UNIVERSITÀ POLITECNICA DELLE MARCHE

DIISM
Energy systems Group

IDROGENO E TECNOLOGIE PER LA GENERAZIONE ENERGETICA E LA PROPULSIONE NEI TRASPORTI GREEN

"Study of power-to-power systems: hydrogen technologies modelling on Python and their technical improvement for integration in different scenarios"

Presenter: Francesca Mennilli, Ph.D. student

AIMSEA Associazione Italiana delle Macchine a fluido e dei Sistemi per l'Energia e l'Ambiente

ati

Giornata di Studio, UNIGE, 25/01/2024

UNIVERSITÀ POLITECNICA DELLE MARCHE

Energy Systems Group @ UNIVPM

					
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Research goals

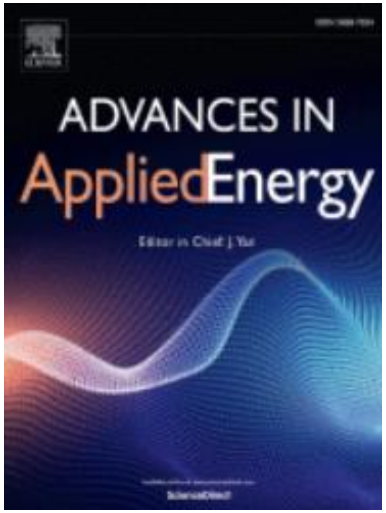
Main objectives:

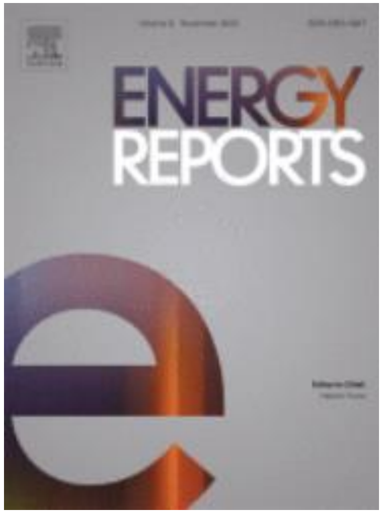
- How to use hydrogen as an energy vector to decarbonise energy systems
- How to manage both the hydrogen production and utilization technologies to be coupled with renewable sources to reduce grid instability
- How to use hydrogen in different scenarios, such as the blending within the national gas grid, and what are the main effects?

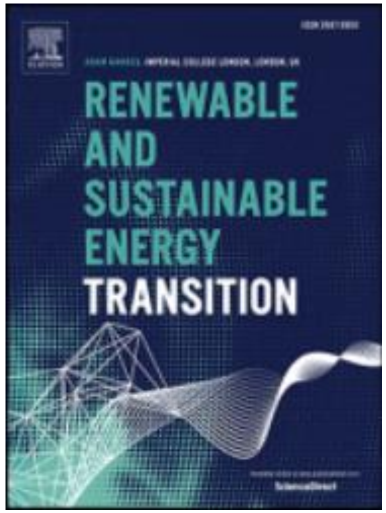
How do we do this?

Through the development of numerical models in the Python environment to resemble the behaviour of electrolysers and fuel cells to characterize the system without performing several experimental tests. This process is supported by optimisation environments, such as Calliope, to individuate the optimal working conditions.

Research activities on Hydrogen







Research activities on Hydrogen

The hydrogen research has started in 2015 in collaboration with the national research center (ENEA):

1. **Carlos Boigues Muñoz, Davide Pumiglia, Stephen J. McPhail, Dario Montinaro, Gabriele Comodi, Giulio Santori, Maurizio Carlini, Fabio Polonara,** More accurate macro-models of solid oxide fuel cells through electrochemical and microstructural parameter estimation – Part I: Experimentation, Journal of Power Sources, Volume 294, 2015, Pages 658-668,ISSN0378-7753, DOI: 10.1016/j.jpowsour.2015.06.118

→ The distributed relaxation times (DRT) method has been employed in order to deconvolute the electrochemical impedance spectroscopy (EIS) measurements carried out on a solid oxide fuel cell (SOFC). This allowed to built an equivalent circuit model (ECM) to be used for obtaining parameters which describe the microstructural and electrochemical properties of the SOFC.

2. **Carlos Boigues-Muñoz, Davide Pumiglia, Stephen J. McPhail, Giulio Santori, Dario Montinaro, Gabriele Comodi, Maurizio Carlini, Fabio Polonara,** More accurate macro-models of solid oxide fuel cells through electrochemical and microstructural parameter estimation – Part II: Parameter estimation, Journal of Power Sources, Volume 286, 2015, Pages 321-329, ISSN 0378-7753, DOI: 10.1016/j.jpowsour.2015.03.129

→ This work is the second part of the one previously described. The ECM obtained in the first part has been used to estimate the microstructural and electrochemical features of the SOFC cell. The resulting parameters have been used to generate an accurate CFD macro-model which has been then validated with experimental data.

Research activities on Hydrogen

3. Andrea Monforti Ferrario, Andrea Bartolini, Francisca Segura Manzano, Francisco José Vivas, Gabriele Comodi, Stephen John McPhail, José Manuel Andujar, A model-based parametric and optimal sizing of a battery/hydrogen storage of a real hybrid microgrid supplying a residential load: Towards island operation, Advances in Applied Energy, Volume 3, 2021, 100048, ISSN 2666-7924, DOI: 10.1016/j.adapen.2021.100048

In this study the optimal sizing of a hybrid battery/hydrogen Energy Storage System "ESS" has been assessed via a model-based parametric analysis in the context of a real hybrid renewable microgrid located in Huelva, Spain. Four storage configurations (battery-only, H2-only, hybrid battery priority and hybrid H2 priority) have been assessed under different Energy Management Strategies. Results showed that a hybridised ESS capacity is beneficial from an energy security and efficiency point of view but can represent a substantial additional total cost (between 100 and 300 k€) to the hybrid energy system, especially for the H2 ESS which presents higher costs.

Research activities on Hydrogen

4. Mario Lamagna, Andrea Monforti Ferrario, Davide Astiaso Garcia, Stephen Mcphail, Gabriele Comodi, Reversible solid oxide cell coupled to an offshore wind turbine as a poly-generation energy system for auxiliary backup generation and hydrogen production, Energy Reports, Volume 8, 2022, Pages 14259-14273, ISSN 2352-4847, DOI: [10.1016/j.egyr.2022.10.355](https://doi.org/10.1016/j.egyr.2022.10.355)

This work investigates the coupling of a reversible Solid Oxide Cell (rSOC) with an offshore wind turbine to evaluate the mutual benefits in terms of local energy management. This integrated system has been simulated with a dynamic model under a control algorithm which manages the rSOC operation in relation to the wind resource, implementing a local hydrogen storage with a double function: (i) assure power supply to the wind turbine auxiliary systems during power shortages, (ii) valorize the heat produced to cover the desalinization system needs. The results showed the compatibility between the auxiliary systems supply of a 2.3 MW wind turbine and a 120/21 kWe rSOC system which can cover the auxiliaries demand during wind shortages or maintenance. The total volume required by such a system occupy less than the 2%, if compared with the turbine tower volume.

