PhD Program in Maritime Science and Technology

Curriculum in Engineering for Marine and Coastal Environments

June 2025 Call, XLI cycle - Starting date: 1st of November 2025

The research projects submitted for the admission to the PhD program must be prepared in accordance with one of the projects listed in this file, which are organized by general thematic.

Project: Sea water and CO2 co-electrolysis, a perfect mix for CO2 rich stream valorization of and hydrogen production

Keywords:

Co-electrolysis, Solid Oxide Cells. CO2 valorization, Syngas, mixed ionic concductivity

Brief Description:

The main target of the project is to study reversible electrochemical systems for the valorization of CO2 rich streams via co-electrolysis of CO2 and sea-water in syngas with the aim of solid oxide cells (SOC). Particularly the project focus materials with mixed ionic conductivity (anionic and protonic) able to work at intermediate temperature. The advantages of the proposed systems with respect to the state of the art one are:

- Separation of water and CO2 in the two cell compartments
- Hydrogen production without water
- Selectrive pressurization of the two champers.

Moreover, the system open new challenges thanks to the combination of co-electrolysis and reverse water gas shift reaction (RWGS) in the cathodic side of the cell, managing separately sea water and CO2

This project focus in particular materials and understanding of the electrochemistry combining experimental and modelling activities.

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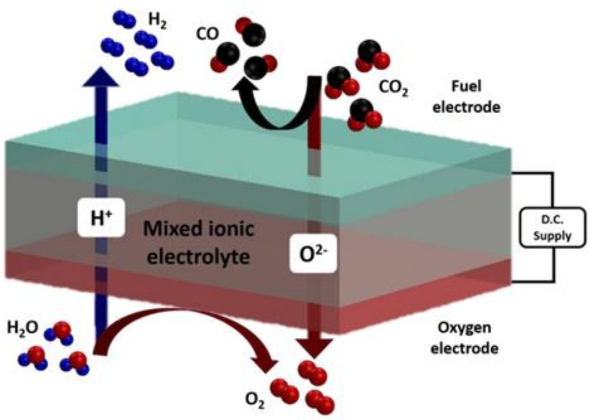

Figure: mechanism of co-ionic conduction in a Solid Oxide Cell

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Project: Coastal Flooding hazard under present conditions and in the framework of future climate change

Keywords: Coastal flooding; Wave storm; Extreme levels; Climate Change

Description: Coastal erosion and coastal flooding are the main hazard for the management of the coastal zone and could pose many disruptions to different human production activities. A detailed knowledge of the processes and on the intensity of the phenomenon is crucial to provide managing authorities and institutions, and economic stakeholders, the necessary information and scenarios for decision making and policies development. The research projects will develop a methodological approach suitable for the definition and estimation of extreme levels of coastal flooding due to different physical processes such as wave run-up and set-up, storm surge and long-term sea-level variation due to climate change. The research activities will consist in developing a suitable numerical model suite for the description of wave storms in the coastal region, giving insight into wave run-up and set-up processes, the characterization of storm surge levels and the use of sea level variation projections under different Shared Socioeconomic Pathways (SSPs) for mid and end of the century (2050 & 2100). After developing a wide dataset of metocean forcings the analysis of flooding processes will be carried out through the employment of process based numerical models, having as the final objective of the project the evaluation of return levels for coastal inundation areas along the coastline of the Mediterranean Sea with specific attention to hot spots with respect to coastal infrastructures, lowlands and populated areas.

