CONFERENCE ABSTRACT

NETWORK FOR ENERGY SUSTAINABLE TRANSITION

THE MILLENNIUM CLEAN and SUSTAINABLE POWER workshop 2025

4-5 September 2025, Genoa

University of Genoa - Polytechnic School

Contributions were in the following topics:

- Agro-energy and bio-energy technologies and demo applications (NEST spoke 3)
- Hydrogen production and storage (NEST spoke 4)
- Hydrogen transportation and usage (NEST spoke 4)
- High performance fuel cell system concepts (NEST SPOKE 4)
- Electrical and Mechanical Energy storage (NEST spoke 5)
- Thermal Energy Storage (NEST spoke 5)
- High Temperature Heat Pumps (NEST SPOKE 5)
- Reversible power cycles and thermo-mechanical energy storage (NEST SPOKE 5)

Preface

We are pleased to share the abstracts from the conference 'THE MILLENNIUM CLEAN and SUSTAINABLE POWER workshop 2025'.

The conference provided a unique opportunity to discuss emerging technologies, applied research and sustainable energy transition. In line with the objectives of the NEST programme, the workshop will bring together experts, researchers, companies and stakeholders committed to building a decarbonised, efficient and resilient energy future.

"Fondazione NEST, with over €118 million in funding and 24 key partners, is committed to creating Italian leadership in the energy transition by uniting scientific excellence, technological innovation, and societal impact. The Millennium Clean and Sustainable Power Workshop 2025 reflects our conviction that sustainable energy transformation requires teamwork, partnerships, and international dialogue. The future of clean energy will be built on shared knowledge, collaboration, and the power of people."

Gabriella Scapicchio, General Manager of Fondazione NEST.

"It was with great pleasure that University of Genoa and the Thermochemical Power Group successfully hold the 2025 Low Emission Advanced Power cycle workshop (LEAP) inside "The Millennium Clean and Sustainable Power Workshop 2025", NEST project dissemination event.

The LEAP workshop, launched for the first time in June 2010 by University of Genoa (IT) and the National Energy Technology Lab (US), has always been the ideal place for academia and industry involved in the power cycle technology development to share ideas, perspectives, issues and opportunities in a highly-qualified scientifically-recognized environment, with the possibility of spontaneous presentation and speeches. This year, the synergy with the NEST event allowed to bring additional hydrogen-flavored interventions as well as members from different sectors to the workshop: in this respect, I would like to recognize the organizing efforts of NETL (US), DLR (D) and Politechnic of Milan (IT) for having contributed to chairing the LEAP sessions along the two-day workshop.

We trust that clean and affordable energy sources as well as innovative conversion technologies are key for a sustainable and peaceful future, for which we passionately work every day. "

Alberto Traverso**, **Università degli Studi di Genova - DIME

Summary

Click on the title to go to the relevant abstract page

- Techno-economic analysis of e-methane and e-methanol production from water electrolysis and CO2 capture in a waste incinerator
- Techno-economic analysis of renewable e-fuels powered by undispatchable RES
- Techno-economic assessment of a transcritical CO2 Carnot battery for long duration energy storage
- The potential of green hydrogen and applications in South America context: the Paraguay case
- Towards the Demonstration of Molten Salt TES: Development of Laboratory- and Pilot-Scale Unit

Back diffusion of OH^- ions during hydrogen production in half seawater electrolyzer

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Abstract. With the aim of reducing the environmental energy impact and making hydrogen production spreadable and sustainable, seawater is a promising alternative to the use of freshwater in electrolyzers, due to its higher availability (~97%) and because its direct use bypasses the costly processes of desalination and purification. To promote the oxygen evolution reaction (OER), while inhibiting the evolution of chlorine (CER) responsible for the anode corrosion, state-of-the-art technologies mainly use alkaline electrolytes such as KOH or NaOH, thus bypassing seawater utilization, or derivatize the latter adding those hydroxides to it. Combined in a configuration where seawater is employed at the cathode, it forms the so-called half seawater electrolyzer (half-SWE). Such setups, nevertheless, do not completely take advantage of the direct application of seawater, as can happen in a full seawater electrolyzer (full-SWE), hence restricting possible advantages in terms of resource sustainability and system simplification. Although half-SWE prevents anode corrosion, as well as promoting the OER, it also encourages the back diffusion of OH^- ions due to anode-cathode pH solutions difference. This phenomenon promotes progressive catholyte basification, which leads to insoluble salts precipitation (i.e. $Mg(OH)_2$ and $Ca(OH)_2$) that degrades catalyst surfaces and blocks ion transport pathways. This viewpoint tries to evaluate how membrane and catalyst selection affects ion transport, precipitation kinetics, and total cell performance by means of critical analysis of the function of OH^- back diffusion in half-SWE, by switching the alkaline anolyte with a neutral electrolyte composed of a $Fe^{3+/2+}$ redox couple. The redox couple, being governed by electron transfer process, is not able to generate pH variation, those acting as an ideal counter reaction to monitor pH variations coming from the cathode back diffusion of OH^- ions.

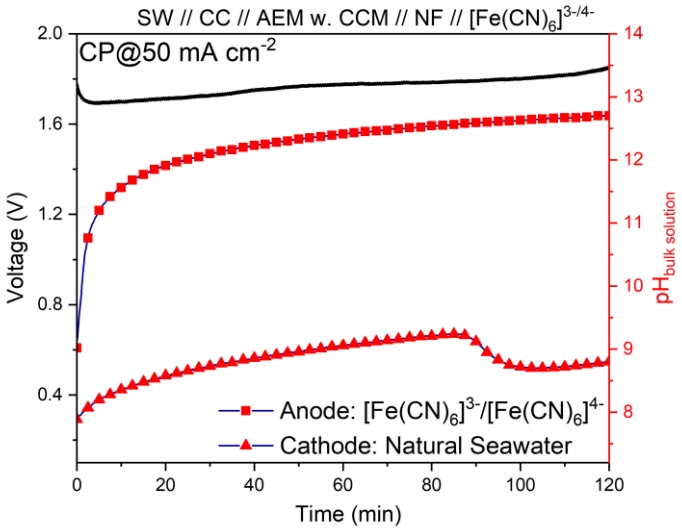

Fig. 1. Variation of pH solutions (red points, right axis) during chronoamperometry (black line, left axis) in a redox/seawater cell configuration (Cathode to Anode: Seawater (SW) / Carbon cloth (CC) / Anionic Exchange Membrane (AEM) with catalysts coated on membrane (CCM) / Nickel Foam (NF) / redox Ferrocyanide solution). The pH of the anodic solution increases in response to the transport of OH^- produced by the HER, while the seawater basifies over time, reaching an inflection point corresponding to the phenomenon of precipitation of insoluble salts.

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CFD modelling of H_2 enriched combustion in glass furnaces

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Abstract. The glass manufacturing industry is characterized by high energy consumption and environmental impact, largely due to the elevated temperatures required for melting raw materials, which result in significant pollutant emissions. In response to the EU's climate neutrality targets for 2050, the sector is moving toward cleaner and more efficient combustion technologies. This study develops a comprehensive Computational Fluid Dynamics (CFD) framework for simulating industrial glass furnaces, with a focus on diffusion flames fed by preheated air. The combustion process is modelled using the Eddy Dissipation Concept (EDC) and is fully coupled with the molten glass bath, allowing for a detailed analysis of heat transfer and fluid dynamics within both domains. Model validation is carried out against experimental data from the IFRF furnace in IJmuiden, a recognized benchmark in industrial combustion research.

The validated model is used to investigate the effects of hydrogen-enriched fuels relative to the baseline natural gas case, under the constraint of constant thermal input power. A comparison of the two cases reveals notable differences in flame structure. In the hydrogen-enriched scenario, the instabilities observed in the baseline case become more pronounced. The steady-state simulation identifies two primary flame patterns: initially, the right flame is stable, while the left one is distorted; later, the left flame becomes dominant, with the right flame becoming distorted. This alternating pattern indicates a cyclic, asymmetric flame behaviour, suggesting reduced combustion stability when hydrogen is added to the fuel mixture in this type of glass furnace. Additionally, the inclusion of hydrogen leads to clearly distinguishable changes in heat distribution and glass surface temperature, resulting in a more asymmetric pattern. Although hydrogen offers promising potential for emission reduction, its use poses challenges in maintaining stable combustion. To address these issues, specific stabilization strategies are proposed, particularly involving modifications to burner geometry (nozzle diameter) and adjustments to the air-fuel ratio, in order to achieve performance comparable to conventional natural gas operation.

Overall, the CFD methodology presented here provides a reliable and versatile tool for optimizing hybrid glass furnaces and supporting the industry's transition toward low-emission, high-efficiency production. This research supports the decarbonization of the glass industry, achieving a 30% reduction in CO_2 emissions, by providing validated numerical insights to guide future technological developments and industrial applications.

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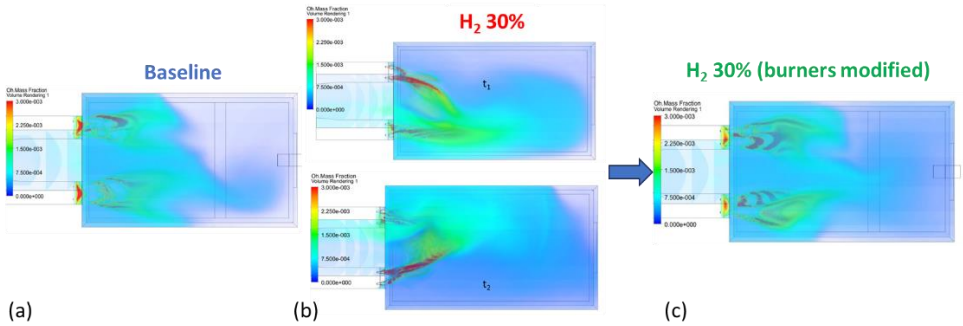

Fig. 1. Comparison of flame structures across different configurations: a) baseline with natural gas; b) H_2-enriched case; c) H_2-enriched case with modified burners.

