Batteries and Fuel Cells

Basic information

Field of study Renewable Energy and Energy Management **Speciality** All **Department** Faculty of Energy and Fuels **Study level** Second-cycle (engineer) programme **Study form** Full-time studies **Education profile** General academic	**Didactic cycle** 2021/2022 **Subject code** EiPEOZS.IIi2S.04e715ffa8f525ddaa51bcc70c0cf0e9.21 **Lecture languages** English **Mandatory** Obligatory **Block** Major Modules **Subject related to scientific research** Yes

Subject coordinator	Magdalena Dudek
Lecturer	Magdalena Dudek, Bartłomiej Lis, Andrzej Raźniak

Period Semester 2	**Examination** Exam **Activities and hours** Lecture: 15, Laboratory classes: 30, Project classes: 15	**Number of ECTS points** 6.0

Goals

C1	The mission of the subject “batteries and fuel cells” is to transfer interdisciplinary knowledge about electrochemical power sources
C2	It is a description of the fundamental design and function of electrochemical power sources (primary, secondary batteries, flow-batteries, fuel cell systems).
C3	The special input was put to the possibility of their application as components of a power system with improved efficiency and low negative impact on the natural environment.
C4	The integration of hydrogen, batteries and fuel cells with an off-grid/on-grid system will be discussed.
C5	An analysis of the use of fuel cells in a circular economy system will be also considered.
C6	The new materials for different types of fuel cells

Subject learning outcomes

Code	Outcomes in terms of	Directional learning outcomes	Examination methods
Knowledge – Student knows and understands:			
W1	Knows and understands the phenomena described in the basic sciences, methods of their thermodynamic description and modelling in connection with the use of materials in the power industry.	EOZ2A_W01	Execution of laboratory classes, Examination
W2	Knows and understands basic and advanced processes occurring during the operation and functioning of machines, networks and power and electrical systems that use renewable energy sources, the importance of automation and control of their operation, the importance of proper design and selection, forecasting and planning of their development and the impact of energy technologies on the environment.	EOZ2A_W02	Execution of laboratory classes, Examination, Engineering project
Skills – Student can:			
U1	Is able to use knowledge to plan and conduct research on energy processes using various methods, including experimental ones, is able to use available software and create own computer codes for the purpose of analysis of the solution, is able to perform a critical analysis of results and prepare a synthetic compilation presenting the results of conducted research in terms of economic and environmental analysis.	EOZ2A_U02	Execution of laboratory classes
U2	Is able also to assess the impact of energy systems on the global functioning of civilization, including society, natural environment, economic and social development and related issues, is able to present own point of view to a wide range of audiences, also using a foreign language and presentations illustrating advanced technical and non-technical problems in the field of energy	EOZ2A_U07	Engineering project
U3	Is able to formulate hypotheses related to the functioning and effectiveness of renewable energy systems, perform verification analysis, apply optimization methods and solve practical technical and economic problems.	EOZ2A_U03	Execution of laboratory classes, Engineering project

Social competences – Student is ready to:			
K1	Is aware of the need to critically assess the information received and knowledge acquired, recognizes the importance of knowledge in addressing cognitive and practical problems, in particular in the field of energy.	EOZ2A_K01	Engineering project
K2	Is aware of responsibility for the tasks performed, is willing to think and act in an entrepreneurial and professional manner, is aware of compliance with the principles of professional ethics and the cultivation and dissemination of appropriate practices, as well as initiation of actions for the benefit of the social community and public interest, including the rational use of energy and provision of the national energy security.	EOZ2A_K02	Engineering project

Programme content that ensure achieving learning outcomes for the module

The subject have research character aimed to achieved the basic knowledge and practical skills for energy systems involving electrochemical power sources. Students are joined in practical research with real power sources. They analyze the impact of choice the type of electrochemical source on the efficiency of real energy system.

Calculation of ECTS points

Activity form	Average amount of hours* needed to complete each activity form
Lecture	15
Laboratory classes	30
Project classes	15
Preparation for classes	30
Preparation of project, presentation, essay, report	45
Realization of independently performed tasks	15
Contact hours	5
Examination or Final test	2
Student workload	**Hours** 157
Workload involving teacher	**Hours** 60