Academic Supervisor: Giovani Besio, giovanni.besio@unige.it

Relevant links: meteocean.science

Project: Hydrodynamics performances and stability of artificial reefs

Keywords: Nature Based Solution, Artificial Reefs, Physical experiments

Description: Submerged artificial reefs (AR) are becoming increasingly popular, as they combine shore protection with environmental restoration. Compared to traditional boulders typically used for submerged breakwaters, AR are characterized by more complex shapes and higher porosity, providing habitats for fishes to nest and shelter from predators (see for instance Figure 1). If built with eco-friendly materials, AR offers additional surface for biofouling, supporting the marine food chain and enhancing the growth of algae and marine fauna. Moreover, the advent of 3D printing allows the construction of aesthetically appealing structures, raising interest in diving and ultimately supporting local activities. Despite being beneficial for a variety of reasons, the hydraulic performances of AR remain relatively unexplored. While the body of literature has steadily increased through the past recent years, most research focus on specific models and shapes without providing a comprehensive overview. Moreover, they mainly investigate the effect of AR on wave propagation, i.e., how they reduce transmitted wave height, reducing in turn flooding and erosion. By contrast, little research has assessed the stability of such porous blocks, which are particularly vulnerable to uplift and must be therefore properly engineered to withstand wave-induced stresses. In this framework, the proposed Ph.D. research aims to conduct an extensive experimental campaign to explore the stability of different AR depending on several features, such as weight, porosity, roughness, etc. Experiments will be carried out at the wave flume of the Enrico Marchi laboratory at DICCA, with the opportunity to conduct additional research at the Universidad de la Republica Oriental de Uruguay. The experimental design will follow a Design of Experiments approach, and the data collected will be analyzed through dimensional analysis. The final goal is to derive general parametric formulas to preliminary assess AR stability and hydraulic performances.

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Relevant links: meteocean.science

Project: Machine Learning for MeteOcean applications: clustering of sea storm data

Keywords: Big Data Analysis, MeteOcean, Climate analysis

Description: The characterization of MeteOcean forcings is crucial for the analysis of different applications in the offshore and coastal region like the design of infrastructures, the evolution of accretion/erosion in the coastal region or the analysis of the fate of contaminants in the coastal region and in the open ocean. The PhD project has the scope to develop an algorithm for a statistical analysis of historical data concerning metocean variables (waves, wind, pressure, sea level, currents) dedicated to the extraction of characteristic scenarios to be used in numerical simulations. The feature identification will be based on different types of algorithms to test their reliability and their power in reproducing meteocean forcings to be used in coastal/offshore applications. Techniques based on CNN and LSTM will be employed on a long time series of variables to extract different characteristic time series able to represent the climatic variability of predefined locations along the world coastline.

Acedemic Supervisor: Giovani Besio, giovanni.besio@unige.it

Relevant links: meteocean.science

Project: Modelling Posidonia Oceanica effects on coastal hydrodynamics

Keywords: Numerical modeling, Posidonia Oceanica, Nature Based Solution

Description: Posidonia Oceanica meadows represent an important asset for the coastal region because they provide different types of eco-system services, ranging from nurseries to carbon capture. In the last years climate change has affected the characteristics of wave storms especially in the Mediterranean Sea, changing the impacts along the nearshore region either in terms of coastal risk (erosion and flooding) and in terms of forcings on the eco-system. One of the effects of this kind of change resulted in the uprooting of different Posidonia meadows in the Northern Tyrrhenian Sea, either natural one or transplanted ones. With the present project we would like to shade a light about possible survival of Posidonia meadows to highly energetic wave storms in specific sites along the nearshore region of the Tyrrhenian Sea comparing numerical modelling results with field observations. Furthermore, a preliminary assessment of a guideline for transplantation site analysis will be developed based on past experience of transplantation projects that suffered plant eradication during strong storm events. Finally, a mix of Deep Learning techniques and numerical modelling results will be employed to develop a forecasting tool for survival probability of transplantation projects.

Academic Supervisor: Giovani Besio, giovanni.besio@unige.it

Relevant links: meteocean.science

Project: Machine Learning for time series forecast of Meteocean variables

Keywords: MeteOcean forecast, Machine Learning, Field Observation

Description: Real-time forecasting is fundamental for maritime operations and for coastal risk alert systems. The project has the scope to implement different algorithm based on Machine Learning approach to develop time-series forecast of metocean variables (mainly ocean waves) based on field measurements obtained using wave buoys installed along the Italian coastlines. The calibration, optimization and validation of this type of tool will enhance the provision of real time forecast for the short-term period (6-12-24-48 hours) at specific locations and the system will be tested in different areas to understand the reliability and the performance level of the different algorithms for different metocean conditions.

Academic Supervisor: Giovani Besio, giovanni.besio@unige.it

Relevant links: meteocean.science

Project: Geo-Hazard of Turbidity Currents on Underwater Infrastructures in a Changing Climate

Keywords: turbidity currents, sediment transport, submarine geohazard, underwater infrastructures, numerical modelling

