ENERGETICS

DENERG- High-temperature electrochemical cells for energy storage and production: manufacturing methods and degradation phenomena in PCC and SOC cells

Funded By	Dipartimento DENERG
Supervisor	GANDIGLIO MARTA - marta.gandiglio@polito.it
Contact	MAROCCO PAOLO - paolo.marocco@polito.it SANTARELLI MASSIMO - massimo.santarelli@polito.it
Context of the research activity	The production of clean energy utilizing resources available within the European Union has become a critical priority. Equally vital is the need to enhance the EU's capability to produce hydrogen independently of fossil-based natural gas. Transitioning from fossil-based, imported energy sources to clean, domestically produced alternatives—including hydrogen—must occur in a manner that is economically feasible and socially acceptable to the citizens of the European Union. Ceramic solid oxide cells technology offers a promising solution to these challenges, as it enables: 1. The use of diverse fuels, such as biofuels, hydrogen, and ammonia, in fuel cell mode. 2. High-efficiency hydrogen production in electrolysis mode and potential for directly generating synthetic fuels. 3. Demand-response management for electricity and hydrogen production based on the availability of renewable energy sources and electricity loads and prices (reversible operation).
	In this context, the proposed PhD research will be supported by two key European projects: • AMPS (Automated Mass Production of SOC Stacks): The AMPS project addresses a primary barrier to the large-scale adoption of SOC technologies—their cost. The project aims to develop, demonstrate, and validate innovative mass-manufacturing and quality control methods to produce SOC components and stacks at reduced costs and high volumes. • ELECTROLIFE (Enhancing Knowledge on Electrolyser Degradation Mechanisms): This project focuses on advancing the understanding of degradation mechanisms in electrolyzers, improving cell performance, and increasing system efficiency by reducing the use of critical materials and extending system lifespans. ELECTROLIFE addresses both low- and high-temperature electrolyzer systems. The overarching aim of the PhD activity is to:

Objectives

• Analyse the design and functionality of ceramic Solid Oxide Cells, operating in both O^{2}¿-conducting (SOC) and H¿-conducting (Proton-Conducting Ceramic, PCC) modes.
• Investigate the impact of novel manufacturing methods on system costs and explore cost-efficient production techniques.
• Assess degradation phenomena during system operation, focusing on control strategies and operating modes to mitigate performance losses.
• Conduct experimental testing of cells and stacks in the laboratories at Politecnico di Torino and abroad to assess the most impacting conditions.
• Validate physical models capturing observed degradation phenomena occurring in various operating modes.
• Develop system-level models that integrate degradation mechanisms, enabling the identification of optimal operating strategies tailored to specific applications while balancing performance and longevity.

Research Activities
The PhD candidate will undertake the following research activities:
1. Conduct a comprehensive literature review on the structure, materials, manufacturing methods, and degradation phenomena of SOC and PCC technologies.
2. Analyse the AMPS project's manufacturing processes and perform a detailed cost breakdown of SOC stack production.
3. Experimentally and numerically investigate degradation phenomena at the component level in SOC and PCC cells, examining the effects of various operating modes (e.g., nominal operation at low/high current, standby operation, thermal cycling).
4. Evaluate optimal operation strategies for SOC and PCC systems, accounting for case-specific applications (e-fuels production, reversible operation, heavy-duty fuel cell applications).
5. Writing dissertations and scientific publications to disseminate findings.

Collaborations and Integration
This research will be conducted within the STEPS (Synergies of Thermo-Chemical and Electro-Chemical Power Systems) research group under the supervision of Prof. Massimo Santarelli.
The candidate will collaborate with leading international partners, including:
• VTT Technical Research Centre of Finland
• Technical University of Denmark (DTU)
• University of Graz

The PhD activity will also engage with ongoing national and international projects within the STEPS research group framework, fostering interdisciplinary collaboration and knowledge exchange.
References

[1] Scataglini R, Wei M, Mayyas A, Chan SH, Lipman T, Santarelli M. A Direct Manufacturing Cost Model for Solid-Oxide Fuel Cell Stacks. Fuel Cells 2017;17:825–42. https://doi.org/10.1002/fuce.201700012.
[2] Liao M, Liu C, Marocco P, Gandiglio M, Santarelli M, Optimal dispatch model for grid-connected wind electrolysis plants, 2024, International Journal of Hydrogen Energy, accepted for publication.
[3] Yi Wang, Wenyuan Li, Liang Ma, Wei Li, Xingbo Liu, Degradation of solid oxide electrolysis cells: Phenomena, mechanisms, and emerging mitigation strategies—A review, Journal of Materials Science & Technology, Volume 55, 2020, Pages 35-55, https://doi.org/10.1016/j.jmst.2019.07.026.
[4] Yakun Wang, Yeqing Ling, Bin Wang, Guowei Zhai, Guangming Yang,

	Zongping Shao, Rui Xiao and Tao Li, A review of progress in proton ceramic electrochemical cells: material and structural design, coupled with value-added chemical production, Energy Environ. Sci., 2023, 16, 5721, https://doi.org/10.1039/D3EE03121G.

Skills and competencies for the development of the activity	- Comprehensive understanding of hydrogen technologies and electrochemical components, including their production and end-use applications. - Experience in laboratory activities and experimental research. - Proficiency in programming within Matlab and/or Python environments. - Willingness to engage in international exchange programs at universities and research centres. - Strong command of the English language, both written and oral.