CFD parametric analysis for optimization of a sorption-based thermochemical storage system designed for residential buildings

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Abstract. Heating and cooling (H&C) represent the largest share of energy demand and CO_2 emissions across Europe. Achieving full H&C electrification and decarbonisation requires maximizing renewable energy generation at the building level. To attain such objective, it is necessary to leverage thermal energy storage (TES) for various purposes: peak load shifting, long-duration renewable energy storage, and system flexibility improvement. Among TES technologies, thermochemical storage – particularly solid sorbent-based systems – offers significant potential for long-duration storage. However, despite the relative advantages of such technology, several challenges hinder its commercialization, including material properties selection, component's geometric configuration, and operating conditions. Experimental investigation of all these issues is usually limiting, time-consuming and costly. In contrast, computational fluid dynamics (CFD) simulations can be proven a cost-effective and accurate alternative, capable of providing insights across the entire component geometry. Therefore, this work presents a parametric analysis using 3D CFD simulations of a sorption-based thermochemical storage system designed for residential applications. The variables of this analysis are: the sorbent material properties (i.e., calcium chloride content, linear driving force constant, thermal conductivity) and the desorption/adsorption operating conditions. According to the numerical results, the accuracy of the mathematical model, as judged by the agreement between simulations and experimental data, is dependent on the selection of appropriate values regarding the material properties. However, the influence of each parameter on model accuracy is not identical for the two processes. Characteristically, in the adsorption phase, closer agreement with experimental measurements is generally achieved when the calcium-chloride content is lower or the thermal conductivity is higher. In contrast, during desorption the effect of thermal conductivity is minor, while reducing the calcium-chloride content tends to worsen the model's accuracy. Furthermore, combining suitable operating conditions with well-chosen material properties can yield high process efficiency together with smoother temperature and pressure gradients. More specifically, a similar material with ~17% reduced calcium chloride content, 50% larger diameter size and different expression in the equilibrium uptake is possible to ensure the same thermal efficiency with smoother temperature and pressure gradients, provided the operating conditions are optimized. The simulation results provide critical conclusions regarding the operability, efficiency, and performance of the component, enabling the determination of suitable combinations of material properties, geometry, and operating conditions that optimize the techno-economic performance of the component.

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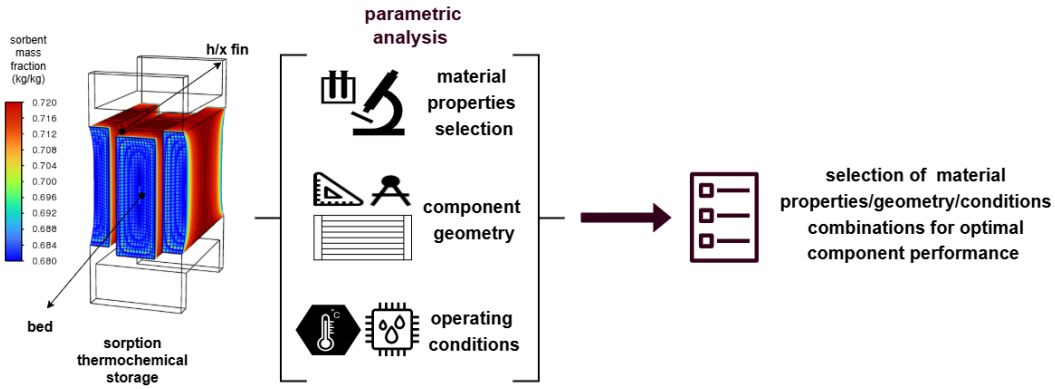

Fig. 1. Overview of the performed CFD parametric analysis for sorption component and process optimization

Characterization and Performance Assessment of Short Anion Exchange Membrane Electrolyzer Stacks

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Abstract. As part of the EU's strategy to net-zero emissions by 2050, anion exchange membrane water electrolysis (AEM) represents an emerging and promising technology because it allows to combine the low costs of alkaline electrolysis, potentially employing non-precious metals or earth-abundant elements as catalysts, with the high power and flexibility of PEM electrolysers, potentially reaching higher energy efficiency, greater hydrogen production rate, and more compact design. In any case, the use of electrocatalysts is necessary because the complex and multiphase electrochemical reactions occurring in the electrolytic cell make the electron transfer rates between the metal electrodes and the species in solution very slow. This is particularly true at the anode side where the oxygen evolution reaction (OER) involves the transfer of four electron per O_2 molecule resulting in sluggish kinetics and high voltage losses. The present work assessed and compared the performances of different anode catalysts based on non-Platinum Group Metals like Ni, Fe and Co. The analysis was conducted at stack level in terms of voltage as a function of current density (polarisation curves) under constant operating conditions. A number of short AEM stacks were assembled and integrated into a full electrolyser test bench, including balance-of-plant components (e.g., pumps, gas separators, controls, etc.). This approach permitted us to evaluate the overall functionality of the system and display phenomena being often hidden in MEA or single-cell analysis.

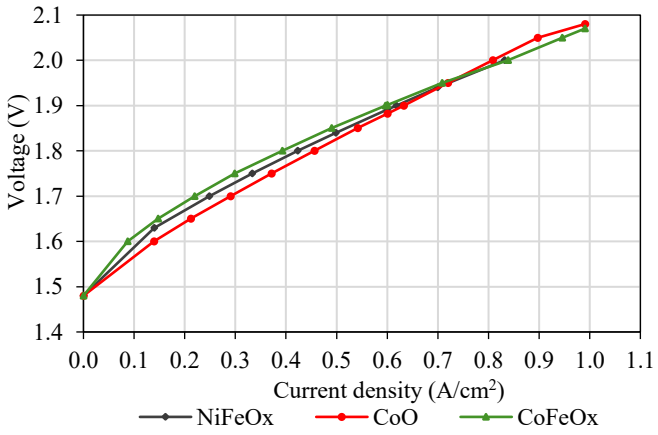

Fig. 1. Performance comparison of AEM stacks provided with different anode catalysts

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Characterization of fluids for energy transition

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Abstract. The energy transition strategy implies several actions for the reduction of the greenhouse gas emissions in the power, industrial, transportation and residential sectors. Particular attention is given to the energy conversion and industrial sectors as they account for more than 40% of the overall CO_2 emissions. The COFFEE project (Characterization of Fluids for Energy Transition) aims primarily to identify and experimentally characterize innovative working fluids, either pure fluids or mixtures, suitable for both direct and reverse cycles. These fluids must be capable of operating at the thermal levels required by the application (power cycles at 500-550 °C or large heat pumps at 150-200 °C) and enhancing the performance of the investigated thermodynamic cycles. The innovative fluids have been identified through detailed modelling of the closed power cycle validated through an experimental campaign, following the methodology highlighted in Fig.1. The thermal stability test set the maximum operating temperature at which the fluids can operate without chemical decomposition, while Vapor-Liquid Equilibrium test is needed to identify the interaction between the chemical species in a binary mixture. The thermodynamic efficiency of various power cycle layouts with the selected potential working fluid is then evaluated with a process simulation tool software: various cycle layouts are considered for each potential fluid, in order to match the variable-temperature heat source and heat sink with a rather simple and efficient power block.

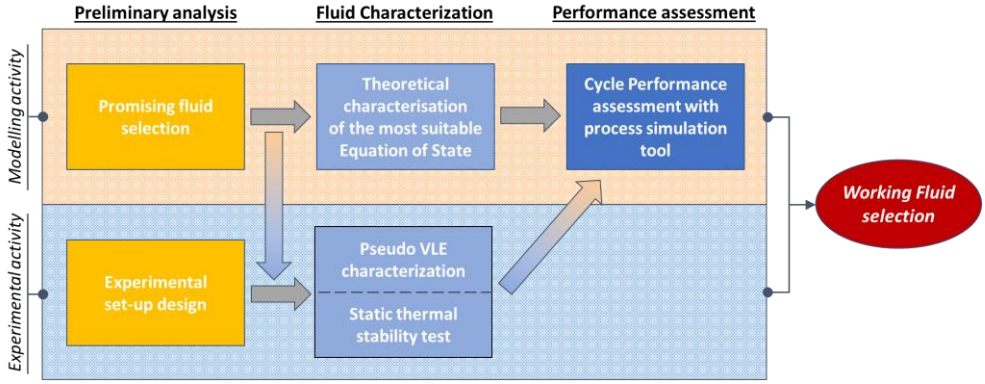

Fig. 1. Innovative fluid selection methodology

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Design, Synthesis and Characterization of Fluorinated Metal-Organic Frameworks as Potential Candidates for Gas Adsorption

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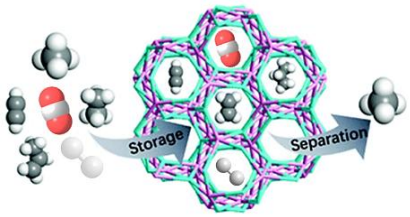
Abstract. Metal-organic frameworks (MOFs) are a diverse class of porous crystalline materials formed by the self-assembly of metal ions or clusters with organic linkers. Due to their exceptional tunability, high surface area, and structural diversity make MOFs attractive for selective gas separation and energy storage. However, many MOFs suffer from limited structural stability and competitive adsorption of gases, which can hinder their practical uses. The incorporation of fluorine atoms—owing to their high electronegativity, low polarizability and strong C–F bonds—imparts outstanding chemical and thermal stability to the framework. This modification also creates a unique electronic environment that improves gas adsorption properties for molecules such as H_2, CO_2 and CH_4, making fluorinated MOFs (F-MOFs) excellent candidates for advanced gas storage and energy applications.

This study focuses on the synthesis of novel F-MOFs using partially fluorinated organic ligands coordinated with transition metal centers. The synthesis employs straightforward methodologies under ambient conditions, facilitating scalability and reproducibility. Single-crystal X-ray diffraction (SCXRD) analysis confirms the formation of robust 3D frameworks with well-defined pores. The resulting F-MOFs exhibit remarkable stability in common organic solvents and water. The synergy of enhanced stability and tunable porosity in these materials offers significant potential for gas storage, particularly hydrogen and carbon dioxide capture, supporting future sustainable energy and environmental solutions.