Description: The aim of this PhD fellowship is analysing the impact of turbidity currents on underwater infrastructures. Turbidity currents are sediment gravity flows that, once initiated, can traverse considerable distances, spanning hundreds to thousands of kilometres into the deep ocean, and reach velocities as high as 20 m/s (Piper et al., 1999). The potential consequences for infrastructure along their path are severe, as demonstrated by the impact on the submarine cable sector dating back to the installation of the first transatlantic cables, notably during the 1929 Grand Banks earthquake and other subsequent events. Recent cable displacements and ruptures in Taiwan's Gaoping Canyon and in the Congo Canyon serve as a stark reminder of this ongoing risk faced by offshore facilities (Carter et al., 2012; Talling et al., 2022). Amid the rapid expansion of submarine telecommunication and power cables, offshore oil & gas projects, scientific monitoring experiments, deep-sea mining, and renewable energy initiatives since the 1990s, the exposure of seafloor infrastructures to storm-induced turbidity currents becomes an increasingly significant geo-hazard that demands effective management strategies. Coupled with the increased exposure associated with the growth of offshore infrastructure installations trends in climate change indicate that a warming ocean could lead to the development of larger and stronger cyclonic storms (Emanuel, 2003). Understanding the effect of stronger storms, on coastal climate on the frequency and magnitude of turbidity currents is a topic that remains largely unknown.

In response to these challenges, this PhD research project involves a comprehensive and systematic investigation of the complex interactions between storms, triggering and development of deep-sea sediment gravity flows. The project's multi-faceted approach starts with the analysis of synthetic tropical cyclone databases, enabling controlled studies even in regions with limited historical data, such as those at the edges of cyclone basins. This approach combines the benefits of using global climate models and synthetic modelling to generate future climate synthetic tropical typhoons spanning hundreds of years (Bloemendaal et al., 2022). Parametric relations for cyclonic wind and pressure fields will be employed to extract site-specific data from these databases, while refined parametric formulas for cyclone-induced waves and storm surges will provide crucial information on wave and water level conditions across selected study sites. The analytical wind field formulation will be calibrated through the results of high-resolution simulations of typhoons performed in selected areas of interest.

The outcome of this research project will aid in developing targeted mitigation strategies, enhancing the resilience of energy and telecommunication networks, discriminating between natural and anthropogenic risks for underwater infrastructures, and supporting sustainable coastal and offshore development in storm-prone areas, paving the way for sustainable development and climate adaptation in the face of increasing cyclonic activities and sea level rise.

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Project: Molten carbonate fuel cells for maritime sector decarbonization

Keywords: Carbon capture, fuel cells, material engineering, process analysis, industrial scale-up

Description: Description of project proposal (max 1 page with figures).

In the current context of the energy transition and decarbonization efforts, the development and implementation of innovative clean technologies is both necessary and urgent, including in the maritime sector. Within this framework, molten carbonate fuel cells (MCFCs) emerge as a particularly promising solution due to their dual capability to generate clean energy while simultaneously capturing CO_2. This makes them an ideal candidate for effective and rapid retrofitting of existing maritime systems.

This PhD project aims to advance the key components of MCFC technology, specifically the electrodes, the matrix, and the electrolyte, through a combination of theoretical investigation and experimental research conducted at the CapLab laboratory in collaboration with the industrial partner Ecospray.

The primary objective is to optimize these components to achieve competitive performance levels, while ensuring that their production processes are environmentally sustainable, economically viable, and scalable for future industrial applications.

Specific chemical and morphological characteristics of the components must be achieved to ensure the required properties, such as electrical, ionic, and thermal conductivity, mechanical strength, and heterogeneous catalysis. This will involve investigating innovative fabrication recipes and processes beyond those currently found in the literature. Additionally, the design and optimization of the cell layout and fuel cell stacks will also be studied to enable effective integration onboard maritime systems.

The project requires a multidisciplinary skill set, including material and chemical engineering, hands-on laboratory experience, and proficiency in modelling and simulation of the entire fuel cell system.

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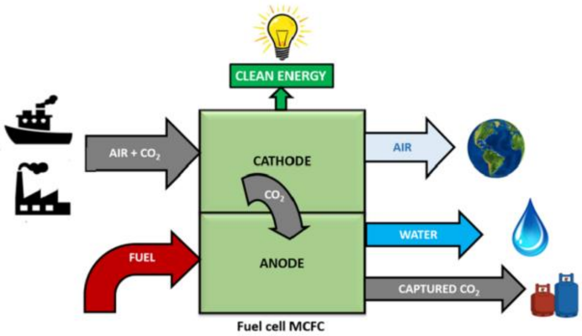

Project: Treatment of agro-industrial wastewaters using microalgae

Keywords: emerging pollutants, microplastics, new plant development, microalgal biomass exploitation.