Research activities on Hydrogen

This work has been carried out in collaboration with SNAM:

Lingkang Jin, Andrea Monforti Ferrario, Viviana Cigolotti, Gabriele Comodi, Evaluation of the impact of green hydrogen blending scenarios in the Italian gas network: Optimal design and dynamic simulation of operation strategies, Renewable and Sustainable Energy Transition, Volume 2, 2022, 100022, ISSN 2667-095X, DOI: 10.1016/j.rset.2022.100022

This work analyses the blending of hydrogen produced from PEM electrolysis coupled with Renewable Energy Sources (RES) in the existing Natural Gas network (NG). Different scenarios of green hydrogen blending (Blend Ratio BR equal to 5/10/15/20%vol) are analyzed at the national level with different temporal constraints (hour/day/week/month/year) based on real gas demand data in Italy. Higher BRs showed a rapidly increase in design requirements (1.3-1.5 GWe/%vol and 2.5-3 GWe/%vol for PEM electrolyzers and RES capacity, respectively) and a significative increase of the total gas mixture volume (0.83%/%vol) which hinders the CO2 reduction potential (0.37%/%vol). Moreover, the Levelized Cost Of Hydrogen (LCOH) has been preliminarily estimated at around 7.3 $/kg for yearly scenarios (best-case).

How does a numerical model work?

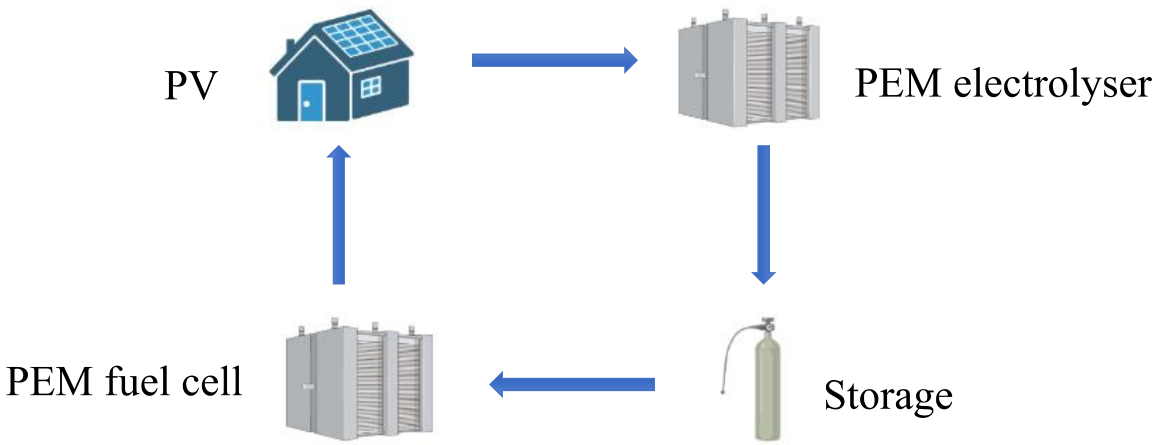
Input parameters →

- Operating parameters (e.g., cell temperature and pressure, electrolyte molarity and flow rate)
- Geometric parameters (e.g., number of cells, cell area, electrode and membrane thickness)
- Kinetic parameters (e.g., exchange current density, charge transfer coefficient, reference membrane conductivity)

Output →

- Polarisation and efficiency curve
- Temperature and pressure dependency
- Performance variations with geometric and kinetic parameters

Focus on the utilisation of hydrogen in the residential sector:



Francesca Mennilli, Lingkang Jin, Mosè Rossi, Alice Mugnini, and Gabriele Comodi, Energy analysis of a hydrogen integrated system in the residential sector, J. Phys.: Conf. Ser. 2648 012057, 2023, DOI: [10.1088/1742-6596/2648/1/012057](https://doi.org/10.1088/1742-6596/2648/1/012057)