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[2] W. Fan, X. Liu, X. Wang, Y. Li, C. Xing, Y. Wang, W. Guo, L. Zhang, D. Sun, *Inorg. Chem. Front.* **2018**, *5*, 2445.

Acknowledgements

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Evaluation of water-energy-food intensity for e-fuels and green fertilizers synthesis in South Africa

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Abstract. Africa has a very good potential for green hydrogen synthesis by water electrolysis, thanks to the high solar and wind potential. Green hydrogen can be then converted into green ammonia, which can be used for fertilizers synthesis, allowing for an increase in terms of food production by agriculture. However, electrolysis has also an impact in terms of pure water, whereas many African Countries suffer from persistent water insecurity. Moreover, the whole plant requires a significant area, which can be translated in a loss in terms of food production. This study aims to perform a techno-economic analysis and Water-Energy-Food (WEF) impact evaluation of multiple-use co-located systems for both electrical energy and fertilizers by green ammonia considering PV solar panels in South Africa. The socio-geographic context guarantees a high solar potential, but implies also to operate in an already fragile scenario, characterized by water scarcity and limited electrification.
The analysis is performed assuming a commercial PEM electrolyser (1 MW, operating at 30 bar): the produced hydrogen is compressed, mixed with nitrogen in tanks and sent to a reactor for ammonia synthesis. The analysis is performed on time-dependent basis on one year, and the integration with a battery as electrical energy storage, to avoid frequent power-to-ammonia system shutdowns, is considered. A techno-economic feasibility analysis of the solution for the synthesis of green fertilizers is carried out and the optimal installed PV (and batteries) size was determined to minimize the Levelized Cost of Ammonia (LCOA). Then, the water-energy-food nexus is evaluated considering both the water intensity and the required area (not available for agriculture purpose) for the proposed solution.

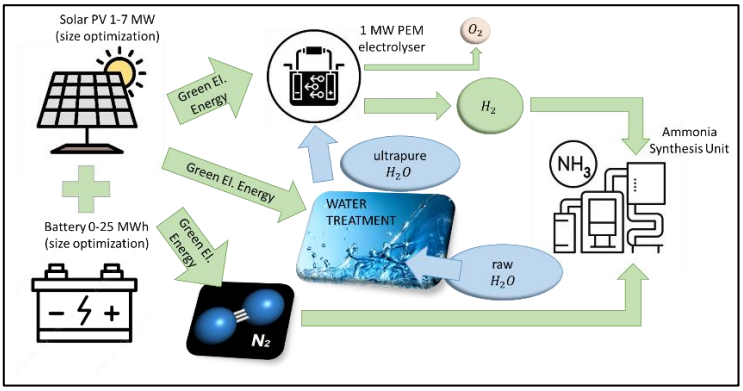

Fig. 1. Simplified plant layout for green ammonia in Africa scenario

Exploring A Single Cell of Anion Exchange Membrane Water Electrolyzer

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Abstract. Electrolyzers convert water into hydrogen and oxygen using electricity, and when powered by renewable energy sources such as solar or wind, the produced hydrogen is termed "green," offering a promising pathway toward decarbonization and a sustainable future. Low-temperature anion exchange membrane (AEM) electrolyzer is a promising technology that employs a hydroxide-conducting membrane as the core component. The membrane not only facilitates selective ion transport but also ensures gas separation for safe and efficient operation. AEM electrolyzers utilize cost-effective nickel-based electrodes and operate in a mildly alkaline environment, making them safer and more economical compared to proton exchange membrane systems. Key components include bipolar plates and porous transport layers that support electrical conduction and fluid distribution. Challenges remain in improving membrane durability, conductivity, and scaling up the technology, as well as in developing non-noble metal electrocatalysts for the oxygen evolution reaction optimized for industrial application. We focus on an overview of the AEM electrolyzer cell design, operation principles, advantages, and current research challenges. We adopt a systematic process that includes compression testing with Fujifilm and conductivity measurements. Protocols are optimised for I–V curves, EIS, durability tests, and mass analysis of the output gases.

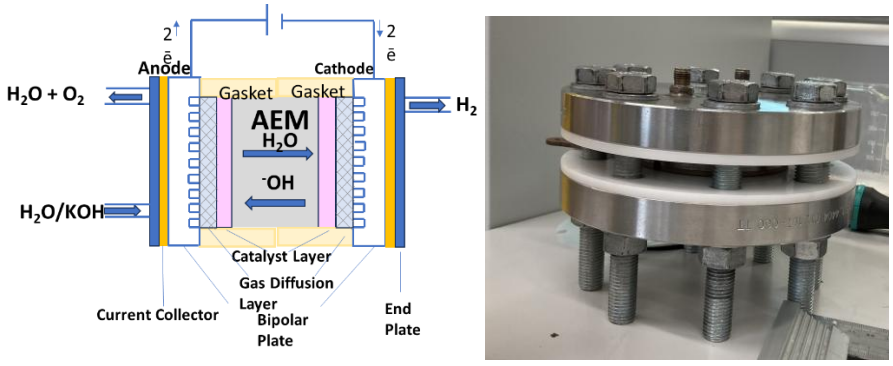

Fig. 1. Schematic (left) and actual (right) single cell for AEMWE.

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Exploring the potential use of metal hydrides as separation unit for Natural Gas/Hydrogen blends

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Abstract. The potential future injection of hydrogen into national natural gas grids calls for efficient (from a cost and energy point of view) separation technologies to recover high-purity hydrogen for end-use applications. This work explores the potential of metal hydrides as a selective separation tool for hydrogen from NG/H_2 blends. Metal hydrides (MH) offer reversible absorption-desorption behavior, enabling selective hydrogen capture based on thermodynamic properties under mild conditions. We present a techno-thermodynamic analysis of candidate hydride materials, focusing on equilibrium pressures, kinetics, and selectivity in typical pipeline conditions (3.5–40 bar, 5–40 °C). Scientific literature shows that tailored hydride systems can achieve high hydrogen recovery efficiency while excluding methane. This approach may serve as a compact, modular, and energy-efficient alternative to conventional membrane or PSA systems for decentralized hydrogen separation, as cheaper and less energy intensive. In this paper, the possibility to install a commercial AB5 MH hydrogen separation unit will be evaluated to be installed in a real decompression unit of Natural Gas Pipelines from National transmission line (40 bar) to urban distribution one (3,5 bar) also looking at potential exploitation of local waste cold for the proper thermal management of MH.

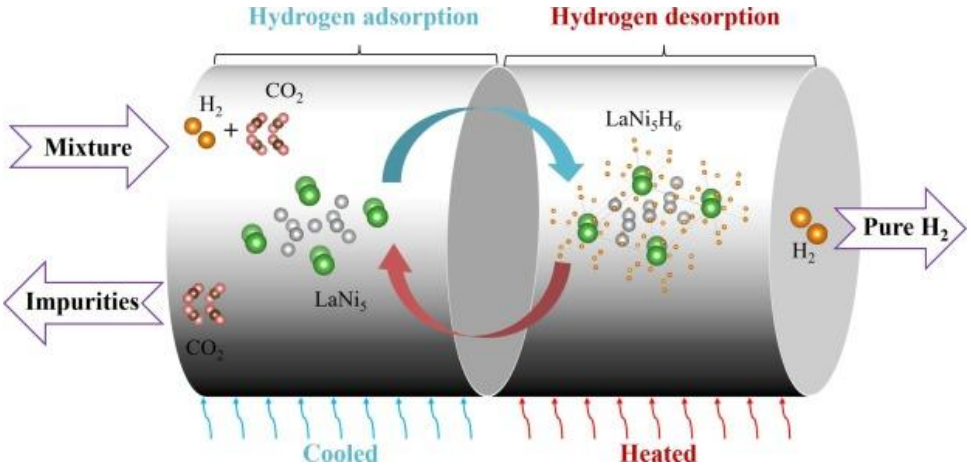

Fig. 1. Potential use of LaNi5 powders as hydrogen separation solution[*]

[*] *L.Guo et al., Efficient hydrogen recovery and purification from industrial waste hydrogen to high-purity hydrogen based on metal hydride powder, Chemical Engineering Journal, Volume 455, 2023, https://doi.org/10.1016/j.cej.2022.140689*

Faults and degradation simulation on a PEMFC 4 kW stack

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Abstract. Polymeric Electrolyte Membrane Fuel Cells (PEMFCs) have garnered significant attention as a zero-emission technology for electrical power generation. Despite their potential, widespread adoption remains limited due to performance degradation over time, which shortens their operational lifespan compared to conventional systems.

This study investigates common faults and degradation mechanisms in a 4 kW air-cooled PEMFC stack using a MATLAB®/Simulink® model. The focus is on evaluating the impact of various faults on membrane hydration and voltage losses across a range of operating currents.

Simulations include ±20% variations in the air-cooling flow rates and a 30% reduction in cathode-side humidity. Results show that reductions in the air-cooling flow and cathode-side humidity notably decrease membrane water content, especially at low currents, thereby increasing ohmic losses. Additionally, the variations in air-cooling flow rates affect concentration losses by altering water accumulation in the gas diffusion layer and shifting membrane water transport between the anode and cathode.

The study also explores performance degradation by simulating a 30% reduction in the cell's active area relative to its beginning of life state. Voltage losses across the current range are assessed, along with the increased cooling demand required to maintain optimal cell temperature. Results indicate a voltage drop ranging from −2.97% to −22.6%, accompanied by an increase in required air coolant mass flow rate from +23.85% at minimum current to +103.41% at maximum current.

