Track descriptions for HySET

Fuel cell systems engineering: Fuel and electrolyser cells offer an efficient way to convert power-to-fuel and fuel-to-power to other energy conversion and storage technologies. These systems have great potential to become a cornerstone in a future sustainable energy system. Low-temperature fuel and electrolyser cell technology is particularly interesting for transport applications, for example in cars, trucks, busses, boats and even airplanes, but also for back-up power and portable electronics. In contrast, high temperature cell technology can be suitable for multiple applications from use as auxiliary power units in vehicles to stationary power generation in building or marine applications. The development of large-scale energy storage and energy conversion technologies is needed to improve the efficiency of energy storage and conversion processes and solve the mismatch of energy supply and demand. The cell system is complex, and everything from the details of the cell components, to how the cell is operated and controlled, to how the hydrogen fuel is produced, distributed, and stored needs to be optimized for cells to become a viable option for energy conversion.
In this track, we will get an introduction to the critical components in the fuel and electrolyser cells as well as to the system integration around the cell, how they operate and how to control them. Therefore, the students will be exposed to concepts from material and chemical engineering, fluid mechanics, electrochemistry, thermodynamics, heat transfer, manufacturing and electrical and electronics engineering as they apply to cell systems. This is a true multidisciplinary track. The interdisciplinary nature of the track requires a team teaching approach with backgrounds in multiple engineering.

Course guide

Title: High-temperature solid oxide cells

Department: 702 - CEM – Department of Materials Science and Engineering

Coordinating lecturer: Miguel Morales Comas

Others: Vicente Roda Serrat (Laboratory professor); Attila P. Husar

Prior skills: Basic knowledge in materials and chemical engineering; process engineering; thermodynamics.

Requirements:

DEGREE COMPETENCIES TO WHICH THE SUBJECT CONTRIBUTES
Specific:
1- Understand, describe and analyze, in a clear and comprehensive manner, the entire energy conversion chain, from its status as an energy source to its use as an energy service. They will also be able to identify, describe and analyze the situation and characteristics of the various energy resources and end uses of energy, in their economic, social and environmental dimensions, and to make value judgments.
2- Efficiently collect data on renewable energy resources and their statistical treatment and apply knowledge and endpoint criteria in the design and evaluation of technology solutions for using renewable energy resources, for both isolated systems and those connected to networks. They will also be able to recognize and evaluate the newest technological applications in the use of renewable energy resources.
3- Employ technical and economic criteria to select the most appropriate electrical equipment for a given application, dimension thermal equipment and facilities, and recognise and evaluate the newest technology applications in the field of production, transport, distribution, storage, and use of electric energy.
4- Analyze the performance of equipment and facilities in operation to carry out a diagnostic assessment of the use system and establish measures to improve their energy efficiency.

Generic:
1- Ability to apply the scientific method and the principles of engineering and economics, to formulate and solve complex problems in processes, equipment, facilities and services, in the field of high-temperature fuel cells and electrolysers.

TEACHING METHODOLOGY
- Lectures and conferences: knowledge exposed by lecturers or guest speakers.
- Participatory sessions: the collective resolution of exercises, debates, and group dynamics, with the lecturer and other students in the classroom; classroom presentation of an activity individually or in small groups.
- Theoretical/practical supervised work: classroom activity, carried out individually or in small groups, with the advice and supervision of the professor.
- Homework assignment of reduced extension: carry out homework of reduced extension, individually or in groups.
- Homework assignment of broad extension (PA): design, planning, and implementation of a project or homework assignment of broad extension by a group of students, and writing a report that should include the approach, results, and conclusions.

LEARNING OBJECTIVES OF THE SUBJECT

- To develop scientific and technical skills to design and test high-temperature fuel and electrolyzer cells, and to set up the basis for their implementation, optimization and/or modification.
- To develop technical criteria to define and select a high-temperature fuel and electrolyzer cell system with the participation of other energy devices (fuel processing, hybridization with other fuel cells, or other energy technologies).
- To identify the challenges and weaknesses of Solid Oxide Cells materials, cells, devices, and systems, and to provide engineering solutions.
- To develop scientific skills to implement new ideas related to high-temperature fuel and electrolyzer cells.