* hour means 45 minutes

Study content

No.	Course content	Subject learning outcomes	Activities
1.	Introduction to subject : Electrochemistry and Electrochemical Engineering Science; electrochemical interface; power sources (batteries, fuel cells and supercapacitors, Faraday efficiency and energy efficiency of electrolyser and fuel cells, world market for industrial power sources, electrochemical storage technologies, hydrogen economy; Laboratory exercises I - Introduction to electrochemistry : The electrical characteristic of hydrogen-fuel single fuel cells, battery , supercapacitor. The comaprative studies of main group of power sources. Project analysis of electrical paramters of such devices, and calculation capacity, time of operation under variable electrical load. The analysis of technical data of batteries, fuel cells, supercapacitors, supplied by manufacturer Lecture duration : 1,5h	W1, W2, U1, U2, U3, K1, K2	Lecture
2.	Lecture: Primary batteries (General Characteristic and Application of Primary Batteries), Types and characterization of primary batteries. Zinc-carbon batteries, magnesium and aluminium batteries, zinc - air batteries. Rechargeable batteries : lead acid battery, nickiel cadmium battery, nickiel metal hydride, lithium polymer batteries, lithium-iron phosphate battery. The rules of construction batteries for mobile and stationary applications. Battery Managment systems (BMS) and Life Prediction. Lecture duration (1,5 h) Laboratory : Li-Pol battery for mobile applications (bike, scotter battery). The characteristic of batery under stateady -state conditions (charging vs.dischraing process in statedy state conditions and under variable electrical load. The analysis of current, voltage and capacity. Project: Concept, design of battery for pratical applications (drone, bike, PV pannel, etc)	W1, W2, U1, U2, U3, K1, K2	Lecture, Laboratory classes, Project classes
3.	Lecture : Redox Flow Batteries: Fundamentals and Applications : Classic vanadium redox flow batteries; types and configurations of redox flow batteries; Redox active organic electrolytes. The pratical application of redox flow batteries. Supercapacitors; types, challenges and opportunities for supercapacitors, application in devices. (Time duration 1.5 h) Laboratory : Charging and discharging of single supercapacitors, or supercapacitors battery, Project: Supercapacitors vs. batteries in power secor and transport application	W1, W2, U1, U2, U3, K1, K2	Lecture, Laboratory classes, Project classes

4.	Lecture Polymer membrane fuell cells PEMFCs. Introduction to PEMFCs (low temperature polymer membrane fuel cells LT-PEMFCs, high temperature polymer membrane fuel cells HT-PEMFCs). Main types and structures of PEMFCs, Electrochemical process in PEMFCs, Brief introduction to electrochemical kinetics, polarization and energy losses. LT-PEMFC stack construction (colling media : air, lidiud medium, passive cooling system). Comparsion LT-PEMFC and HT-PEMFC stack performance. Time duration (1.5h) The laboratory : LT-PEMFC and HT-PEMFC 5kW power sources Project : LT-PEMFC and HT-PEMFC in the CHP system for domestic application	W1, W2, U1, U2, U3, K1, K2	Lecture, Laboratory classes, Project classes
5.	Lecture : Molten carbonate fuel cells (MCFC) and Solid Oxide Fuel Cells (SOFCs). Introduction to MCFC and SOFCs fuel cells. The analysis of Fuels, which can be used to supply them. Electrochemical and chemical processes in MCFC and SOFCs. Current Technolgies of MCFC and SOFCs system, Performance and durability of MCFC and SOFC in power enegineering sectors. Time duration (1.5h) Laboratory: The influence of type of fuel on the performance solid oxide fuel cells. Project : The design and construction of SOFC stack (tubular or planar configuration)	W1, W2, U1, U2, U3, K1	Lecture, Laboratory classes, Project classes
6.	Lecture : Advanced Batteries for Electric Vehicles, Stationary and Emerging Applications (Traction Batteries, batteries for telecomunications and ups, load levelling, batteries for solar and wind energy storage, Miscellaneous application I : Metering Power Tool, Alarm/Security/Medical Equipments. Miscellaneous Application II. Tracking Systems, Toll Collection, Oil Drilling, Car acessories, Oceanography. Battery Mangment and Life Prediction Time duration : 1.5 h Laboratory : The battery - HT-PEMFC as power system for UPS and cars applications Project : The design of electrochemical hybrid source for smart grid applications	W1, W2, U1, U2, U3, K1, K2	Lecture, Laboratory classes, Project classes
7.	Lecture : Battery collection and recycling (Eco-efficiency study on recycling techniques), battery collections schemes, recycling of mixed batteries, recycling of NiCd batteries, NiMH batteries, recycling Li-polymer batteries Project : materials and energy recovery from waste batteries.	W1, W2, U1, U2, U3, K1, K2	Lecture, Project classes