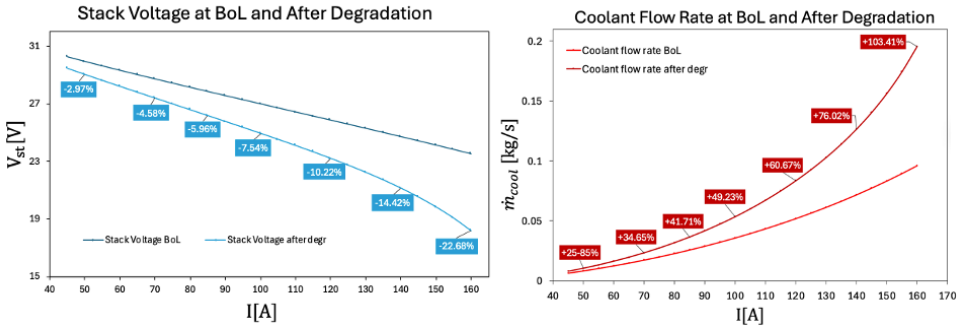

Fig. 1. BoL and after degradation comparison. Figures display the voltage drop (right) and the required coolant mass flow rate increase (left) after degradation.

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Fuel comparison for maritime Molten Carbonate Fuel Cell-integrated CO_2 capture systems

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Abstract. The decarbonization of maritime transport is a key challenge in the global effort to mitigate climate change, especially in light of the sector's substantial contribution to anthropogenic CO_2 emissions. With limited access to zero-carbon propulsion options and a strong dependency on carbon-intensive fuels, shipping remains a difficult sector to decarbonize. In this context, integrating carbon capture technologies directly on board offers a viable mid-term solution to reduce emissions without requiring radical changes to ship propulsion systems. Among the available technologies, Molten Carbonate Fuel Cells (MCFCs) have shown significant potential for onboard Carbon Capture and Storage (CCS) thanks to their ability to simultaneously generate power and separate CO_2 from exhaust gases. Their modularity and tolerance to low CO_2 concentrations make them suitable for marine applications and retrofitting on existing vessels. This study investigates a novel process layout aimed at enhancing the overall CO_2 capture rate. A core aspect of the analysis is the comparative evaluation of different marine fuels, including Liquefied Natural Gas (LNG), bioLNG, methanol, biomethanol, grey ammonia and green ammonia. Among these, bio-LNG and biomethanol stand out for achieving over 85% emission reduction with low energy demand, while methanol provides a favorable balance between performance and cost (down to 27 USD/ton CO_2). Green ammonia offers advantages in reducing storage volume, but, like other biofuels, it remains economically challenging at present. The results provide a comprehensive overview of the trade-offs associated with each fuel in terms of environmental performance and system integration

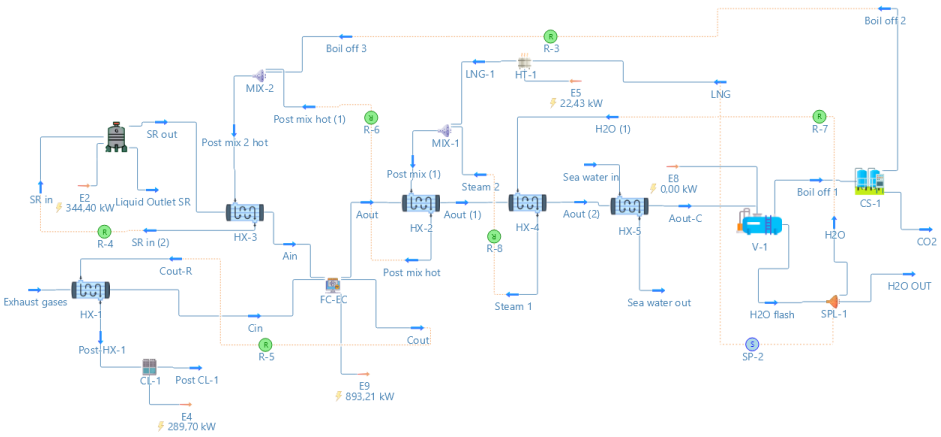

Fig. 1. Simulation scheme of the MCFC-based onboard carbon capture system.

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Hydrogen production through thermal degradation of confined ammonia borane

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Abstract. The development of highly efficient materials for chemical hydrogen storage is one of the great challenges for driving the hydrogen economy to a major breakthrough as show in figure 1. The safety of hydrogen tanks and the energy required for compression to high pressure have drastically slowed down the spread of the hydrogen-based mobility. Several alternatives have been proposed to overcome these problems using inorganic or organic carriers. Among all the available species, ammonia borane (AB) is one of the most interesting compounds with a theoretical gravimetric hydrogen storage capacity of up to 19.6 wt % [1]. The most challenging and attractive AB dehydrogenation route is the solid state thermal-induced dehydrogenation. Nevertheless, this reaction is complex, involves several pathways and mechanisms that could be promoted or suppressed by the presence of additives. The solid-state dehydrogenation kinetic of AB under thermal stimuli is widely investigated by directly mixing AB with dehydrogenation catalysts [2] or by confinement into a porous matrix [3].
Nevertheless, an interesting process to tune the AB systems is the preparation on an unstable confined AB with a tuned the degradative pathways by adding a chemical species such as high boiling point amine. In our work, we proposed a new route to modify the thermochemical behaviour of AB by solid state encapsuling in tailored polymeric matrix and by formulating AB mixture with high boiling point amines. We diffusely studied these systems using TGA-IR, DSC and IR and Raman spectroscopy producing a solid interpretation based on kinetic and thermodynamic parameters of the chemical pathways reporting a hydrogen storage capability up to 10 wt.%.
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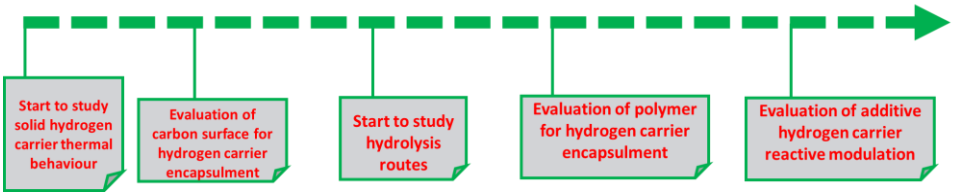

Figure 1: Wok flaw for the development of hydrogen storage systems based on AB

HyStoVal - Hydride-based hydrogen Storage Value chain

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Abstract. Hydrogen is conventionally stored in high-pressure cylinders or as a cryogenic liquid, both of which present economic and safety limitations. Solid-state hydrogen storage in metal hydrides offers a safer and potentially more efficient alternative, thanks to their high gravimetric and volumetric capacities and favourable thermodynamics. The HyStoVal project aims to develop a complete value chain for the implementation of hydride-based hydrogen storage systems.
An alloy powder supplied by Fabit Enertech was characterized using Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), and other techniques. The as-received powder consisted of plate-like particles with a LaNi5-type crystalline structure. Ball milling significantly reduced particle size and increased microstrain, without altering the equilibrium pressures for hydrogen absorption and desorption. Activation was successfully achieved at mild conditions (18–40 °C) with repeated cycling, eliminating the need for extreme pressure or temperature treatments.
To enhance material handling and thermal management, composites were prepared by incorporating the metal powder into SAN (Styrene-acrylonitrile) and ABS (Acrylonitrile butadiene styrene) polymers, followed by cold pressing into pellets (Figure 1). Structural analyses (SEM, XRD, DSC, ATR-FTIR) confirmed that polymer addition did not affect the crystallinity or chemical stability of either component. Hydrogen storage capacity and equilibrium pressures remained unchanged, indicating that polymer blending has no detrimental effect on sorption behaviour. However, some sample inhomogeneity was observed.

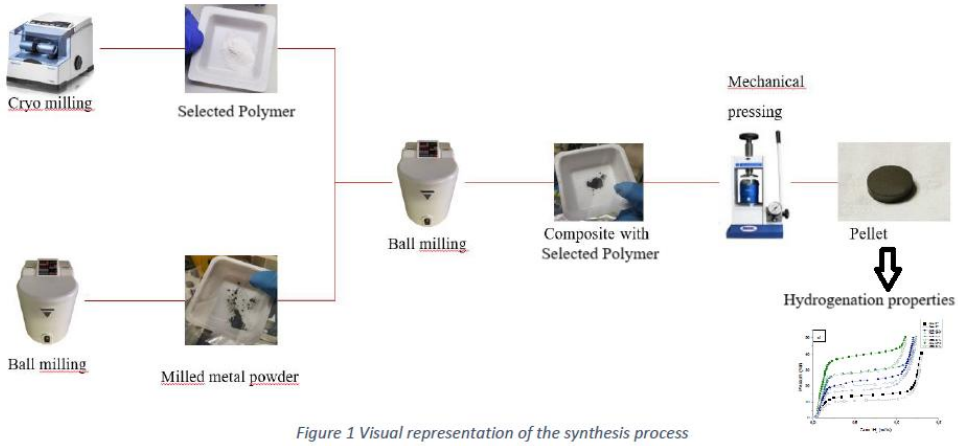

Figure 1 Visual representation of the synthesis process

Subsequent development focused on improving thermal conductivity using GPPS-based composites (General Purpose Polystyrene) with varying carbon black content (10–50 wt%). Four pelletized samples containing 95 wt% metal powder were prepared and analysed. Structural and thermal studies showed no degradation in material properties, while in-house hydrogen cycling tests at room temperature demonstrated stable performance under 30 bar absorption and 2 bar desorption conditions. A custom setup, developed in collaboration with an industrial partner, enabled real-time monitoring of heat effects and hydrogen uptake kinetics.
These findings validate the potential of polymer–hydride composites for solid-state hydrogen storage and lay the foundation for further development and scaling within the HyStoVal project.

