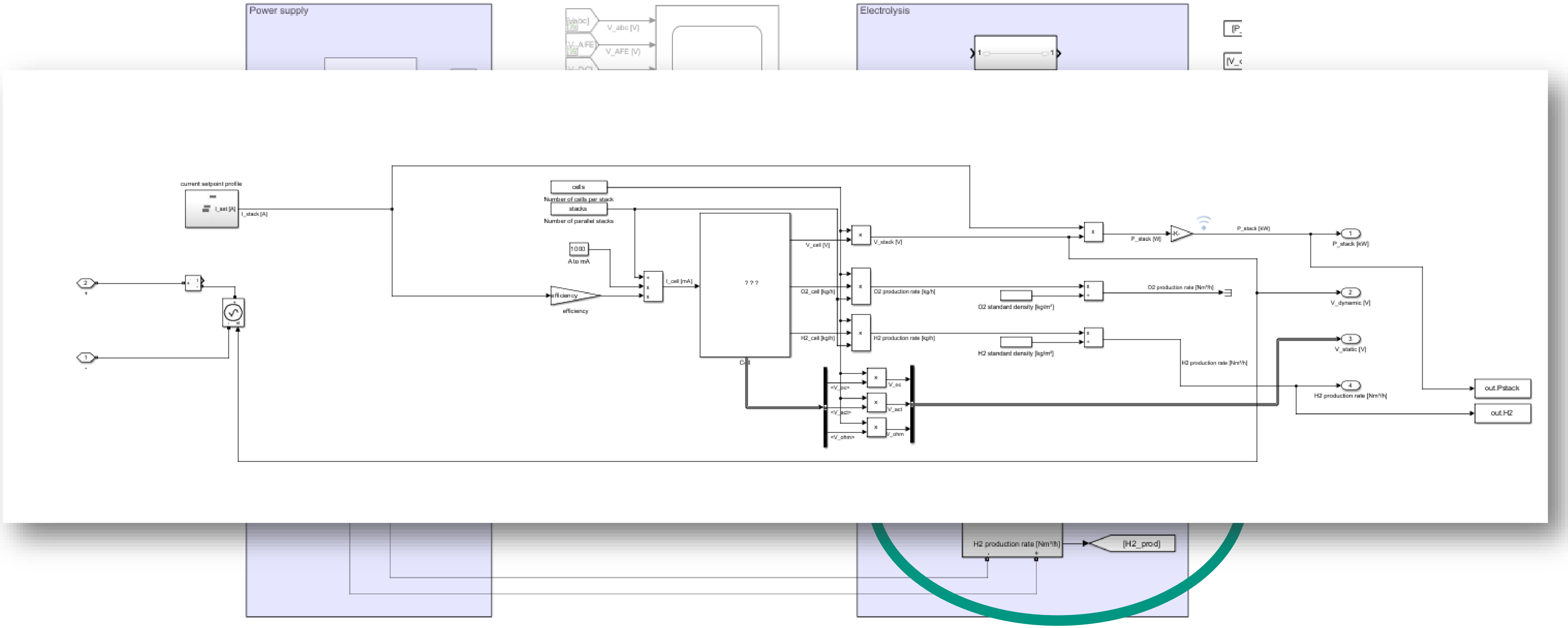
Results

- At current technology costs, **hydrogen storage cost is really high**: LCOE = 0.946 EUR/kWh vs. grid price of 0.352 EUR/kWh.
- The NPC is -498,470 EUR: **the system generates a net loss over 20 years** despite annual savings of 23,746 EUR.
- **Cost reduction in electrolyzers and H2 tanks is the critical path** to economic feasibility in future scenarios.

General results:

- Hydrogen storage cost is prohibitive in standard energy systems scenarios
- **Hybrid hydrogen storage provide an economically viable solution in specific scenarios**, e.g. when connection to grid is too expensive

Modelling development



Thank you

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