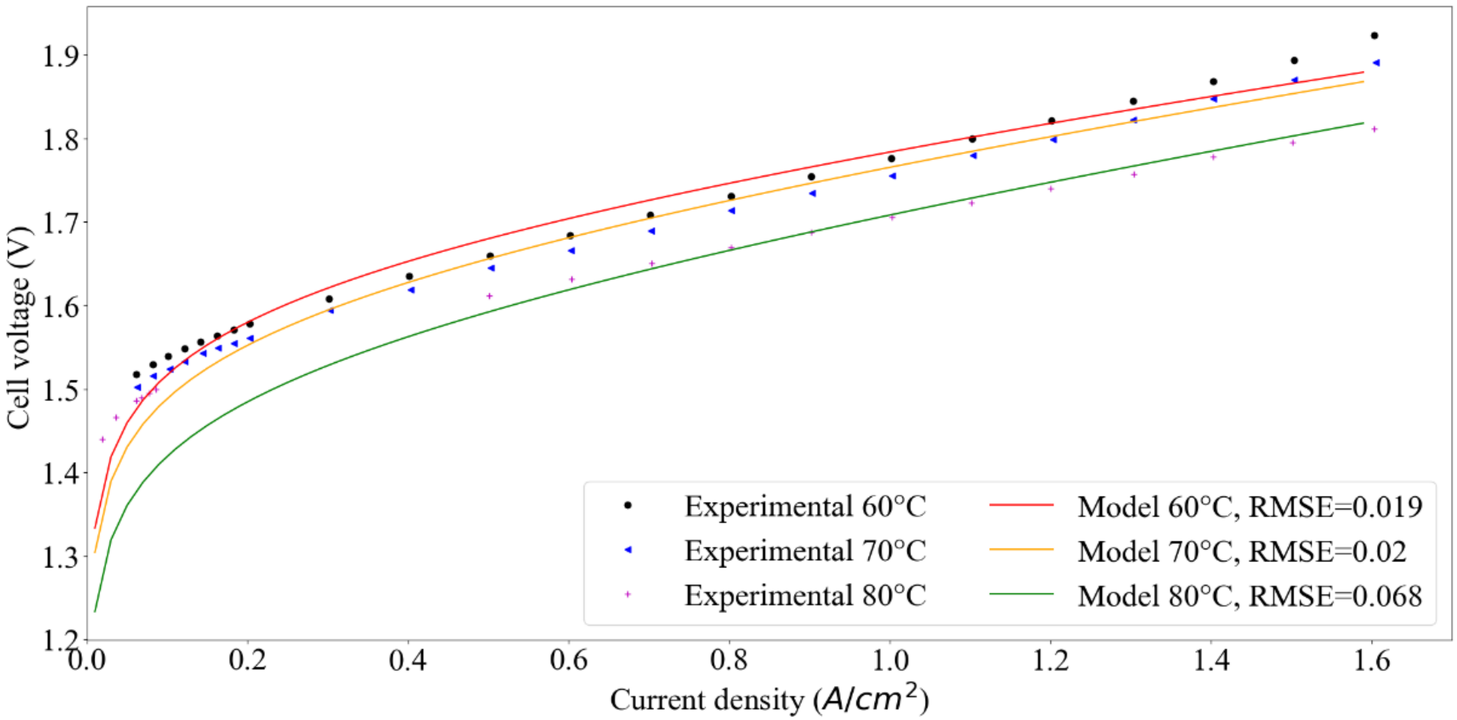
Research activities on Hydrogen

Integrated hydrogen system in the residential sector modeled with Python

PEM electrolyser model

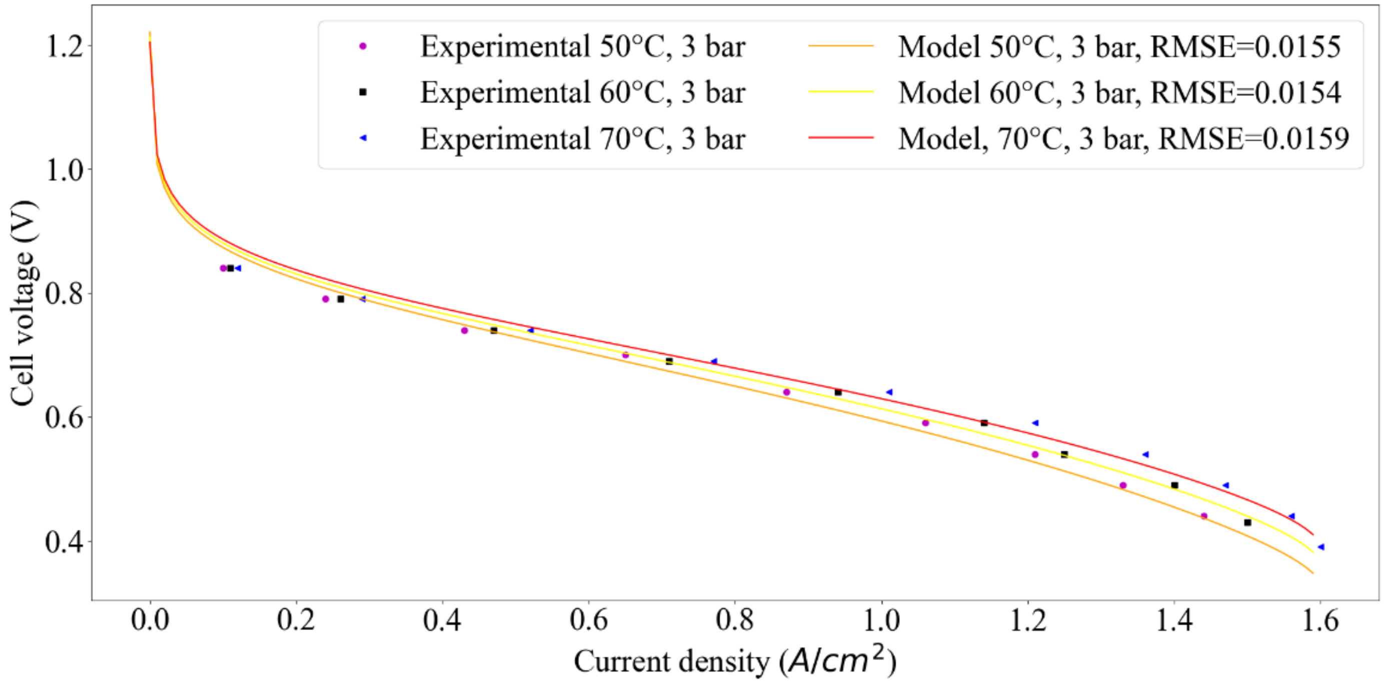
spyder

$$V = EOCV + Vact,c + Vact,a + Vohm$$



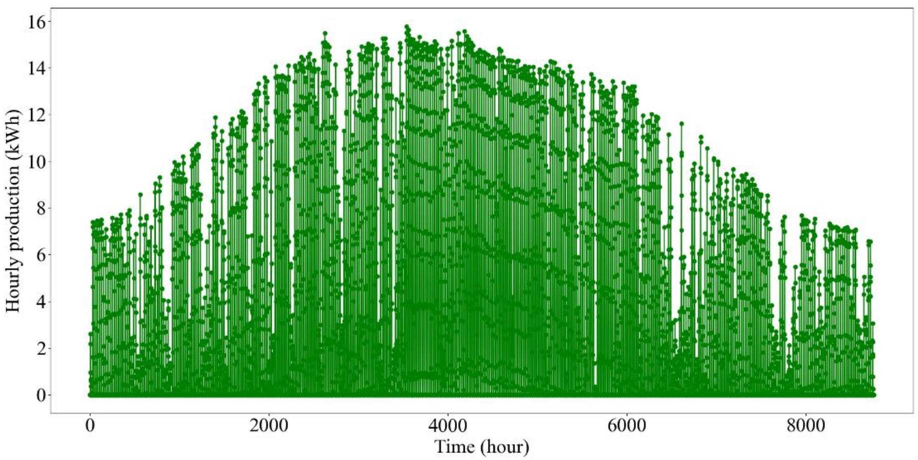
PEM fuel cell model

$$Vcell = E_{OCV} - Vact - Vohm - Vconc$$

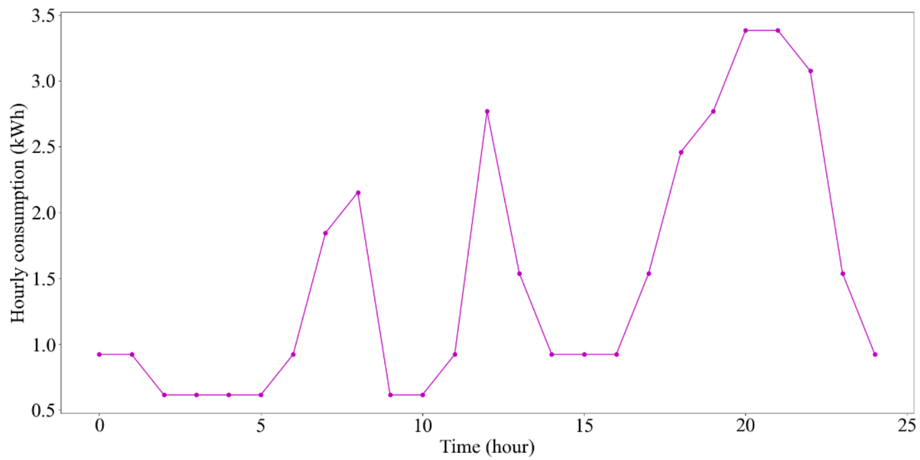


Research activities on Hydrogen

Integrated hydrogen system in the residential sector modeled with Python



Production peak of 15.8 kW on the 28/05

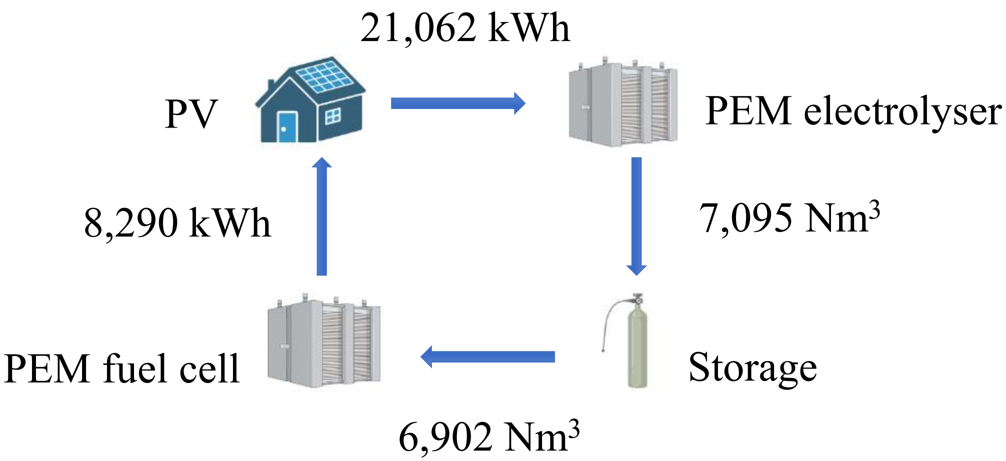


Daily consumption peak of 3.4 kW
Overall electric demand of 13,362 kWh

