



UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Energy Storage and Conversion: From Technologies To Applications

2627-2-F7603Q010

Aims

The course aims to provide the students with knowledge related to the electrochemical systems for energy storage and conversion such as fuel cells, water electrolyzers, power to gas technologies and batteries. The course will include a brief overview of the materials used, the composition and structure of these technologies, their integration into the existing network of renewable energies and their operations. Other storage technologies such as flywheels and hydroelectric and other emerging technologies will be presented. The needs of each technology including pro and cons, advantages and disadvantages to balance the peaks of renewable output for conversion and storage will be analyzed. Environmental-Techno-Economical analysis will be carried out with specific examples related to transportation, industrial sector, buildings and agriculture. Water and its quality are directly connected to energy storage and conversion and will be crucial for sustaining the green energy revolution. Electrochemical devices and their integration into the existing energy network or with hard-to-abate sectors is cardinal for reaching the EU goal of the full carbon-neutrality by 2050.

Knowledge and understanding

At the end of the course the student will have a fundamental understanding of:

- global warming and greenhouse effect;
- electric grid distribution;
- hydrogen economy and pathways for decarbonization;
- hard to abate processes;
- Haber Bosch process to synthesize ammonia;
- classic production of cement and steel;
- chemical industries decarbonization processes;
- energy conversion and storage technologies and applications;
- batteries and supercapacitors;
- economical behaviour;
- economics on energy conversion and storage.

Applying knowledge and understanding

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

- identify and describe the different energy technologies;
- evaluate pro and cons of each technology from technological environmental and economical point on view;
- understand the impact of energy storage and conversion for sustainability;
- evaluate techno-economical analysis of these energy technologies;
- calculate mass and energy flows energy conversion and storage;
- evaluate behavior in using energy technologies and their recycle.

Making judgements

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

- apply the acquired knowledge in various contexts;
- transfer the concepts and approaches introduced in a certain context to connected fields;
- elaborate the concepts of energy conversion and storage and their interaction with the electric grid discussed in the course;
- analyze the materials used, their criticality and possible recycling routes;
- critically evaluate the results obtained from the application of the models;
- identify possible interventions to reduce the impacts.

Communication skills

At the end of the course the student should be able to

- analyze an energy conversion and storage related problem in a clear and concise way;
- explain with a suitable language the objectives, the technologies introduced, the operations and the impacts of related energy technologies;

Learning skills

At the end of the course the student should be able to understand the topics covered in the scientific literature concerning energy conversion and storage.

Contents

- Greenhouse gases, concept and consequences.
- Mass and energy balance.
- Hydrogen economy.
- Decarbonize hard to abate industries.
- Electrochemical conversion and production through fuel cells and electrolyzers.
- Electrochemical storage through batteries.
- Other energy storage.
- Environmental Analysis.
- Techno-economic analysis.
- Psychology meets economics: what does behavioral economics study?
- Cognitive and evaluative biases in economic decision-making.
- Behavioral policy-making: nudging and real-world applications.

Detailed program

- Greenhouse gases and manmade global warming: discussion using the IPCC.
- The transition from fossil fuels to renewable energy through the Green Deal.
- Concepts of mass flow and energy flow to introduce energy storage and utilization.
- Hydrogen economy, concepts and integration into the existing industrial context.

- Concept of hydrogen colours and hydrogen production.
- Hard to abate industries: the case of ammonia production.
- Hard to abate industries: the case of steel production.
- Hard to abate industries: the case of cement production.
- Decarbonize transportation through hydrogen technologies for automotive.
- Electrolyzers types and operations.
- Economics on utilization of water.
- Economics on water electrolyzers considering critical raw materials.
- Fuel cells types and operations.
- Economics on fuel cells considering critical raw materials.
- Power-to-gas: converting electrochemically carbon dioxide into valuable products.
- Batteries types and operations.
- Economics on utilization of primary and secondary batteries.
- Hydraulic energy type and operations.
- Economics on hydraulic energy.
- Flywheels and their implications.
- Environmental implications.
- Life cycle assessment over examples of electrochemical technologies.
- Behavioral economics: assumptions and methodological approaches.
- Kahneman's architecture of choice.
- Cognitive and evaluative biases: framing effects, loss aversion and status quo bias, sunk-cost bias, information aversion, intertemporal choices, and present bias.
- Nudging: default options, salience and framing of relevant information, cooling-off periods, soft constraints, gamification, social norm salience, and SMarT interventions.
- Applications in the field of energy use and consumption behavior.