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Impact of Carbon Formation on Methane Dry Reforming Kinetics on Rh-Based Catalysts

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Abstract. Methane Dry Reforming reaction ($CH_4 + CO_2 \rightarrow 2CO + 2H_2$, MDR) is a promising route for H_2 sustainable production from biogas and CO_2-rich natural gas. Still, industrially MDR is constrained by catalyst deactivation due to carbon deposition, a phenomenon with mechanisms and kinetic implications still under debate.[1] Our study shed light on the relationship between catalyst activity and the rate and structure of carbon deposition, combining kinetic measurements in an annular reactor with *operando* Raman spectroscopy to understand the carbon formation pathway and its kinetic consequences during MDR over Rh-based catalysts.[3] We demonstrated that on Rh, carbon formation and growth are significantly influenced by the CO_2/CH_4 ratio as highlighted in our experimental results in Figure 1a, with a significant increase in catalyst activity and stability when working in over-stoichiometric conditions. As shown in Figure 1.b-e, Raman spectra acquired in over-stoichiometric conditions show no presence of carbon peaks (i.e. G and D peaks) over 24 h. Conversely, at stoichiometric or sub-stoichiometric ratios, G and D peaks are visible respectively after 3 h and after 5 minutes from the beginning of the catalytic test. In particular, the gradual decrease in CH_4 conversion observed under stoichiometric conditions ($CO_2/CH_4 = 1$) is consistent with the progressive carbon deposition evidenced by operando Raman spectra (Figure 1c). Our findings indicate that carbon deposition markedly impacts catalyst stability and activity, which is improved by a higher concentration of CO_2 in the feed.

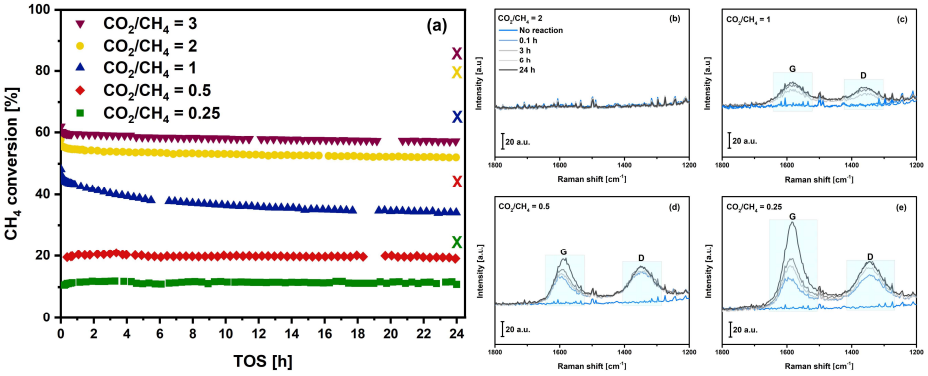

Fig. 1. a) Experimental (symbol) and equilibrium ("X" symbol) CH_4 conversion at different CO_2/CH_4 ratios at inlet CH_4 = 8 vol.% during 24 h tests. T = 600°C, P = 1 atm, GHSV = 1.4×10^6 NL/kgcat/h; b-e) Raman spectra acquired before the reaction; after 5 min; and after 3, 6 and 24 h.

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Impacts and opportunities of hydrogen injection into the existing natural gas network

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Abstract. Hydrogen can play a crucial role in the decarbonization of energy systems and in the progress towards the energy transition. Among the different possible applications, the integration of hydrogen into natural gas networks can be considered a very interesting strategy as it allows the use of existing infrastructures and can therefore be one of the strategies that allow the most immediate implementation. Clearly, all stages of the hydrogen value chain, from production from renewable sources to final uses, must be carefully studied and integrated.

Considering the growth of production from renewable sources (particularly photovoltaic) and the increasingly imbalances between demand and solar energy peak production occurs, hydrogen production from renewable sources has great potential. The blending of hydrogen with natural gas produces a change in the thermofluidynamic characteristics and in the chemical composition of the mixture. It results in lower density, higher diffusivity and different combustion characteristics, which influence the energy delivery and the flow rate properties within the pipeline infrastructures. All these aspects represent crucial challenges to ensure the reliability, safety, and efficiency of the existing networks. The presented research activity has comprehensively explored the thermofluidynamic implications of hydrogen blending and the opportunities offered by hydrogen injection into the existing natural gas network. Starting from the reasonable limits for hydrogen blending, including the effects on combustion, flow dynamics and safety, the possible integration of hydrogen into the natural gas network has been assessed.

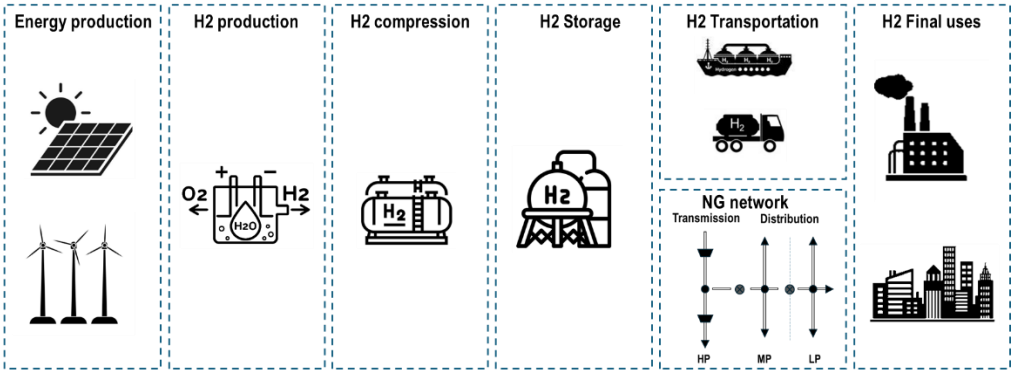

Fig. 1. Hydrogen chain: from green production to final uses.

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Improvements in Electrode and Matrix Fabrication for Molten Carbonate Fuel Cells applications

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Abstract. Nowadays, reducing carbon emissions is one of the most pressing global challenges. Carbon Capture and Storage (CCS) is a key strategy to address this issue. In this context, Molten Carbonate Fuel Cells (MCFCs) play an important role, as they are capable of simultaneously generating energy and capturing CO_2 from flue gases.
The main goal of this work is to present innovative and sustainable materials used in MCFC applications. Sustainability is a central aspect of this study, which focuses on replacing environmentally harmful components with greener alternatives. The first component developed is the matrix, the middle layer that has a twofold function: to separate the anode and cathode and to retain the electrolyte. The electrolyte, based on a standard mixture of lithium and potassium carbonates powder, guarantees the ionic carbonate conduction, CO_3^{2-}, from the cathode side to the anode side.
Based on a review of the literature, several materials were selected and modified to enhance their environmental compatibility. The second key component fabricated is the nickel-based electrode. Various analyses were performed to investigate the properties of both components, and cell tests were carried out to assess their performance. Each fabrication method was designed with scalability in mind for potential industrial application.

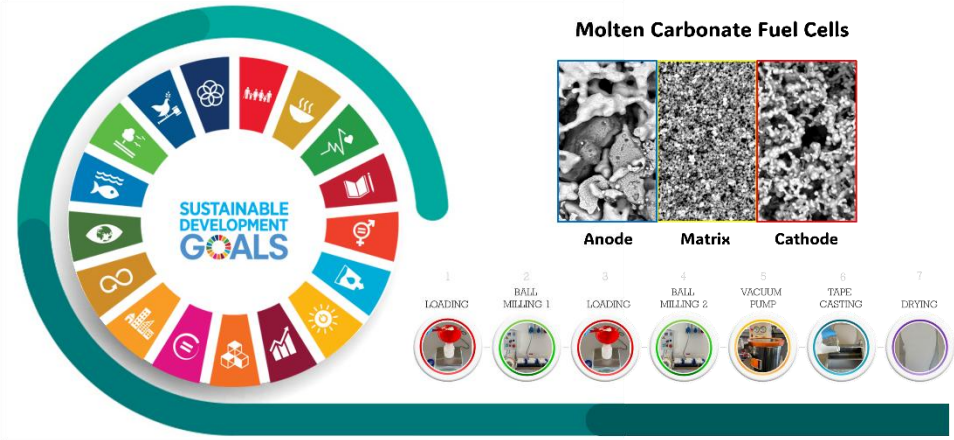

Fig. 1. Molten Carbonate Fuel Cell components

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Installation and preliminary operation of versatile test bench for reversible Solid Oxide Cells (r-SOCs) electrochemical characterization

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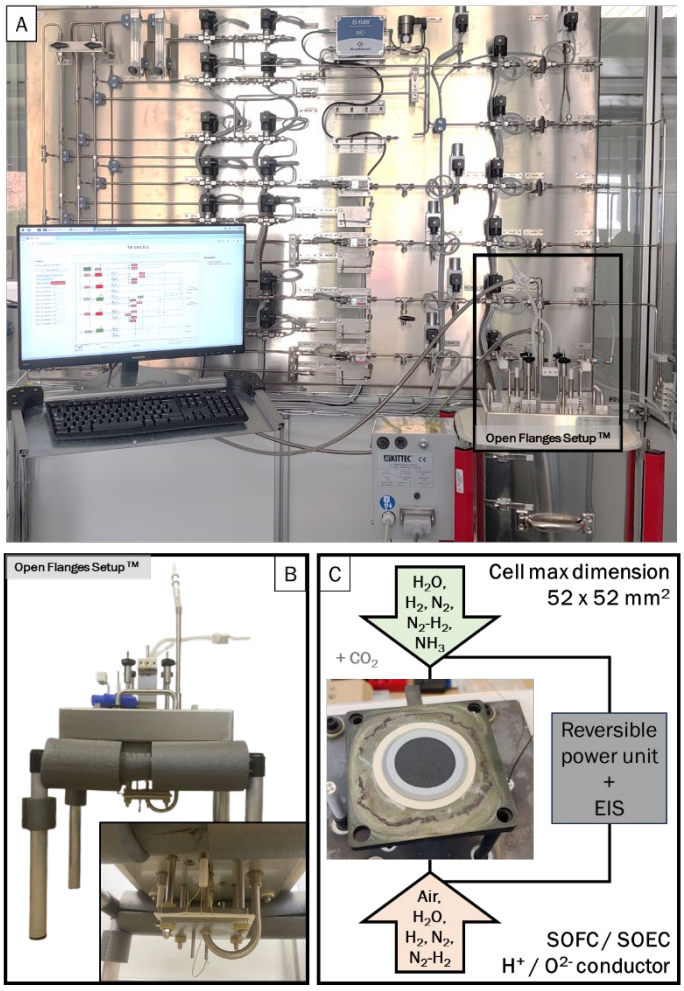

Fig. 1. Testing setup for the electrochemical characterization of reversible Solid Oxide Cells (r-SOCs) installed at the Hydrogen Laboratory of FBK. A: overview of the test bench (sensors, electrical panel, and potentiostat are omitted); B: detail of the cell housing and piping; C: open cell housing with a benchmark cell in place, schematic of the different testing conditions available.