8.	Lecture : Fuel Cell Energy for the Recycling, waste materials as fuel for supplying fuel cells, electrochemical conversion of waste materials in fuel cells for production heat and power. Biochemical, biological fuel cells, time duration 1.5 h Laboratory : Biochemical hydrogen fuel cells, Project : Biohydrogen production from waste organic materials for supplying PEMFC or SOFC stack	W1, W2, U1, U2, U3, K1, K2	Lecture, Laboratory classes, Project classes
9.	Lecture Hybrid energy systems for off-grid power supply and hydrogen production based on renewable energy: A techno-economic analysis Time duration 1.5 h Laboratory The efficiency analysis of grid off autonomic system involving PV pannels, battery, hydrogen and fuel cells Project The eficiency analysis of PV pannels-wind tubrine, electrolyser, hydrogen, battery system for electricity and heat production for small house	W1, W2, U1, U2, U3, K1, K2	Lecture, Laboratory classes, Project classes
10.	Lecture :Codes, standard and safety regulations for testing and application of electrochemical applications in stationary and transport application Project : Integration of safety and law regulations for hydrogen application in different area of transport, buildings, stationary applications	W1, W2, U1, U2, U3, K1, K2	Lecture, Laboratory classes, Project classes

Course advanced

Teaching methods:

Lectures, Laboratory classes, Discussion, E-learning, Case study, Group work method, Design thinking, Problem based learning

Activities	Examination methods	Credit conditions
Lecture	Examination	pass the exam
Lab. classes	Execution of laboratory classes	postive marks from pratical exercises and reports
Project classes	Engineering project	Solve enginnering tasks, description project, data analysis and conclusion are obligatory for positive mark

Additional info

Requirements and method of completing particular forms of classes

Credit conditions for the course
Lectures : positve mark from test, obligatory :yes
Laboratory : pratical performance of laboratory exercise, elaborating experimental data acording to instructions and preparing report, positive mark from all reports, obligatory : yes

Project - solving corectly the pratical task (concept, calculation and description), obligatotry : yes

Method of calculating the final grade

The final mark of the subject will be calculated from the formula: 0.4 * E + 0.4 * L + 0.2 * P and it applies to all dates of crediting E-exam, L-Laboratory, P-project. The final grade is determined to two decimal places without rounding. In accordance with the following rule depending on the numerical value : 1) from 3.0 verbal rating : sufficient (3.0);
2) from 3.21 verbal mark: plus sufficent (3.5), 3)from 3.71 verbal mark: good (4.0), 4) from 4.21verbal mark :plus good (4.5), 5) from 4.71 verbal mark: very good (5.0)
The grade indicate that a student is able to think beyond the boundaries and explore the possibilities for solving problems related to the integration of hydrogen, batteries and fuel cells in the energy system (in reference to EIT OLO 3), i.e. is able to:
5.0 - find solutions to address all problems related to the integration of considered electrochemical power sources,
4.5 - find solutions to address and solve main problems related to the integration of considered electrochemical power sources,
4.0 - find solutions to address and solve some problems related to the integration of considered electrochemical power sources,
3.5 - combine a collection of available ideas to address and solve some problems related to the integration of considered electrochemical power sources,
3.0 - reformulate and apply available ideas to address and solve some problems related to the integration of considered electrochemical power sources,
2.0 - no evidence of the Learning Outcomes shown.

Method and procedure for compensating for missed coursework resulting from student absence from classes

A student who was absent from classes is required to pass laboratory classes on the date agreed with the staff.
A student who, due to random reasons, was absent from project classes, is also obliged to complete the arrears by the date indicated by the teacher

Entry requirements

basic knowledge about electrochemistry, power and electrochemical enginering

Attendance requirements for particular classes, with indication whether student attendance is compulsory

Credit conditions for the course
Lectures : positve mark from test (T)
Laboratory : pratical performance of laboratory exercise, elaborating experimental data acording to instructions and preparing report, positive mark from all reports (L)
Students should participate in lectures, the obligatory participation of students in laboraotory and project classes is required
Project - solving corectly the pratical task (concept, calculation and description), (P)

Literature

Obligatory

1. Wolf Vielstich (Editor), Arnold Lamm (Editor), Hubert A. Gasteiger (Editor) Handbook of Fuel Cells: Fundamentals, Technology, Applications, 4 Volume Set ISBN: 978-0-471-49926-8
2. Vladimir S. Bagotsky Alexander M. Skundin Yurij M. Volfkovich Electrochemical Power Sources: Batteries, Fuel Cells, and Supercapacitors, Print ISBN:9781118460238 |Online ISBN:9781118942857

Optional

1. G. Glaize, S. Genies, Lead and Nickiel Electrochemical Batteries, ISBN: 978-1-118-56312-0, Willey
2. Dr. Ru-Sh, i Liu Lei Zhang, Xueliang Sun, Hansan Liu , Jiujun Zhang Electrochemical Technologies for Energy Storage and Conversion, 1and 2 Print ISBN:9783527328697 |Online ISBN:9783527639496

Research and publications

Research

1. The characterization of different types of batteries as power sources for construction propulsion units
2. The impact of different type of fuels on the performance of fuel cells. Analysis of possible energy losses in different fuel cells
3. Electrochemical hybrid electrochemical sources for application in stationary and mobile systems
4. New materials for construction different types of fuel cells
5. Electrochemical conversion of waste materials in fuel cells, circular economy