Prerequisites

- Basic knowledge of organic and inorganic chemistry and biology.
- Basic notions of thermodynamics.

Teaching form

- 8 CFUs of theoretical lessons in the classroom (68 hours): 48 hours classes and 20 hours exercises
- > 16 two-hour lectures (32 hours total), in person, Delivered Didactics.
- > 8 two-hour lectures (16 hours), online, Mixed Didactics / Seminar.

Attendance to lectures and interactive exercises is highly recommended.

Textbook and teaching resource

- Slides.
- Notes shown during lectures and additional material on selected topics, *i.e.*, scientific articles, made available on the e-learning website of the course.

Semester

I semester (October - January)

Assessment method

The final exam consists of a single written exam at the end of the course, with a score between 18-30 / 30, which comprises the discussion of various topics covered in the course, with an emphasis also on the connections between concepts and processes.

Assessment will be based on the following criteria:

- (1) knowledge and understanding;
- (2) ability to connect different concepts;
- (3) autonomy of analysis and judgment;
- (4) ability to correctly use scientific language.

Grade < 18

Knowledge and Understanding: The student only partially identifies the characteristics of the concepts. The connections between the concepts are fragmented and poorly supported by theoretical knowledge.

Ability to apply knowledge and understanding: The student identifies only a few relevant elements in a phenomenon, unable to integrate them into a coherent analysis.

Communication and Argumentation Skills: In the written exam, the student develops a basic argument, lacking logical structure and characterized by numerous inaccuracies.

Learning, self-assessment, and self-regulation skills: The student is able to reconstruct only some aspects of their learning and professional development journey.

Grade 18-22

Knowledge and Understanding: The student recognizes and explains most of the conceptual features and is able to provide a relatively coherent explanation, albeit with some inaccuracies. References are present but not always rigorously.

Ability to apply knowledge and understanding: The student is able to recognize a significant number of elements and provide a partial explanation, while highlighting some gaps in the analysis.

Communication and argumentation skills: In the written exam, the student constructs a basic argument, with a minimal structure but with some inaccuracies.

Learning, self-assessment, and self-regulation skills: The student demonstrates a basic awareness of their learning path, managing to draw essential connections between learning experiences, albeit with some inaccuracies.

Grade 23-27

Knowledge and Understanding: The student demonstrates a thorough understanding of conceptual characteristics. In the oral exam, explanations are well-articulated and supported by an appropriate use of theoretical references.

Ability to apply knowledge and understanding: The student accurately identifies the essential elements of a phenomenon. The application of knowledge occurs with methodological rigor that is not always solid.

Communication and argumentation skills: In the written exam, the student develops a coherent and well-organized argument, demonstrating good command of language and a solid logical-argumentative structure. Writing is clear and effective.

Learning, self-assessment, and self-regulation skills: The student analyzes his or her learning journey in a clear and structured manner, highlighting significant relationships between the various energy technologies and demonstrating a good capacity for critical reflection.

Grade 28-30

Knowledge and Understanding: The student demonstrates a thorough mastery of concepts, articulating complex connections and providing comprehensive explanations. Theoretical references are used with relevance and rigor.

Ability to apply knowledge and understanding: The student demonstrates an advanced ability to analyze a phenomenon, comprehensively identifying and interpreting all salient elements. Knowledge is applied with methodological rigor, supported by solid and detailed argumentation.

Communication and argumentation skills: In the written exam, the student develops a solid and detailed argument, with a rigorous logical structure and a high level of textual coherence. The presentation is fluent and well-structured.

Learning, self-assessment, and self-regulation skills: The student demonstrates an advanced capacity for self-reflection, developing a detailed and in-depth analysis of their learning and professional development journey. The connections between learning experiences and theoretical concepts are clear, coherent, and rigorous.

Office hours

Always, after scheduling an appointment *via* e-mail.

Sustainable Development Goals

QUALITY EDUCATION | CLEAN WATER AND SANITATION | AFFORDABLE AND CLEAN ENERGY |
INDUSTRY, INNOVATION AND INFRASTRUCTURE | RESPONSIBLE CONSUMPTION AND PRODUCTION |
CLIMATE ACTION