Description: The increasing of urbanization and industrialization leads to the production of large quantities of wastewater around the world. Part of this waste can be treated and exploited for the growth of microalgae, reducing their cultivation costs, and making chemicals recovery and biofuel production more feasible.

Using the mixotrophic metabolism, microalgae are able to absorb and use many of the organic molecules contained in wastewater (antibiotics, heavy metals, microplastics, etc.), reducing its polluting load, leading to the production of additional microalgal biomass and to the purification of the water used. After the growth, the microalgae biomass can be collected and used for the production of biofuels and for the recovery of chemicals of interest.

Batch and continuous microalgal growth systems are available in the laboratory of the research group. By means of these plants, wastewater (e.g.: olive mill and winery wastewaters, landfill leachate, sewage wastewaters, etc.) will be micro-phytotrophically treated and then analysed.

An ad hoc plant for the growth and the collection of microalgae in wastewaters will be studied and tested, reaching the goal to work in a full continuous mode. A pumping system, operating with variable flow rates, will be carefully developed to make the device less energy intensive and to reduce the hydraulic retention time. Downstream of the cultivation system, a plant will be designed for microalgal biomass settling, and the microalgal biomass will be collected using new methodologies, such as electro-coagulation.

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Project: Anaerobic digestion of agro-industrial residues with a view to a zero-waste approach

Keywords: Agro-industrial waste, zero-waste approach, anaerobic digestion, biogas, microalgae.

Description: This project concerns the application of anaerobic digestion to recover energy from agro-industrial residues. Olive pomace from olive oil production will first be dried to stabilize it and later diluted in water and treated in a 7-liter bench-scale digestor equipped with an agitation and temperature control system. Two different research topics will concern biogas upgrading in biomethane and digestate reuse. In the first case, the produced biogas will be conveyed to a photobioreactor in which a microalga will be cultivated autotrophically using the biogas CO_2 as the only carbon source. As a result, biogas will be converted to biomethane with percentage higher than 90%. The second approach will take advantage of the ability of microalgae to grow under mixotrophic conditions in the presence of organic carbon source such as the contaminants still present in the digestate. In this case, the digestate produced in the first step will be treated in the photobioreactor in fed-batch mode in order to significantly reduce its chemical oxygen demand demand (COD). It is aimed, with the combination of the two approaches, to transform an agro-industrial residue such as olive pomace (or other similar residues) exclusively in biomethane and microalgal biomass to be used as a biofuel and as a raw material for biodiesel production, respectively, thus pursuing the zero-waste goal.

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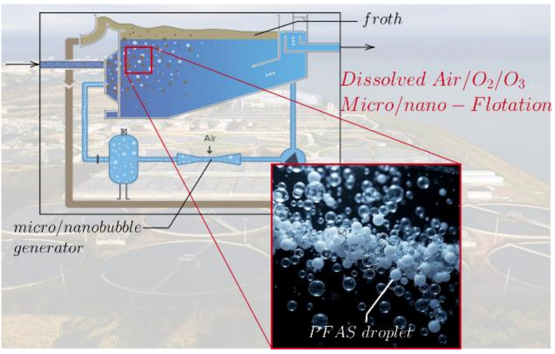
Project: Revolutionising Micro/Nanobubble-based Treatment Process for Micropollutant Removal in Estuarine and Coastal Environments

Keywords: micro/nanobubble flotation, water treatment, particle aggregation, salinity