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Modelling performance decay due to catalyst layer degradation in PEM fuel cells

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Abstract. The urgent need to mitigate climate change is accelerating the adoption of renewable hydrogen technologies, with Proton Exchange Membrane Fuel Cells (PEMFCs) standing out as a commercially promising solution for the heavy-duty transport sector. However, their large-scale deployment is hindered by complex durability limitations driven by a range of interacting degradation mechanisms at the material level. These mechanisms are challenging to disentangle without the support of advanced modelling approaches. This study presents a one-dimensional, time-resolved electrochemical model capable of reproducing key experimental outputs from zero-gradient hardware, specifically polarization curves, limiting current behaviour, and electrochemical impedance spectroscopy (EIS) data. The model incorporates transient terms across all governing equations, enabling the simulation of both reversible and irreversible degradation processes under dynamic operating profiles. Particular emphasis is placed on quantifying voltage losses due to platinum oxide formation/reduction dynamics at the catalyst layer and the transport resistance of oxygen through the ionomer thin film under variable conditions. By integrating physical fidelity with temporal resolution, the model offers new insights into the time-dependent performance decay of PEMFCs during real-world load cycles.

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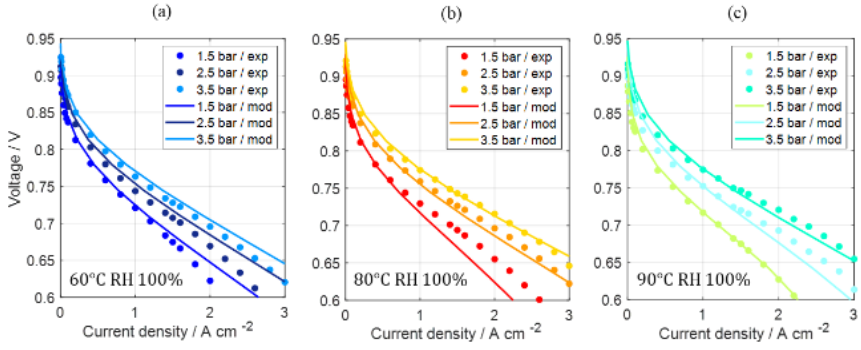

Fig. 1. Comparison between experimental (exp) and simulated polarization curves (mod) under H_2/Air feed, varying inlet pressures, for different temperature: (a) 60°C, (b) 80°C, (c) 90°C with cathode and anode relative humidity (RH) equal to 100%.

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New technological prospects opened by solid oxide cells

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Abstract. Solid oxide cell technology is a multiple-operation device. Fuel cell mode has already reached a commercial level, resulting in combined heat and power systems for stationary applications. Alternatively, an emerging use consists of green chemical production when coupled with renewables. High required working temperatures reduce the electrical consumption, exploiting a fraction of the available heat for the reaction development. Moreover, surplus heat can be used within the plant itself with a net global efficiency increase. In this cell design, the charge carrier consists of oxygen ions that selectively migrate in a ceramic layer from the cathode to the anode. Here, solid oxide cells permit the hydrogen and oxygen production by water dissociation in electrolysis operation (i.e., solid oxide electrolysis cell), as well as the pure oxygen production from air separation in an electrochemical air separation unit (i.e., solid oxide oxygen separator). In view of this bifunctional operation, solid oxide cells result in a promising technology for several application fields. An example consists of revamping the Haber-Bosch loop, where they could substitute both natural gas steam reforming and air distillation columns. Indeed, stacks, alternated in series with intermediated air burners, could directly produce an H_2-N_2-rich mixture. Nitrogen would be introduced into the cathodic synthesis gas, burning the oxygen with a part of the hydrogen generated by the previous electrolysis unit and releasing steam for the following one. Note that the combustion heat could balance the hydrogen fraction loss and the electricity requirement for its following re-synthesis, permitting an isothermal behaviour also below the thermoneutral point. A critical discussion on cell operations is presented (Figure 1), followed by a feasibility analysis to identify the most suitable application fields.

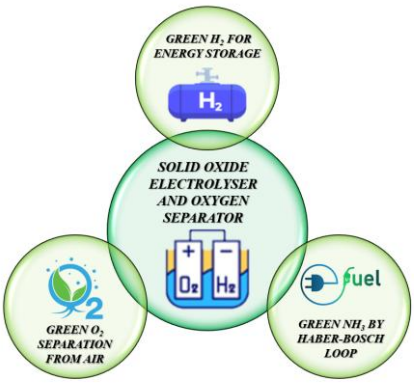

Figure 1. Feasibility analysis on different application fields for solid oxide cells.

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Numerical investigation of pilot ignition for hydrogen-diesel dual direct injection (H2DDI) engines

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Abstract. In the pursuit of cleaner and more efficient internal combustion engines, dual-fuel strategies combining diesel and hydrogen are gaining increasing attention. This study uses detailed computational fluid dynamics (CFD) simulations to investigate the behaviour of pilot diesel injections in dual-fuel diesel-hydrogen engines. The study aims to characterize spray formation, ignition delay, and early combustion phenomena under various energy substitution ratios. Three different combustion models were analysed to determine which one performs better in these particular conditions: Tabulated Well Mixed (TWM), Representative Interactive Flamelet (RIF) and directly integrated chemical kinetics (DLB). In-cylinder pressure measurement and high-speed natural luminosity imaging performed in a large bore optical engine were used to validate the computational model.
Particular attention is given to ignition location since it will affect the subsequent hydrogen ignition. Results show that all three combustion models reproduce rather well the experimental behaviour at high equivalent energy shares despite DLB shows a longer ignition delay with respect to TWM and RIF models. At low equivalent energy share RIF model seems to reproduce better the ignition delay but, due to the use of a single flamelet, it predicts an abrupt ignition of all the premixed charge available in the CFD domain, after the ignition conditions are reached in the mixture fraction domain.

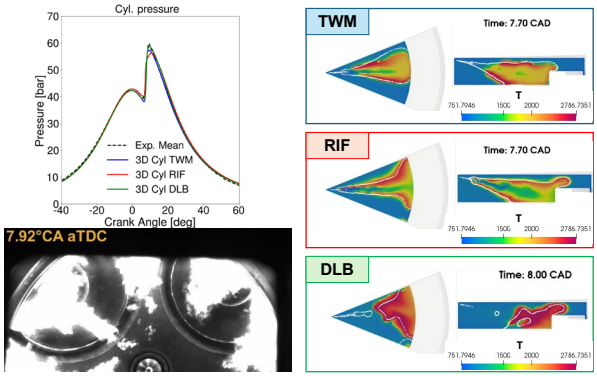

Fig. 1. In-cylinder pressure and ignition location for the 100% equivalent energy share computed with the three different combustion models.

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Optimal mixture design for organic Rankine cycle using machine learning algorithm

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Abstract. Organic Rankine Cycles (ORCs) are thermodynamic systems designed to convert low-temperature heat sources into mechanical or electrical energy. Their flexibility, compactness, and low maintenance requirements make them ideal for distributed generation and the recovery of renewable or waste heat. A key design aspect is the choice of the working fluid, which critically affects efficiency, safety, environmental impact, and compatibility with system components. To overcome the limitations of pure fluids, recent studies have explored the use of fluid mixtures, which offer greater flexibility in tuning thermophysical properties to match specific application requirements.

This work presents a methodology for the optimal design of working fluid mixtures tailored to ORC systems. The proposed tool, developed in Python, combines validated mixing rules, the CoolProp library for property estimation, and a Bayesian optimization algorithm. The framework allows users to define targets and constraints—including power output, efficiency, GWP, and blend simplicity—and explores the design space efficiently via statistical learning.

A case study is presented in which R134a, a common but high-GWP fluid, is replaced with optimized mixtures in a micro-ORC setup. Results show up to 25% improvement in net power output and a reduction in GWP by more than 80% compared to R134a, demonstrating the potential of custom blends for improving both performance and sustainability.

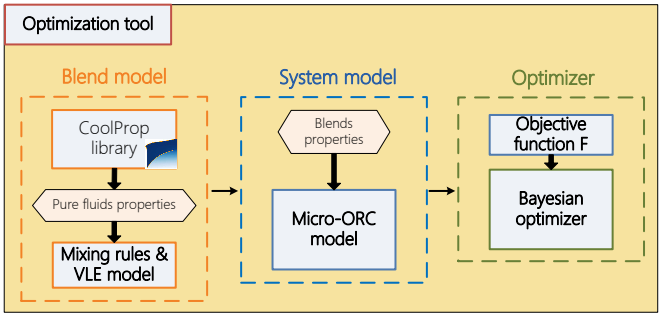

Fig. 1. Workflow of the optimization algorithm.

Optimization of small-scale oxy-steam gasification and catalytic water-gas shift for renewable hydrogen production

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Abstract. Biomass gasification has been identified as a promising renewable hydrogen production pathways. However, especially at the small scale, the industrial-scale implementation of biomass-to-hydrogen systems is hindered by the complexity of multistage processes required for syngas cleaning. Such cleaning operations are required, among others, upstream of water-gas shift reaction trains, a process step necessary to increase the inherently low hydrogen yields delivered by biomass stoichiometry. The work aims to address the current limitations related to biomass-to-hydrogen at the small scale by assessing experimentally a coupled system comprising novel oxygen-steam gasification of residual biomass and catalytic water-gas shift technology. The specific objectives of the proposed experimental work include 1) optimizing the operational parameters (oxygen and steam flow rates) of fixed bed oxygen-steam gasification for maximal hydrogen yield, 2) determining the degree of contamination of the obtained syngas with sulphur compounds that jeopardize the performance of downstream water-gas shift catalysts and 3) testing a water-gas shift fixed-bed lab-scale reactor loaded with selected commercial catalyst and fed with artificial syngas reproducing oxygen-steam syngas. The results of the experimental activity enable determining the expected hydrogen yield on biomass attainable with a coupled process. Moreover, syngas composition results and contaminants tolerance specifications provided by catalyst manufacturers are used to define a conceptual syngas cleaning process adequate for small-scale biomass-to-hydrogen.