Type	Hour	Percentage
Large group/Theory	33	22
Small group/Lab	9	6
Guided activities	21	14
Self-study	87	58

Total learning time: 150h

CONTENTS

Topic 1. INTRODUCTION

Description: Fuel and electrolyzer cells fundamentals and operating principles.

Learning time: 9h
Large group/Theory: 3h
Self-study: 6h

Topic 2. THERMODYNAMICS AND ELECTROCHEMICAL KINETICS

Description: Operating characteristics of cells. Thermodynamic and electrochemical losses. Electrical efficiency and heat rejection. Cell performance variables.

Learning time: 11h
Large group/Theory: 3h
Guided activities: 2h
Self-study: 6h

Topic 3. CELL TYPES

Description: Molten Carbonate Fuel Cell (MCFC). Solid Oxide Cell (SOC). Protonic Ceramic Fuel Cell (PCFC).

Learning time: 11h

Large group/Theory: 6h
Guided activities: 2h
Self-study: 6h

Topic 4. CELL COMPONENTS
Description: Electrolyte materials. Anode materials. Cathode materials. Interconnect materials. Seal materials.

Learning time: 23h
Large group/Theory: 6h
Guided activities: 2h
Self-study: 15h

Topic 5. CELL AND STACK DESIGNS
Description: Planar and tubular design. Cell fabrication. Single-cell performance. Stack performance. Stack scale-up.

Learning time: 32h
Large group/Theory: 6h
Small group/Lab: 3h
Guided activities: 5h
Self-study: 18h

Topic 6. OPERATION CONDITIONS OF CELLS AND STACKS
Description: Testing electrodes. Testing cells and stacks. Area-specific resistance (ASR). Comparison of test results on electrodes and on cells. Non-activated contributions to the total loss. Inaccurate temperature measurements. Cathode performance. Impedance analysis of cells. The problem of gas leakage in cell testing. Assessment of the size of the gas leak.

Learning time: 36h
Large group/Theory: 6h
Small group/Lab: 6h
Guided activities: 6h
Self-study: 18h

Topic 7. SYSTEMS
Description: Fuel processing. Power conditioning. Balance of Plant (BoP). System optimization. System designs. Hybrids.

Learning time: 28h
Large group/Theory: 6h
Guided activities: 6h
Small group: 6h
Self-study: 18h

GRADING SYSTEM

Continuous assessment (2 exams; 30% each written exam), laboratory reports (20%), and final group project (20%).

EXAMINATION RULES

Written exams are individual. Laboratory and projects are carried out in groups.

BIBLIOGRAPHY

Basic

- *Fuel Cell Handbook (Seventh Edition).* U.S. Department of Energy. By EG&G Technical Services, Inc. (2004).
- M Morales, et al. *Materials Issues for Solid Oxide Fuel Cells Design*. Handbook of Clean Energy Systems (2015).
- Mandeep Singh, et al. *Solid oxide fuel cell: Decade of progress, future perspectives and challenges*. International Journal of Hydrogen Energy 46 (2021) 27643.

Complementary

- Neelima Mahato, et al. *Progress in material selection for solid oxide fuel cell technology: A review.* Progress in Materials Science 72 (2015) 141.
- Muneeb Irshad, et al. *A Brief Description of High Temperature Solid Oxide Fuel Cell's Operation, Materials, Design, Fabrication Technologies and Performance.* Applied Sciences 6 (2016) 75.
- M.B. Mogensen, et al. *Reversible solid-oxide cells for clean and sustainable energy.* Clean Energy, 3 (2019) 175.
- Minghai Shen, et al. Progress and prospects of reversible solid oxide fuel cell materials. iScience 24 (2021) 103464.
- Catarina Mendonça, et al. *Towards the Commercialization of Solid Oxide Fuel Cells: Recent Advances in Materials and Integration Strategies.* Fuels 2 (2021) 393.
- Shabri HA, et al. *Recent progress in metal-ceramic anode of solid oxide fuel cell for direct hydrocarbon fuel utilization: a review.* Fuel Process Technol 212 (2021) 106626.
- Shen M, et al. *Progress and challenges of cathode contact layer for solid oxide fuel cell.* Int J Hydrogen Energy 45 (2020) 33876.

RESOURCES

UPC Hydrogen Lab (EEBE)