



UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

SYLLABUS DEL CORSO

Models and Materials for Electrochemical Energy Generation and Conversion

2627-1-FSM02Q018

Aims

The course aims to provide students with the principles and of electrochemical technologies for energy conversion, and to place them in the broader context of the current energy scenario.

Knowledge and understanding

At the end of the course, the student will know:

Basic concepts of electrochemical conversion systems (electrolytes, electrodes, their integration into membrane electrode assembly).

Application of modelling to energy conversion: identification of active sites and descriptors of the catalytic activity, thermodynamic and kinetical aspects of reaction mechanisms.

Main technologies for electrochemical energy conversion including fuel cells and electrolyzers and novel conversion systems such as carbon dioxide conversion and nitrate reduction

Applying knowledge and understanding

At the end of the course, the student will be able to:

Identify the main components of fuel cells and water electrolyzers.

Apply the knowledge for selection of materials.

Apply the acquired knowledge to critically evaluate the choice of materials in different electrochemical energy conversion devices, considering their structural, electronic and functional properties.

Making judgments

At the end of this course, the student must demonstrate the ability to:

Demonstrate mastery of the topics covered in the course

Understand the operating principle of an electrochemical energy storage device

Demonstrate the ability to critically analyze electrochemical data collected in the laboratory. This also includes the ability to organize the data in a scientific paper.

Communication skills

At the end of this activity, the student will be able to orally and with proper language skills present the scientific topics related to energy conversion systems.

Learning skills

Upon completion of the course, the student is able to:

Independently deepen their knowledge of electrochemical energy conversion materials and devices through existing scientific literature.

Constantly update themselves on research developments and technological evolution in the field of electrochemical conversion systems including the substitution of critical raw materials with less noble and precious materials.

Critically evaluate information and data and finally support decision-making and problem solving.

Develop a multidisciplinary (materials science, chemistry and engineering) and multiscale (from atomic level to system level) approach to the study and understanding of electrochemical energy conversion systems.

Effectively continue their learning path both in academic and professional settings, particularly in the field of energy conversion technologies.

Contents

Catalysis and electrocatalysis. Electrochemical technologies for energy conversion and generation. Water electrolyzers, fuel cells, carbon dioxide reduction, reduction of nitrogenous compounds.

Detailed program

From thermal catalysis to electrocatalysis: short recall of fundamental theoretical aspects in heterogeneous catalysis, and electrocatalysis: reaction kinetics, mechanism, barriers, and overpotential.

What is the actual catalyst? The interplay between experiments and modelling in characterizing the structural and chemical features of the catalyst: definition of the active site, morphological and chemical characterization of the active species by means of microscopic and spectroscopic techniques and theoretical modelling.

Electrocatalysis at work: rationalization of the activity trends in oxygen reduction reaction, water splitting, hydrogen evolution reaction, oxygen evolution reaction, CO₂ and nitrogenous compounds electroreduction: reaction mechanisms, expected activity, pros and cons of various electrocatalysts.

From nanoparticles to single atoms: the size aspect of a catalyst. A critical overview on the usage of highly dispersed catalytic species.

Water Electrolyzers. Classification of electrolyzers (AEL, PEMEL, AEMEL, SOEC, CO₂ electrolyzers). Strategies to optimize the reaction pathways (hydrogen evolution reaction, oxygen evolution reaction, CO₂ electroreduction).

Identification of performance, polarization curves, losses, durability issues. Effect of operational parameters (e.g. T, P) on the electrochemistry. Organic, inorganic and hybrid materials for electrocatalysts and membranes.

Fabrication of electrocatalysts architectures, polymeric membranes and their integration in membrane electrode assembly. Identification of gaps and proposed solutions. Substitution of critical raw materials (e.g. Pt, Ir and Co) and fluorinated compounds. Device operations.

Fuel Cells. Classification of fuel cells operating with gaseous feedstock (PEMFC, AEMFC, AFC, MCFC, SOFC) and liquid feedstock (DMFC, DEFC, DFAFC, etc). Strategies to optimize the reaction pathways (hydrogen oxidation reaction, alcohol oxidation reaction, oxygen reduction reaction). Identification of performance, polarization curves, losses, durability issues. Effect of operational parameters (e.g. T, P, etc) on the electrochemistry. Organic, inorganic and hybrid materials for electrocatalysts and membranes. Fabrication of electrocatalysts architectures, polymeric membranes and their integration in membrane electrode assembly. Identification of gaps and proposed solutions. Substitution of critical raw materials (e.g. Pt and Co) and fluorinated compounds.

Prerequisites

Standard physic and mathematic knowledge, thermodynamic and kinetic of chemical systems.

Suggested: Fundamentals of Electrochemistry for Energy Storage

Teaching form

20 two-hour lectures, in person, Delivered Teaching

4 two-hour practical classes, in person, dedicated to the preparation of the final essay. Interactive Teaching

Textbook and teaching resource

Teacher's slides and selected chapters from the following books:

- Selected scientific papers and reviews
- Bard Faulkner: Electrochemical Methods, Fundamental and Applications (2° Edition)
- IRENA Report (IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5oC Climate Goal, International Renewable Energy Agency, Abu Dhabi)
- Fuller and Harb, Electrochemical Engineering, Wiley 2018
- Pei Kang Shen, Chao-Yang Wang, San Ping Jiang, Xueliang Sun, Jiu-Jun Zhang. Electrochemical Energy Advanced Materials and Technologies. 2017. CRC Press
- F. Marken, D. Fermin. Electrochemical Reduction of Carbon Dioxide: Overcoming the Limitations of Photosynthesis. RSC Publishing. 2018
- S. Cosnier. Bioelectrochemistry: Design and Applications of Biomaterials. Publisher: De Gruyter. Edited by Serge Cosnier. ISBN 978-3-11-056898-1. DOI : 10.1515/9783110570526-010
- Xu, Kang "Electrolytes, Interfaces and Interphases Fundamentals and Applications in Batteries", RSC Publishing

Semester

Second semester (entire semester)

Assessment method

Oral exam, based on the discussion of the final essay, followed by some general questions on the topics covered by the course

There are no intermediate ongoing tests.

The presentation method, knowledge of the topic and ability to answer questions will be assessed.

Office hours

On appointment contacting the Lecturers via email.

Sustainable Development Goals

AFFORDABLE AND CLEAN ENERGY