Description: Quest. The equilibrium of aquatic ecosystems in estuarine and coastal environments is particularly sensitive to the presence of micropollutants (such as pharmaceuticals, PFAS, surfactants, plastic and rubber additives), that easily escape the traditional wastewater treatments and, even at very low concentrations, have adverse effects on the ecological environment. Indeed, wastewaters are the main source of micropollutants, which are almost impossible to be detected and removed once they reach the oceans. Nowadays, the most effective strategy to remove the micropollutants is based on the activated carbons that, due to their negative charge, allow them to attract polarised compounds. However, such techniques are expensive and the increasingly restrictive limits of micropollutant concentration imposed on urban wastewaters by European "zero pollution action plan" (Green Deal), require more sustainable processes to be identified.
Aims. The present project aims to deliver a high-efficiency treatment solution with minimal environmental impact, specifically designed to protect and restore sensitive aquatic ecosystems. The project explores the possibility to exploit the physical and chemical properties of micro/nanobubbles, eventually combined with other electrochemical approaches, to separate (by floatation) and remove targeted micropollutants (e.g., PFAS, pharmaceuticals). The removal can be obtained by adsorption or by oxidation (e.g. by using ozone micro/nanobubbles). The effects of the salinity characterising the estuarine and coastal areas will be also considered.
Objectives and Methodology. The objectives of the project are (i) identifying experimentally the micro/nanobubble-based treatment process to aggregate and separate the targeted micropollutants, and (ii) modelling the evolution and the interaction between micropollutant and micro/nanobubble distributions, using the Population Balance Equations. The values of the model parameters will be possibly quantified by means of the Direct Numerical Simulation of the micro/nanobubble-micropollutant interactions when the ambient flow is turbulent. Moreover, (iii) focus will be also directed toward optimizing system performance, evaluating environmental sustainability through Life Cycle Assessment (LCA) methodology, and assessing scalability for broader application in water management. Finally, the project will benefit from the collaboration with the company COGEDE that is specialised in the design and manufacture of wastewater and slurry treatment plants. Therefore, field experiences are also planned. Further information is available at this link.

Referent: Marco Mazzuoli (marco.mazzuoli@unige.it), Erica Gagliano (erica.gagliano@unige.it)

Figure:



Project: CO_2 to capture and use - processes design for Maritime Technologies

Keywords: CO_2, e-fuels, CO_2 utilization, chemical reaction engineering, catalysis

Description: Description of project proposal (max 1 page with figures).

Referent: Prof. Gabriella Garbarino (gabriella.garbarino@unige.it)

Brief Description:

CO_2 use is becoming one of the key challenges for the future, and the development of new technologies and processes is pivotal for achieving sustainable development goals, set out by the United Nations, thus contributing to the carbon neutrality goal in the set target of 2050. The PhD project proposed here will be focused on development of new processes devoted to this application by aiming at the reduction of environmental impact and by possibly outlining new technological solutions by looking at the process, reaction mechanism of chosen reactions, and kinetics to produce e-fuels and e-chemicals. Of utmost importance will be the understanding for maritime applications for combined CO_2 capture and utilization. An experimental point of view will address the present project.

Project: Extreme Event Forecasting via AI-Based Methods and Met-Ocean Models

Keywords: Extreme weather events, Deep learning, Ensemble forecasting, Weather prediction models, AI uncertainty quantification

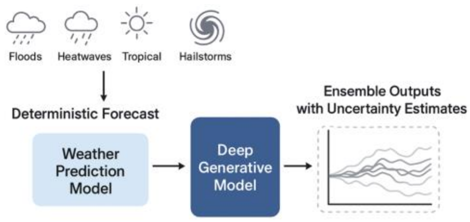
Description:

Extreme weather events such as floods, heatwaves, tropical cyclones, hailstorms, storm surges, extreme wave events are becoming more frequent and intense due to climate change, posing significant challenges to public safety, infrastructure, and resource management. Traditional weather forecasting models, while physically consistent, often struggle to capture the localized and nonlinear nature of such extremes, especially when computational limitations restrict ensemble size or resolution.

This project aims to develop innovative AI-based techniques to enhance the forecasting of extreme events by leveraging the strengths of both numerical weather/wave prediction (NWP/WP) models and modern machine learning architectures. The focus will be on the integration of deterministic forecasts (e.g., from models like WRF/WWIII) with deep learning models capable of generating probabilistic ensemble predictions without requiring multiple physical model runs. The proposed method will explore architectures such as conditional variational autoencoders (CVAEs) trained to predict the full distribution of target variables (e.g., precipitation, lightning, hails, wind gusts) at high resolution. The new idea to explore is to map classical extreme event forecasting into an anomaly detection problem. This is a change of paradigm in the field.

A central aspect of the project will be the use of advanced loss functions for probabilistic forecasting, such as the Continuous Ranked Probability Score (CRPS), and the development of explainability tools to understand AI-driven predictions. Additionally, the project will investigate the synergy between AI and physics by embedding physical constraints or conservation laws within the learning process (so-called Physics-Informed ML).

The developed system will be evaluated on real-world datasets of extreme events using both retrospective and hindcast data (e.g., ERA5, satellite observations, in-house produced regional model outputs). Applications include improved early warning systems and enhanced risk assessment tools, potentially reducing the socioeconomic impact of extreme events.