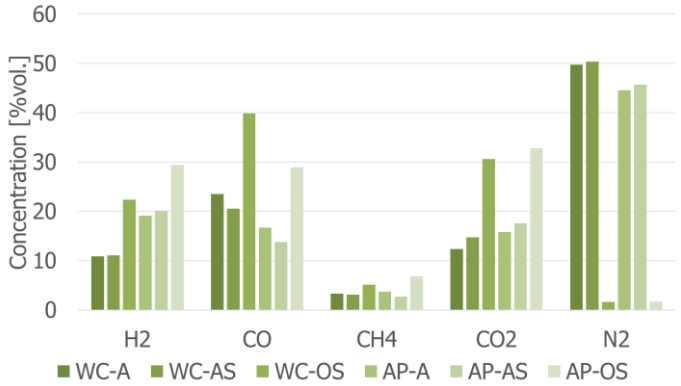

Fig. 1. Syngas gas composition with different biomass (WC=woodchip, AP=Agripellet) and using different gasification agents (A=air, AS=Air-Steam, OS=Oxy-Steam)

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Photon harvesting in large-area TMDs heterostructures for energy conversion applications

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Abstract. Two-dimensional Transition Metal Dichalcogenides semiconductors (2D-TMDs) have recently collected a strong scientific and technological interest due to their peculiar optoelectronic response within a broadband spectrum, and to their tunable bandgap that enables promising optoelectronic and photonic functionalities. Additionally, the superior optical absorption coefficients in the Visible spectrum, enhanced by about two orders of magnitude with respect to conventional bulk semiconductors, qualify TMDs as optimal candidates for photodetection and photoconversion applications[1,2]. However, to fully leverage their potential in extreme thickness regimes, effective photon harvesting strategies and large-area growth techniques are essential.

Here, we show the large-area growth and reshaping of 2D-TMDs layers and heterostructures via physical deposition approaches based on the Ion Beam Sputtering, and laser interference lithography nanofabrication[3-6]. Through periodic modulation of few-layers TMDs (MoS_2, WS_2) on large area nanostructured templates, we efficiently steer light propagation parallel to the 2D material, exploiting photonic anomalies in the flat-optics regime.[1] As a case study, we demonstrate that flat-optics light harvesting in periodically corrugated MoS_2 layers employed as photocatalysts boosts photodissociation of Methylene Blue, a diffuse polluting dye molecule[5]. Additionally, the atomically smooth surfaces and fully saturated in-plane chemical bonds of 2D-TMDs offer an opportunity to engineer vertically stacked large area MoS_2-WS_2 van der Waals heterostructures supported on a large area graphene layer, which acts as a transparent conductive window[5,6]. This configuration ensures a type-II staggered band alignment which in turn allows to split excitons across the junction, thus increasing the lifetime of the photogenerated carriers compared to the individual TMD components. Charge separation can be exploited for energy conversion and photocatalysis, reflected in the superior photodissociation rate of dye probes, and in the photocurrent detected upon illumination of the large area device. These results demonstrate that TMDs van der Waals heterostructures represent optimal building blocks for the fabrication of self-powered photodetectors, exploiting charge separation of photogenerated carriers at the 2D interface without any external bias. These large-area Van der Waals platforms thus represent promising candidates for photoconversion applications with impact in the field of energy conversion and storage.

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Sustainable hydrogen from biomass waste: bridging WGS, MEC, and Fermentation technologies

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Abstract. This paper presents comprehensive research conducted within the AB2H-NEST project, investigating three promising pathways for sustainable hydrogen production from biomass waste: (1) catalytic hydrogen enrichment via the Water Gas Shift (WGS) reaction, (2) bio-electrochemical conversion through Microbial Electrolysis Cells (MEC), and (3) biological production via Photo- (PF) and Dark Fermentation (DF). The WGS process is tailored for upgrading biomass-derived syngas, whose composition depends on feedstock characteristics and gasification parameters. MEC technology harnesses electroactive bacteria to convert organic waste into hydrogen, with system performance critically dependent on electrode materials, proton-exchange membranes, and operational conditions. PF employs photosynthetic bacteria to metabolize organic acids into H_2 under light exposure, while DF utilizes anaerobic consortia to decompose organic matter into hydrogen-rich biogas in dark environments. This study systematically evaluates these technologies to maximize hydrogen yield by examining process key parameters. Advanced computational models simulate process dynamics, while experimental results are obtained through laboratory-scale prototypes. The research addresses critical challenges including syngas composition, MEC scalability, and metabolic pathway control in biological systems. By integrating numerical modeling with experimental surveys, the project provides actionable insights for scaling waste-to-hydrogen technologies. The findings contribute to the development of carbon-neutral energy solutions, aligning with global decarbonization goals through innovative biomass valorization.

Keywords: Biomass waste; Hydrogen production; WGS; Microbial electrolysis; Fermentation.

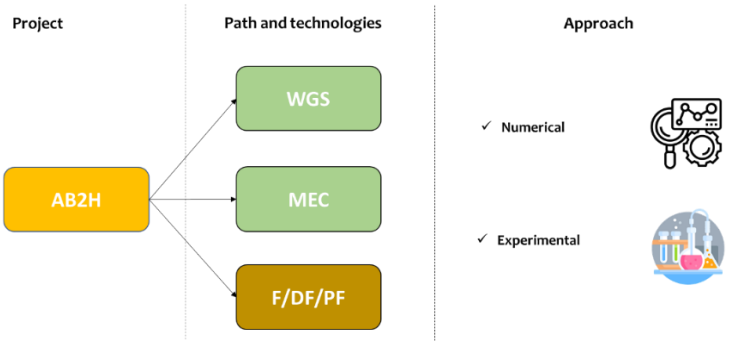

Fig. 1. Paper work path

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Techno-economic analysis of e-methane and e-methanol production from water electrolysis and CO_2 capture in a waste incinerator

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Abstract. In the current scenario, hydrogen storage, transport and final use are still challenging from both technical and economic perspectives. To overcome this limitation and mitigate CO_2 emissions, power-to-gas (P2G) and power-to-methanol (P2M) with carbon capture, utilisation and storage (CCUS) are expected to be two effective decarbonization pathways in the energy transition. Indeed, both methane and methanol exhibit interesting properties not only in terms of hydrogen storage capability but also as fuels for both energy generation and transportation. The aim of this work is to assess techno-economic feasibility of e-methane and e-methanol production starting from hydrogen generated by low-temperature electrolysis and CO_2 captured from flue gases of a waste incinerator (WI). In particular, electrolyzer size is chosen based on WI power size in terms of electricity generation in order to keep electricity production profile constant by performing peak shaving to obtain the necessary CO_2 for e-fuels synthesis; to this end, a post-combustion CCUS unit based on liquid amine solvents is assumed.

The economic feasibility analysis is performed in a reference scenario, in terms of electricity cost and CO_2 emissions costs according to the EU Emission Trading Scheme (ETS), for both the investigated pathways. Economic evaluations are drawn by computing e-fuels levelized cost of production (LCoP). EU ETS impact on LCoP is assessed by performing a sensitivity analysis with respect to EU allowances. The same sensitivity analysis is performed with respect to electricity cost at fixed value of ETS in the reference scenario. Results show a great influence of ETS on LCoP.

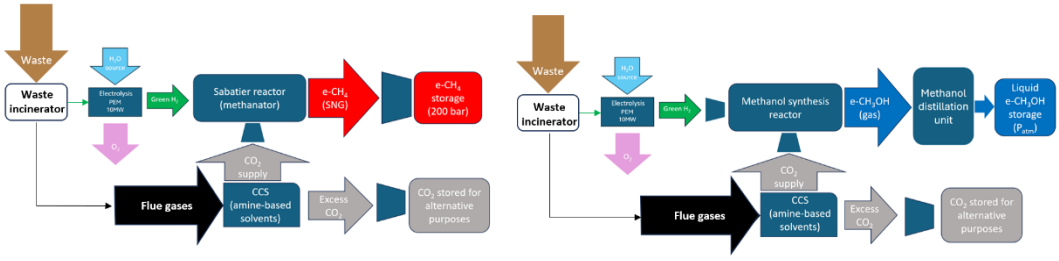

Fig. 1. Comparison of plant layouts in P2G and P2M with CCS from waste incinerator flue gases

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Techno-economic analysis of renewable e-fuels powered by undispatchable RES

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Abstract. Renewable power-to-X solutions may play a crucial role in the energy transition towards a carbon neutral scenario. In particular, renewable power-to-gas and power-to-methanol are interesting pathways for carbon recycling as they allow for CO_2 valorization. Nonetheless, the economic viability of such green e-fuels is still challenging, particularly when they are produced by relying on not dispatchable Renewable Energy Sources (RES), like solar and wind. Indeed, while Polymeric Exchange Membrane Electrolyzers (PEMEL) can work at partial load with fast dynamics response, e-fuels synthesis reactors (e.g. methanator) should operate at fixed working point, as their dynamics is slower. To overcome this issue and decouple these two sub-systems, there are at least two configurations which exhibit different pros and cons both in terms of economics and space occupation. A first option is to interpose a buffer daily hydrogen storage between PEMEL and e-fuel synthesis reactor, pressurized at different levels according to the final product. In this case, electrical energy for compressors can be either bought from the grid or self-produced by relying on an auxiliary Battery Energy Storage System (BESS) which stores excess electricity than PEMEL consumption. Finally, the second option foresees a BESS directly connected to undispatchable RES which in turn powers both PEMEL and compressors, making all the system working in a steadier state. Economic evaluations are performed in the first system configurations with 10 MW PEMEL powered by a solar PV field and wind turbines in Puglia. Results show higher green e-fuels production costs compared to fossil fuel based processes.