Data production and consumption were taken from the literature and elaborated with Python to be used as input of the hydrogen system model

Research activities on Hydrogen

Integrated hydrogen system in the residential sector modeled with Python

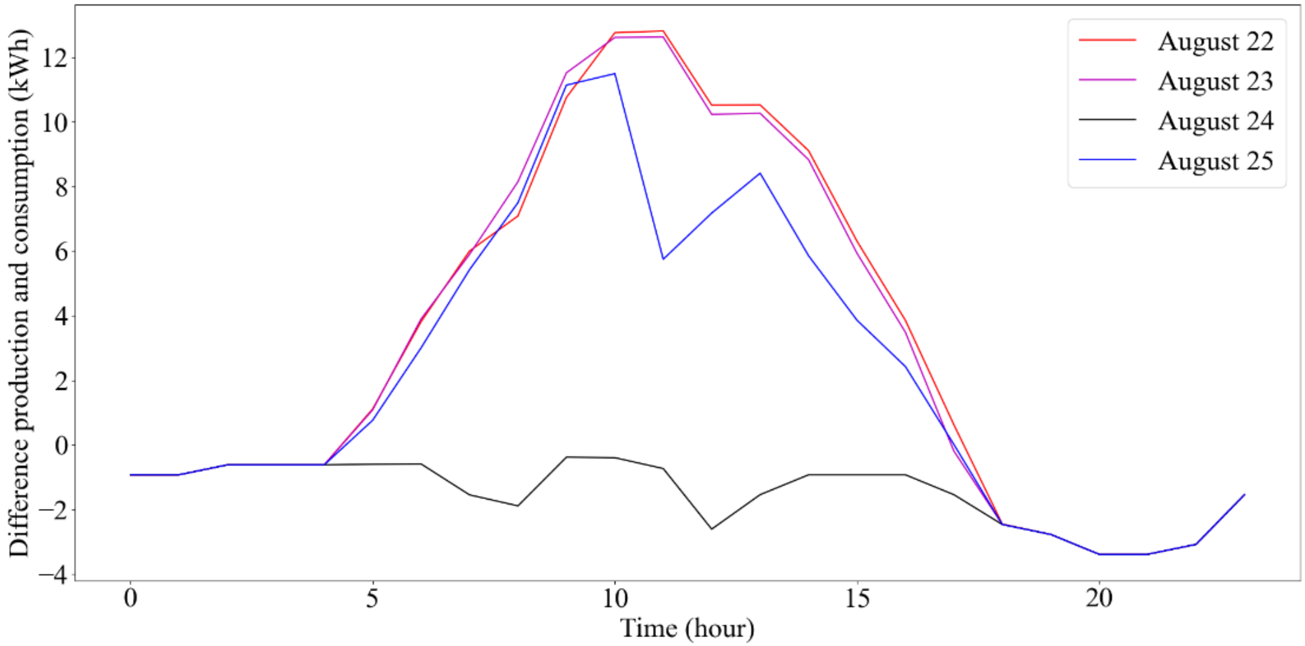


	PEM electrolyser	PEM fuel cell
Rated Power (kW)	13	3
Number of cells	200	200
Cell Area (cm^2)	42.6	25
Rated hydrogen Flow Rate (Nm^3/h)	5.66	2.83
Electric Efficiency	0.67-0.76	0.42-0.77
Current density (A/cm^2)	0.4-1.6	0-1.35
Cell potential (V)	1.65-1.88	0.5-0.9

Research activities on Hydrogen

Integrated hydrogen system in the residential sector modeled with Python

Main results:

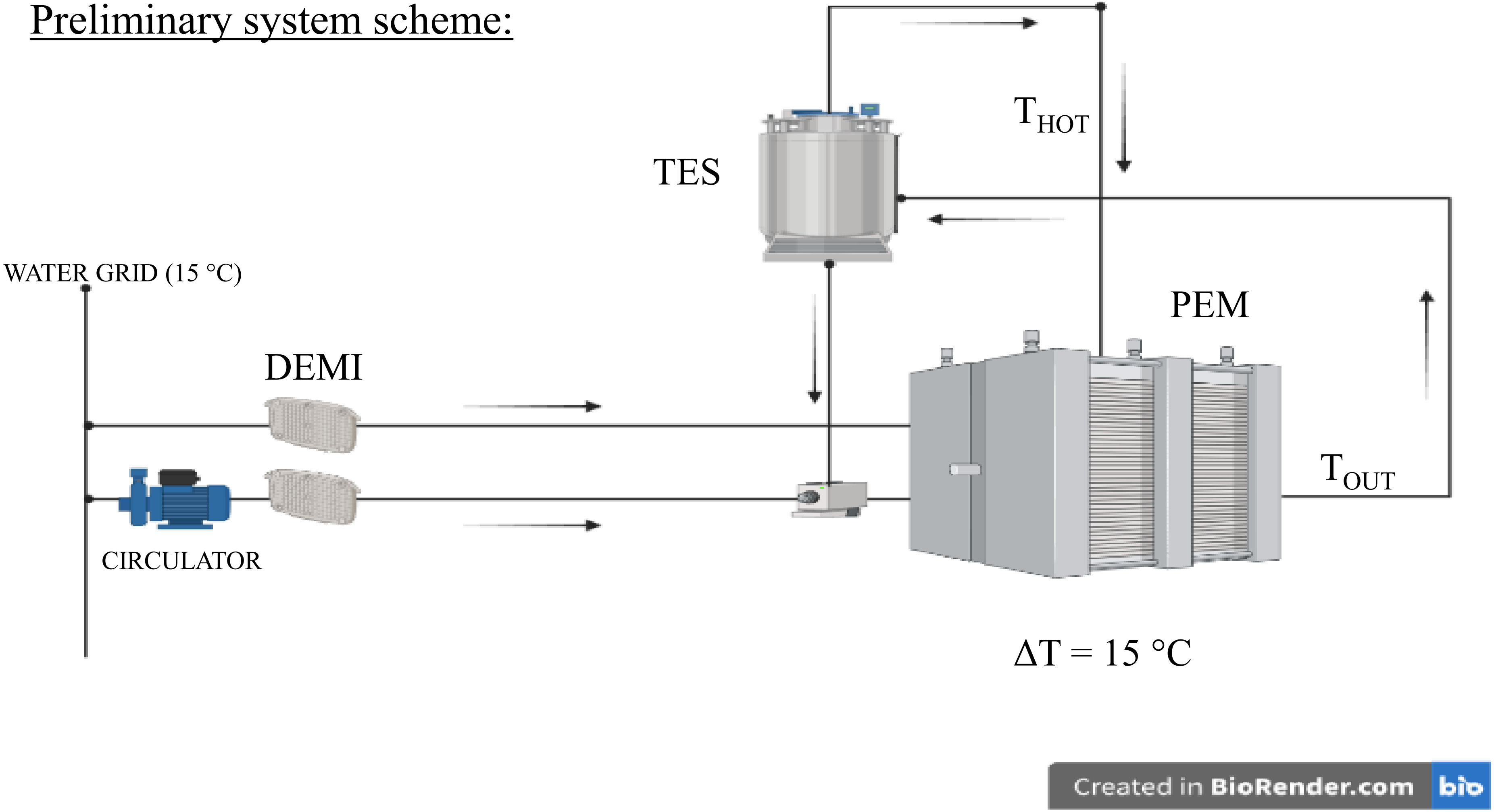


Energy self-sufficiency thanks to the hydrogen stored in the previous days

Research activities on Hydrogen

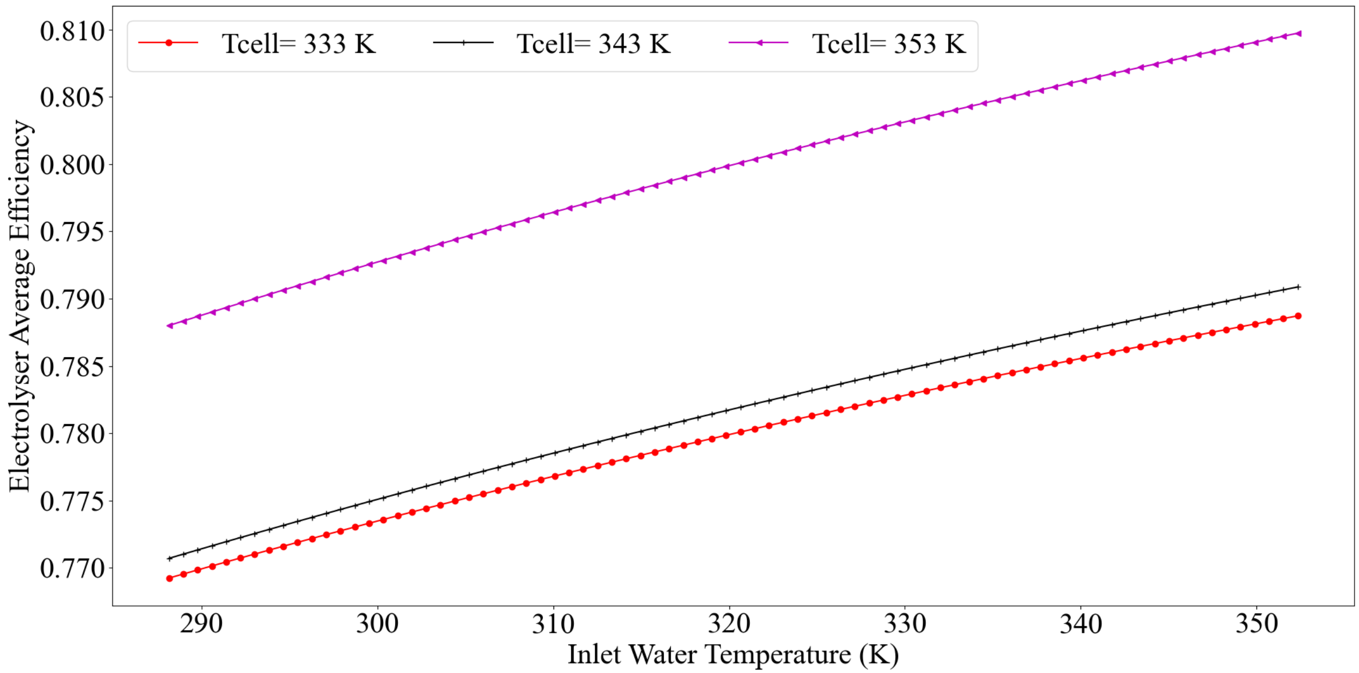
PEM electrolyser with water preheating

Preliminary system scheme:



Research activities on Hydrogen

PEM electrolyser with water preheating



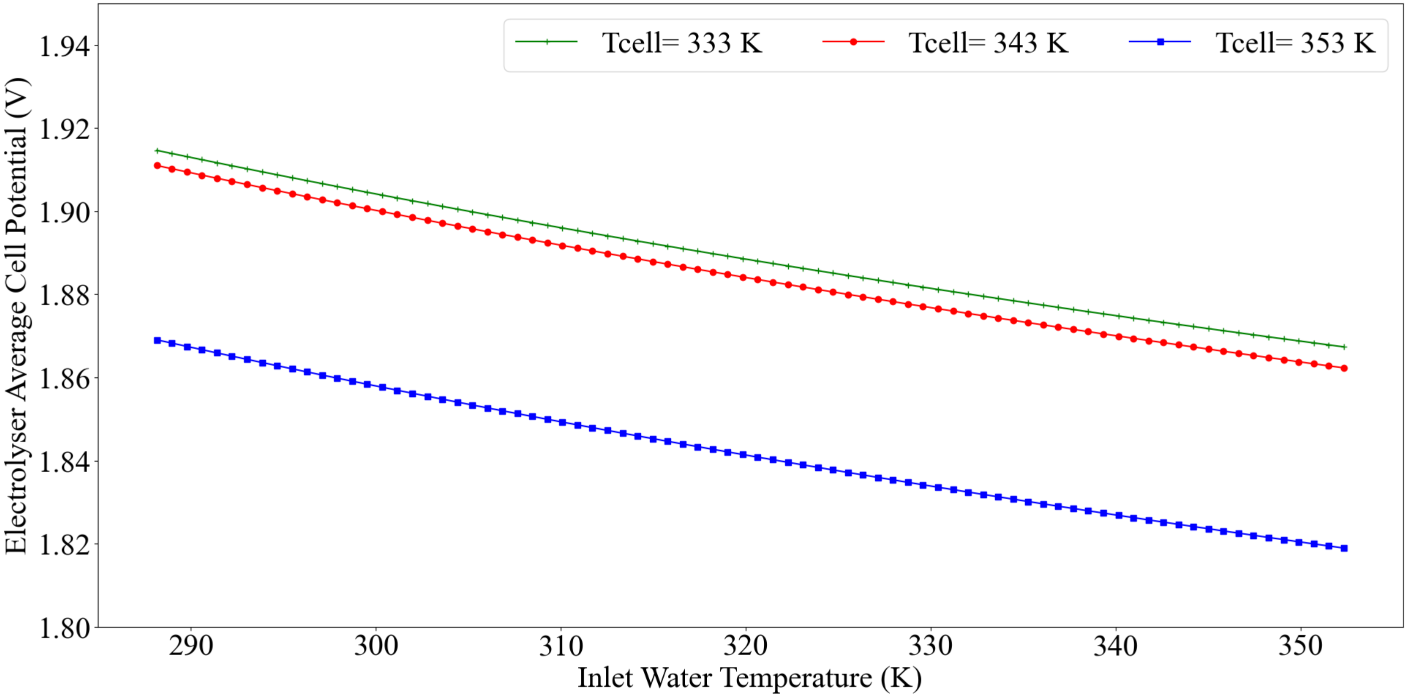
spyder

@ 333 K -> + 2%
@ 343 K -> + 2%
@ 353 K -> + 3%

As expected, there is an increase of the electrolyser efficiency due to a decrease of the electric power consumption which is due to a decrease of the cell losses

