Politecnico di Torino

MATERIALS SCIENCE AND TECHNOLOGY

DISAT - Design, fabrication, and advanced characterization of multifunctional membranes for CO2/H2O capture and ion transport

Funded By	Dipartimento DISAT
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Context of the research activity	The development of advanced membranes is crucial to enable efficient CO2 capture and its conversion into renewable e-fuels. Enhancing selectivity, stability, and ion transport in these materials addresses key limitations in current CO2-to-fuel processes, supporting more sustainable energy systems and contributing to the broader decarbonisation goals of the energy transition.
	The transition toward low-carbon energy systems requires innovative technologies capable of reducing CO2 emissions while producing renewable fuels in an efficient and scalable manner. The European project THUNDER addresses this challenge by proposing a disruptive approach for the production of e-methanol, based on the integration of three traditionally separate steps—CO2/H2O vapour capture, CO2/H2O co-electrolysis, and CO/CO2 hydrogenation—within a single intensified reactor. This configuration reduces energy consumption, capital costs, and process complexity, enabling a more sustainable and compact route to synthetic fuels. A key enabling element in this integrated process is the development of multifunctional membranes able to perform selective gas separation and controlled ion transport under challenging chemical and thermal environments. These membranes must exhibit high CO2 selectivity, effective water management, robust ionic conductivity, and long-term stability, while also being compatible with zero-gap electrochemical configurations. Their performance directly impacts the efficiency of CO2 capture, electrochemical conversion, and reactor integration, making membrane development a central scientific and technological objective of THUNDER. The research activity of this PhD project is situated precisely within this framework. Its overall scope is to design, develop, and understand advanced membrane materials that can support the operational requirements of THUNDER's tandem process for e-methanol production. The work will focus on polymers of intrinsic microporosity (PIMs), functionalised ionomers, and CRM-free polymer systems, representing sustainable alternatives to conventional fluorinated membranes. By combining synthesis, advanced

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<td>Objectives</td>
<td>characterization, and prototype testing, the research aims to establish clear relationships between membrane structure, transport properties, and electrochemical performance.

The main objectives of the research activity include:

Design and synthesis of advanced polymer membranes, tailored for selective CO_2/H_2O vapour capture and efficient ion transport. This includes the development of PIM-based materials and functionalised ionomers engineered for stability, mechanical robustness, and controlled microporosity.

Understanding structure–property relationships through advanced material characterization and operando studies. Special attention will be given to the influence of free volume, chemical functionality, hydration behaviour, and morphological features on gas permeation, ion conductivity, and overall membrane performance.

Optimisation of CO_2 selectivity and ionic transport, two fundamental parameters for ensuring efficient operation of the integrated reactor. The goal is to achieve permeability–selectivity balances and conductivity values compatible with co-electrolysis requirements, while also ensuring adequate water retention and reduced crossover phenomena.

Development of membrane–electrode assemblies (MEAs) through controlled deposition of catalyst layers and hot-pressing techniques. The PhD research will assess adhesion, wettability, catalyst distribution, and mechanical integration, followed by electrochemical testing in 5 cm^2 and 100 cm^2 prototype cells.

Investigation of degradation mechanisms and long-term durability, including chemical ageing, humidity-induced stress, structural reorganisation, and performance decay under continuous electrochemical operation. These studies will guide the identification of strategies for improving membrane lifetime.

Contribution to predictive modelling and material-by-design approaches, integrating experimental data with transport models and mechanistic insights to support rational optimisation of membrane materials for THUNDER's reactor design.

The interdisciplinary nature of the activity—spanning materials science, chemical engineering, electrochemistry, and energy technologies—will provide the PhD candidate with a comprehensive research environment. The project foresees strong interactions with international academic and industrial partners involved in THUNDER, enabling exposure to cutting-edge methodologies and real-world technological challenges.

Ultimately, the goal is to deliver innovative membrane materials capable of significantly improving the efficiency, stability, and sustainability of THUNDER's integrated e-methanol production process. The research will contribute to advancing Europe's technological capabilities in CO_2 utilisation, supporting the broader transition toward renewable fuels and climate-neutral energy systems.</td>
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<td>Skills and</td>
<td>The candidate should have a background in materials science, chemical engineering or related fields, with interest in membranes and sustainable</td>
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competencies for the development of the activity	energy. Required skills include basic electrochemistry, polymer or thin-film processing, and materials characterization. The candidate must show strong motivation, problem-solving abilities, autonomy in laboratory work, and readiness to collaborate in an interdisciplinary environment.