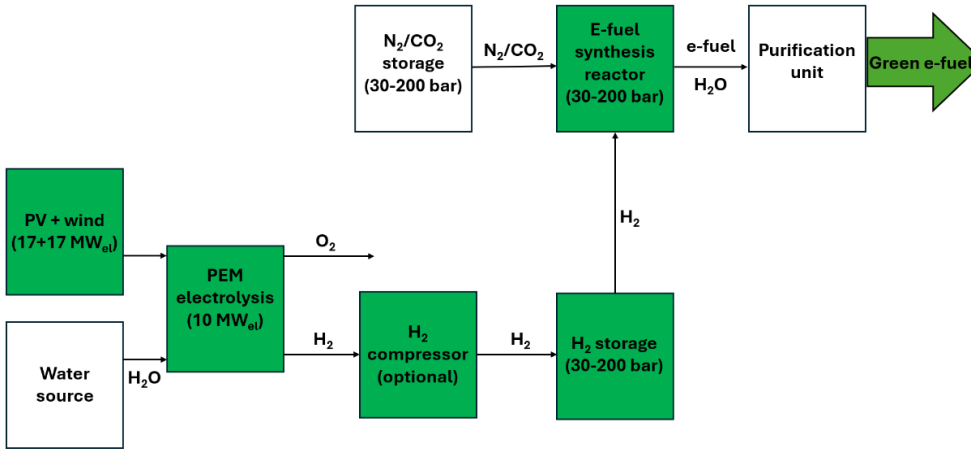

Fig. 1. General plant layout for renewable e-fuels synthesis with buffer H_2 storage

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Techno-economic assessment of a transcritical CO_2 Carnot battery for long duration energy storage

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Abstract. Electricity generation from non-dispatchable renewables has grown rapidly, driven by solar PV and wind cost reduction and incentives related to strong decarbonization policies. While this has reduced the energy sector carbon intensity, it has also caused grid imbalances and curtailments in regions like California, China, and Ireland. These challenges have increased interest in efficient, scalable energy storage solutions. CO_2-based Carnot batteries represent a promising option for multi-MW-scale, long-duration energy storage, with capacity higher than 8 hours. They can achieve round-trip efficiencies above 60% without requiring specific geographical features and offer the added advantage of storing both hot and cold thermal energy, enabling their integration with district heating and cooling networks. This work presents the detailed sizing of the main components of a transcritical CO_2 Carnot battery system. A key feature of the system is the use of the same heat exchangers during both charging and discharging phases, namely hot storage, cold storage, and recuperator. The hot storage system includes two heat transfer fluid loops - pressurized water (up to 150°C) and diathermic oil - each with dedicated insulated tanks, while cold storage is based on an ice slurry tank at 0°C with integrated coiled exchangers. A MATLAB tool has been developed to properly design a 50 $MW_{el,ch}$ system and optimize its main variables to maximize the round-trip efficiency and minimize the storage cost. The optimal solution is designed with a sensible hot storage between 72°C and 294°C, having a maximum pressure of 250 bar, resulting in a round-trip efficiency of 54.6% and specific costs of 2412 €/$kW_{el,ch}$ for 10h of storage. The levelized cost of storage is estimated around 0.1-0.3 €/kWh, depending on the electricity selling price, with 20°C being the optimal temperature difference for the hot storage.

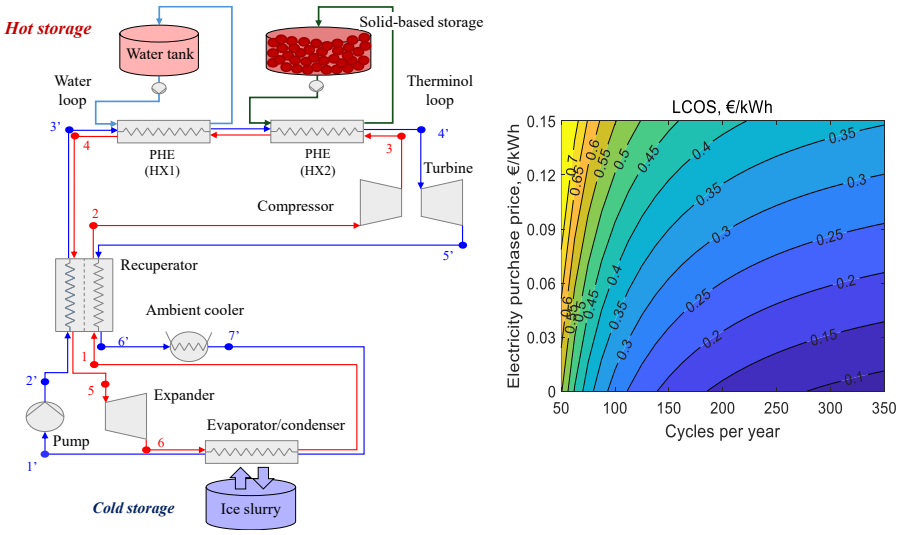

Fig. 1. Investigated transcritical CO_2 Carnot battery layout (left) and resulting LCOE as function of charge/discharge cycles per year and price of purchased electricity (right).

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The potential of green hydrogen and applications in South America context: the Paraguay case

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Abstract.

Paraguay presents an energy paradox. While its energy matrix is almost entirely based on an impressive hydroelectric capacity (approximately 9 GW installed) and generates significant exportable electricity), 40% of its final energy consumption relies on imported fossil fuels, mainly diesel and gasoline for transportation. This situation contrasts with Paraguay's enormous potential to become a leader in green hydrogen production, with estimated costs ranging from 1.8 to 2.4 USD/kg, thanks to its low-cost renewable electricity (approximately 30 USD/MWh). Considering the power capacity of the Itaipu Hydroelectric Dam (14 GW) of which Paraguay owns 50%, this study aims to investigate: (i) a Power-to-hydrogen plant for internal use, to feed H_2 vehicles for sustainable mobility circulating in the plant's region; (ii) a Power-to-ammonia plant, considering its export to nearby Countries, leveraging the Paraná Waterway for efficient international transport and commercialization. The levelized costs of products are calculated for both the solutions to evaluate the economic feasibility in the Paraguay context, considering the low electricity costs.

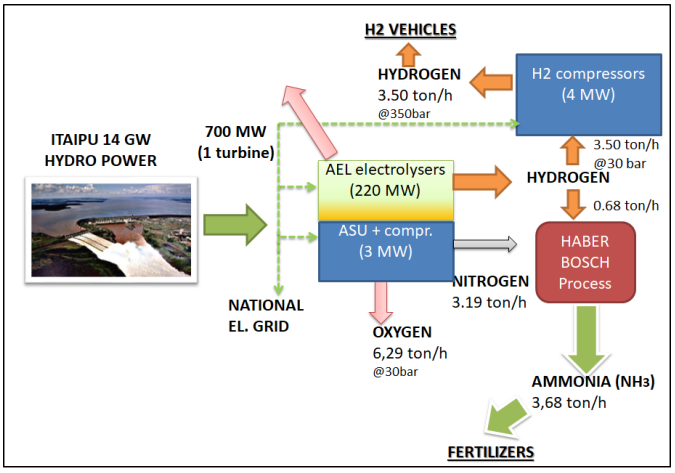

Fig. 1. Simplified process for green H_2 and NH_3 synthesis from Itaipu hydropower in Paraguay

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Towards the Demonstration of Molten Salt TES: Development of Laboratory- and Pilot-Scale Unit

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Abstract. Molten salt (MS) thermal energy storage (TES) is a promising technology for supporting the decarbonization of both energy and industrial sectors. This paper details the design, development, and experimental work led by Centrum výzkumu Řež (CVR) on two high-temperature TES units: a laboratory-scale and a pilot-scale unit. The pilot TES unit (4 MW, 9 MWh_t) will be integrated into the existing infrastructure at the fossil power plant Mělník, Czech Republic. It employs a traditional two-tank configuration storing solar salt at 560 °C, with charging via electric resistance heating and discharging through a set of heat exchangers to generate superheated steam for combined heat and power production. This setup will demonstrate the operational performance and economic feasibility of MS TES systems under conditions relevant to coal-fired power plants, as well as their potential application in thermal power plants. A laboratory-scale unit (30 kW, 200 kWh_t) is being developed to gain operational experience and support pilot unit development. It will test two concepts: (i) a two-tank MS system, and (ii) a dual-media thermocline TES combining MS with basalt rock. Discharge is enabled via a supercritical CO_2 cycle, making this experimental setup unique by coupling TES with another emerging technology. This work highlights key design strategies and supporting analyses from the development of both TES units. Additionally, it serves as a valuable reference for future MS storage deployments

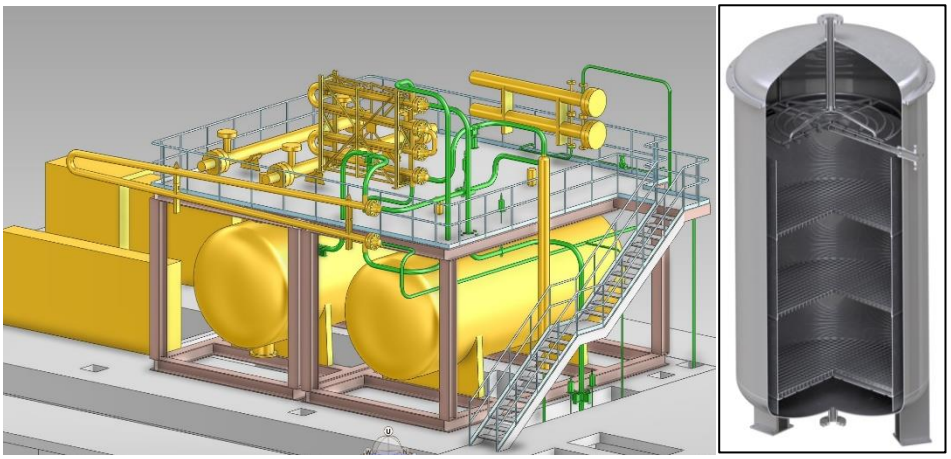

Fig. 1. 3D Model of the Pilot TES System (left); 3D cutaway view of thermocline storage tank (right)

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