Research activities on Hydrogen

PEM electrolyser with water preheating

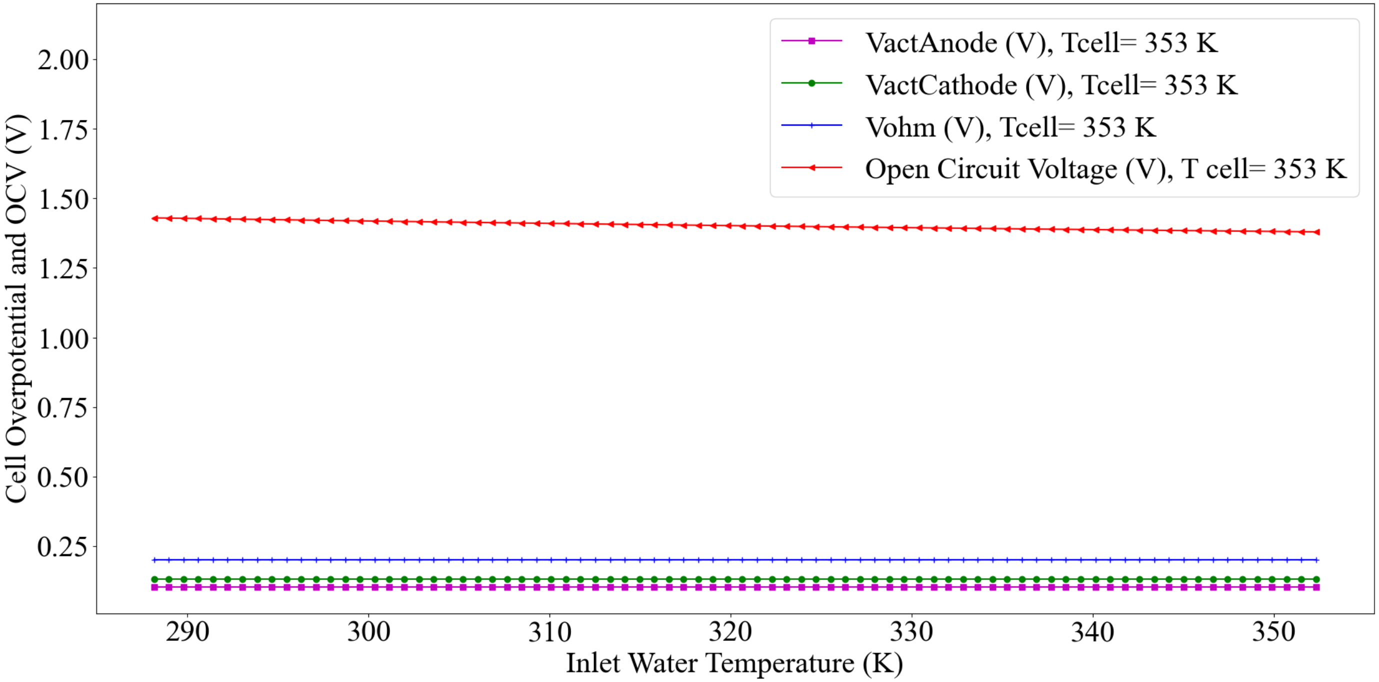


@ 333 K -> - 4%
@ 343 K -> - 5%
@ 353 K -> - 5%

Research activities on Hydrogen

PEM electrolyser with water preheating

spyder



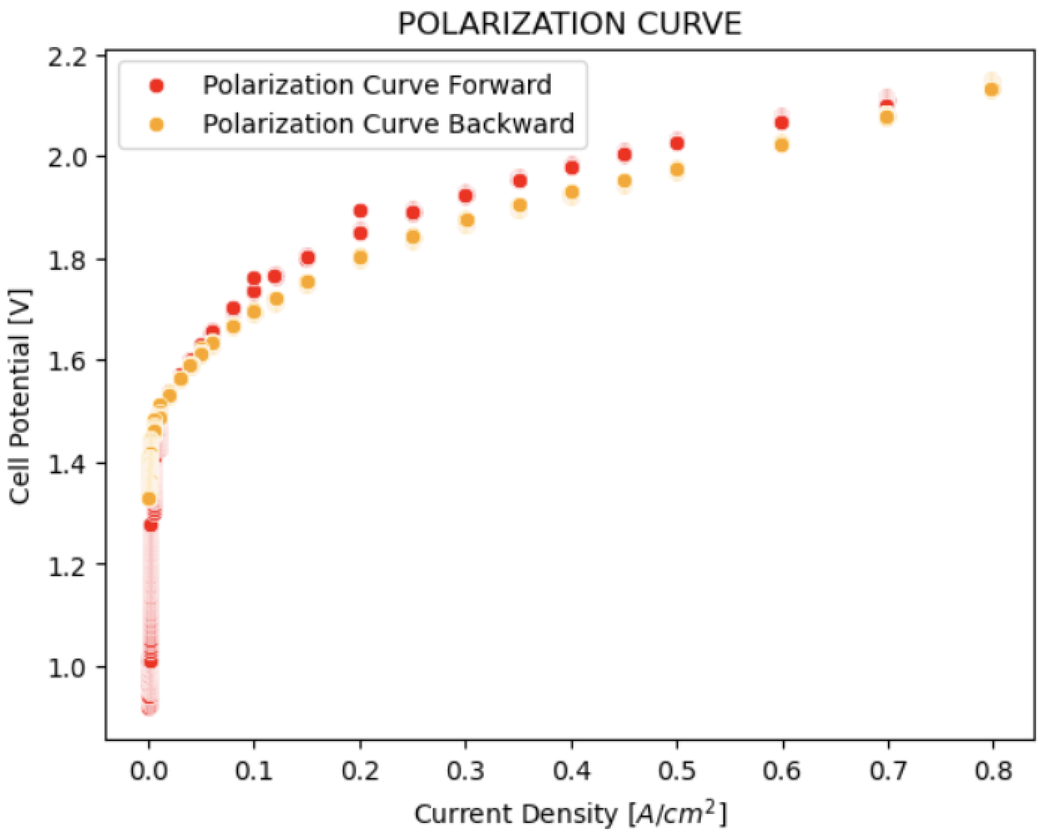
E_{OCV} -> - 5%

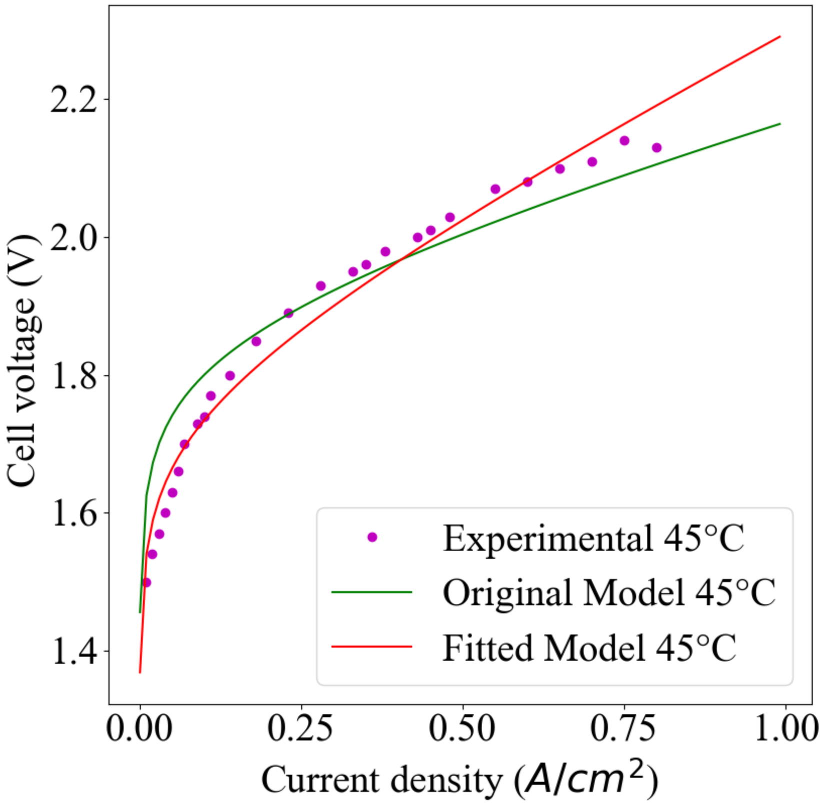
The increase of the inlet water temperature leads to the increase of the partial pressure of water vapour inside the cell, thus decreasing the hydrogen production and the oxygen partial pressure. As a consequence, the OCV decreases as well

Research activities on Hydrogen

AEM electrolyser modelling

Experimental data provided by an Italian company:





Application of a fitting process to obtain the kinetic coefficients (e.g., reference exchange current density and reference membrane conductivity) that are difficult to find in the scientific literature

Hydrogen integrated system @ DIISM

The models can be validated, for the alkaline (electrolyser) and PEM (fuel cell) technologies, through the hydrogen integrated system installed in our Department (DIISM)

ALKALINE ELECTROLYSER

RATED OPERATING CONDITIONS

- Rated power: 23 kW
- Rated hydrogen flow rate: 4 Nm^3/h
- Rated hydrogen pressure: 5 bar
- Purity of hydrogen produced: 99.3-99.5%
- Efficiency: $\eta = \frac{\dot{m}_{H2} \cdot LHV_{H2}}{Pel.} = 52\%$

$LHV_{H2} = 120$ MJ/kg

HYDROGEN PURIFIER

hydrogen produced purification from the impurities present (small quantities of oxygen and electrolyte liquid, water vapour)