Publications

1. Electric motor-glider powered by a hydrogen fuel cell stack / Piotr Czarnocki, Magdalena DUDEK, Krzysztof Drabarek, Wojciech Frączek, Grzegorz Iwański, Tomasz Miazga, Marcin Nikoniuk, Andrzej RAŹNIAK, Maciej ROSÓŁ // MATEC Web of Conferences [Dokument elektroniczny]. 2019 vol. 304 art. no. 03011, s. 1–8.
2. The usefulness of walnut shells as waste biomass fuels in direct carbon solid oxide fuel cells / Magdalena DUDEK, Bartosz ADAMCZYK, Maciej SITARZ, Michał Śliwa, Radosław LACH, Marek Skrzypkiewicz, Andrzej RAŹNIAK, Magdalena ZIĄBKA, Jarosław Zuwała, Przemysław GRZYWACZ // Biomass & Bioenergy ;2018 vol. 119,
3. Power sources involving $~$ 300W PEMFC fuel cell stacks cooled by different media / Magdalena DUDEK, Andrzej RAŹNIAK, Bartłomiej LIS, Michał Kawalec, Mariusz Krauz, Tadeusz WÓJCIK // E3S Web of Conferences
4. Analysis od the impact of the power source on the properties of brushless permanent magnet DC motor for the propulsion of UAV / Piotr Bogusz, Mariusz Korkosz, Piotr Wygonik, Magdalena DUDEK, Bartłomiej LIS // Przegląd Elektrotechniczny / Stowarzyszenie Elektryków Polskich ; ISSN 0033-2097. — 2015 R. 91 nr 5, s. 139–143
5. Ba0.95Ca0.05Ce0.9Y0.1O3 as an electrolyte for proton-conducting ceramic fuel cells / M. DUDEK, B. LIS, R. LACH, [et al.], M. GAJEK, M. SITARZ, M. ZIĄBKA // Electrochimica Acta : Journal of the International Society of Electrochemistry ; ISSN 0013-4686. — 2019 vol. 304, s. 70–79
6. Biomass fuels for direct carbon fuel cell with solid oxide electrolyte / Magdalena DUDEK, Piotr TOMCZYK, Robert Socha, Marek Skrzypkiewicz, Janusz Jewulski // International Journal of Electrochemical Science 2013 vol. 8 iss. 3, s. 3229–3253
7. Inkjet printing of direct carbon solid oxide fuel cell components / R.I. Tomov, M. DUDEK, S.C. Hopkins, M. Krauz, H. Wang, C. Wang, Y. Shi, P. TOMCZYK, B.A. Głowacki // ECS Transactions / The Electrochemical Society ; ISSN 1938-5862. — 2013 vol. 57 no. 1, s. 1359–1369
8. Synthesis and characterisation of sulphided lithium manganese spinels prepared by sol-gel method / M. Molenda, R. Dziembaj, D. Majda, M. DUDEK // Solid State Ionics ; ISSN 0167-2738. — 2005 vol. 176 iss. 19–22, s. 1705–1709.
9. XPS and ionic conductivity studies on Li1.3Al0.15Y0.15Ti1.7(PO4)3 ceramics T. Šalkus, E. Kazakevičius, A. Kežionis, V. Kazlauskienė, J. Miškinis, A. Dindune, Z. Kanepe, J. Ronis, M. Dudek, M. Bućko, J. R. Dygas, W. Bogusz & A. F. Orliukas, Ionics 16, 631–637(2010)

Directional learning outcomes

Code	Content
EOZ2A_K01	Is aware of the need to critically assess the information received and knowledge acquired, recognizes the importance of knowledge in addressing cognitive and practical problems, in particular in the field of energy.
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EOZ2A_U03	Is able to formulate hypotheses related to the functioning and effectiveness of renewable energy systems, perform verification analysis, apply optimization methods and solve practical technical and economic problems.
EOZ2A_U07	Is able also to assess the impact of energy systems on the global functioning of civilization, including society, natural environment, economic and social development and related issues, is able to present own point of view to a wide range of audiences, also using a foreign language and presentations illustrating advanced technical and non-technical problems in the field of energy.
EOZ2A_W01	Knows and understands the phenomena described in the basic sciences, methods of their thermodynamic description and modelling in connection with the use of materials in the power industry.
EOZ2A_W02	Knows and understands basic and advanced processes occurring during the operation and functioning of machines, networks and power and electrical systems that use renewable energy sources, the importance of automation and control of their operation, the importance of proper design and selection, forecasting and planning of their development and the impact of energy technologies on the environment.