Extreme event forecasting via AI-based architecture

Referent: Andrea Mazzino, andrea.mazzino@unige.it

DICCA Ph.D. PROGRAM IN CIVIL, CHEMICAL AND ENVIRONMENTAL ENGINEERING

Project: Ecomorphodynamics of coastal tidal environments

Keywords: Saltmarshes, biodiversity, morphodynamics, tides, sea-level rise

Description: Tides, storms, rising sea level due to climate change and sediment availability are the main features governing the dynamics of tide dominated coastal areas environments such as estuaries and lagoons. In particular, concerns about an increasing sea level and the related ability of intertidal areas to maintain their intrinsic characteristics have deserved a considerable attention in the last years. One of the issues that this project aims to determine the effectiveness of the natural based solution interventions in salt marshes by evaluating the flood risk reduction using a simplified numerical morphodynamic models involving biodiversity indicators and sediment transport parameters .

Referent: Nicoletta Tambroni, Nicoletta.tambroni@unige.it

Figure:

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Project: Experimental and theoretical investigation of the formation of preferential microplastics patterns under non-breaking wind waves

Keywords: turbulence, coastal ecosystems, particle clustering, wave flume, adhesive biofilm

Description:

Quests. The transport of microscopic plastic particles dispersed in coastal shallow waters is strongly affected by wave-related flows. Indeed, as non-breaking waves approach the coast, they interact with the bottom and a boundary layer develops where turbulence frequently appears, in particular if small-scale bedforms are present. The way turbulence may promote the formation of preferential patterns of plastic particles, eventually in the presence of flow stratification (e.g. due to salinity gradient), is mostly unknown. Moreover, the presence of a biofilm naturally developing on the particle surface can result in adhesive forces that contribute to the particle aggregation. The question whether turbulence supports or inhibits the formation of aggregates of different size is still unsolved.

Objectives and Methodology. The objectives of the project are (i) identifying experimentally the appearance of patterns of either slightly positively or negatively buoyant plastic particles, (ii) determining the conditions (turbulence properties, density gradient) that allow the stratification of plastic particles above the bottom, (iii) exploring the possibility for bio-adhesive plastic particles to stick to each other forming aggregates, and the capability of such aggregates to resist the turbulent stresses close to the wave bottom, (iv) modelling the dispersion of microplastics in the framework of the Population Balance Equations. The experiments will be carried out in the large wave-flume at DICCA, suitably equipped with a wavy bottom, mimicking the sand ripples, and instrumented to measure the flow properties in the wave boundary layer and the trajectory of individual microplastic particles. The experimental results will complement those obtained on a smaller facility at the University of Catania by the research team led by Prof. Luca Cavallaro in the context of the PRIN Project "MARINE DUST".

Referents: Marco Mazzuoli (marco.mazzuoli@unige.it)

Project: Reversible and symmetric solid oxide electrolysis cells with innovative design fed by sea water

Keywords: electrolysis, SOC, seawater, stability, reversibility

Description: The use of hydrogen as a fuel in the naval sector is technically possible and represents one of the most promising solutions for the decarbonisation of the sector, especially in a long-term perspective. The advantages of this technology are many: zero local emissions (if the hydrogen is green), absence of vibrations, high efficiency. Producing hydrogen directly from seawater for use in an offshore or recreational/long-coastal context would also make sense, since ships and port infrastructures have direct access to seawater and this would eliminate the need for transport or storage of fresh water.

The production of green hydrogen from seawater electrolysis via solid oxide cells (SOCs) represents a promising technology: firstly, the high operating temperatures determine favourable thermodynamics and reaction kinetics, allowing unparalleled conversion efficiencies; secondly, the possibility of using inexpensive raw materials; third but not least, the potential synergies from the integration with downstream chemical syntheses, such as the production of methanol, synthetic fuels or ammonia is a convenient strategy from the point of view of logistics, energy density and environmental sustainability. However, seawater-fueled SOCs still suffer from critical issues related to degradation both during the fabrication phase and during operation: degradation is mainly due to the chemical and mechanical instability of the ceramic materials currently used and to the microstructural conformation of conventional electrodes. At the stack level, there are also issues related to the metal interconnections and gaskets typically used. In light of these considerations, the topic of this research consists in the fabrication and characterization of symmetric SOC cells with an engineered porous structure that improves the mechanical stability of the system and in the subsequent realization of a microstack fed by direct steam from seawater. In addition to the morphology, the study will focus on the choice of readily available materials to be used both at the oxygen and the hydrogen side and inexpensive and easily scalable fabrication techniques.

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