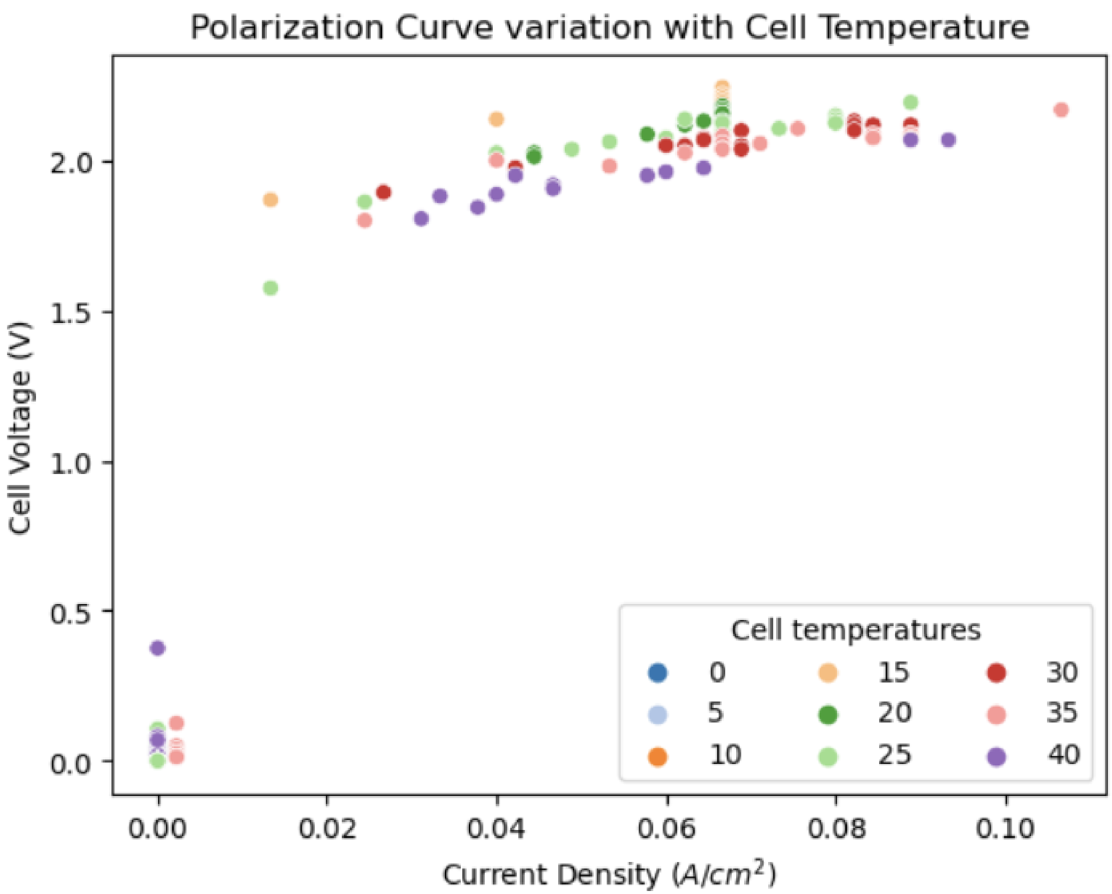
METAL HYDRIDES STORAGE SYSTEM

- Storage capacity: 3000 lt.
- Physical bulk: 5.8 lt.
- Weight: 22 kg
- Charge pressure: 5-12 bar

Hydrogen integrated system @ DIISM

PEM FUEL-CELL

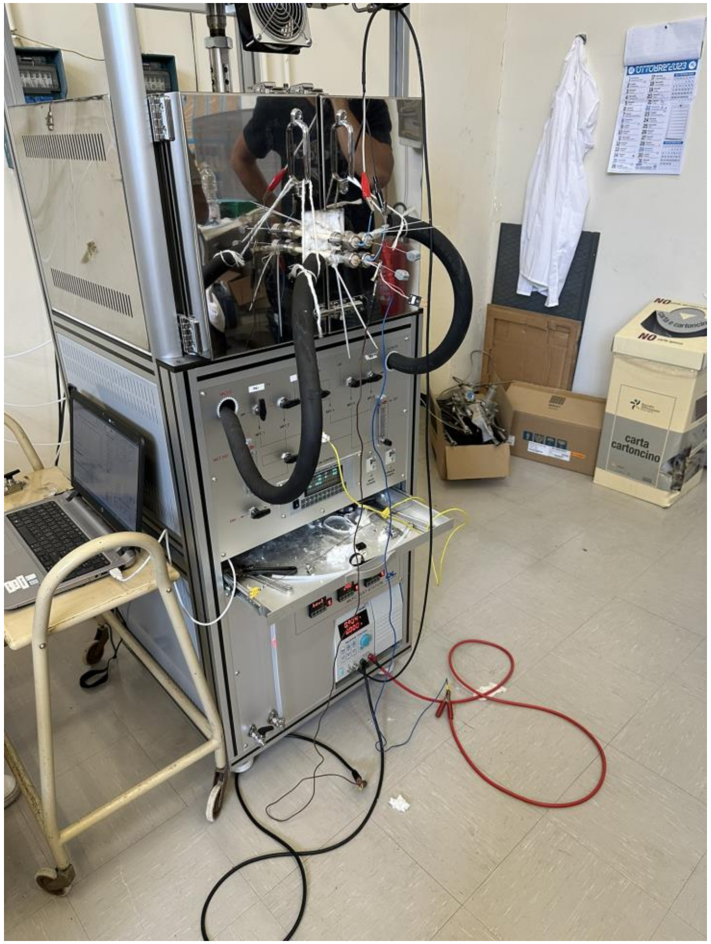
- Rated power: 1 kW
- Hydrogen inlet pressure: 0.55-0.75 bar
- Rated consumption: 0.78 Nm^3/kWh
- Start-up time: 2 min (at T_{env})
- Rated efficiency: 42%



Experimental data will be used to validate an alkaline electrolyser model customized for the system previously shown. This model will be used to analyse the electrolyser behaviour under different conditions of electrolyte flow rate, molarity and pressure. This allows to establish the optimal working conditions for the system.

Research activities on Hydrogen

rSOC systems modelling



ENEA Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

#1: Utilisation of rSOC systems in the residential sector

spyder

#2: Utilisation of rMCFC systems in the residential sector

UNIVPM involved in projects

eneuron

H2020 greEN Energy hUbs for local integRated energy cOmmunities optimizatioN

DOI: 10.3030/957779

Funded by EU

UNIVPM assignment € 212,800

2020 - 2024

Coordinated by ENEA

UNIVPM involved in projects

a novel GReen Energy Technology based on fuel cells, Hydrogen And renewables

INFO ON: https://hydronews.it/

Funded by EU

UNIVPM assignment € 236,809 through PNRR hydrogen

2023 - 2025

Coordinated by Graded S.p.A.

UNIVPM involved in projects

PC H2 R

Research Operative Plan on Hydrogen

INFO ON: https://www.enea.it/it

Funded by EU

UNIVPM assignment € 60,000 through PNRR hydrogen

2023 - 2025

Coordinated by ENEA

UNIVPM involved in projects

RdS
Elettrico Nazionale
<u>Hydrogen Technologies Integrated Project</u>

- **INFO ON:** https://www.enea.it/it
- Funded by MiTE — MINISTERO DELLA TRANSIZIONE ECOLOGICA
- **UNIVPM assignment** € 60,000
- 2023 - 2024
- Coordinated by ENEA

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"Study of power-to-power systems: hydrogen technologies modelling on Python and their technical improvement for integration in different scenarios"

THANKS FOR THE ATTENTION!
Q&A

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