National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

Department of the Electrical Engineering Automation & Mechatronic Complexes (EEAMC)

INFRASTRUCTURE OF TECHNOLOGIES FOR THE PRODUCTION AND ACCUMULATION OF HYDROGEN FOR ENERGY AND TRANSPORT

Working program of the academic discipline (SYLLABUS)

Details of the academic discipline

Level of higher education	***Second (master's)***
Branch of knowledge	*14 Electrical engineering*
Specialty	*141 Power engineering, electrical engineering and electromechanics*
Educational program	*Engineering of intelligent electrotechnical and mechatronic complexes* ***Certificate programm****: Engineering and automation of hydrogen energy systems and technologies*
Discipline status	*Selective*
Form of education	*Full-time (day)/remote*
Year of training, semester	*1 year of study, spring semester*
Scope of the discipline	*5.0 credits 150 hours (36 hours of lectures, 18 hours of practical, 96 SRS)*
Semester control/ control measures	*Credit, MKW*
Lessons schedule	*http://roz.kpi.ua/*
Language of teaching	*Ukrainian*
Information about the head of the course / teachers	Lecturer: *Doctor of Technical Sciences, Professor, Boichenko Sergii,* *tel. 093-457-01-13,* *E-mail : boichenko.sergii@lll.kpi.ua, chemmotology 1 @gmail.com*[1] Practical/Seminar: *Doctor of Technical Sciences, Professor, Boichenko Sergii*
Placement of the course	*Link to the remote resource:* *Google Classroom: https :// classroom . google . com / c / NTg 0 MDc 0 NTA 4 NDc 3* https://classroom.google.com/c/NTgzMzk2MDk2NTc3 (correspondence form) *https://campus.kpi.ua/*

Program of educational discipline

1. Description of the educational discipline, its purpose, subject of study and learning outcomes

The discipline "Infrastructure of technologies for the production and accumulation of hydrogen for energy and transport", like other special disciplines, performs both basic educational and developmental and general educational functions, the essence of which is the formation of integrated knowledge and skills necessary for future creative engineering activities a specialist in hydrogen energy systems and technologies.

The main goal of teaching the educational discipline" Infrastructure of technologies for the production and accumulation of hydrogen for energy and transport " is the study of production technologies and equipment for the accumulation and storage of hydrogen, its physical-chemical, operational and ecological properties of fuel and energy resources, as well as the essence of technological processes, related to production, infrastructure and further rational use of hydrogen in energy and as motor fuel.

The subject of the educational discipline is the infrastructure of technologies for the production and accumulation of hydrogen.

Program competences: The main task of the educational discipline is the acquisition of professional skills by students on the basis of practical and theoretical materials regarding the main technological processes of production, accumulation and storage of hydrogen. The ability to apply methods of system analysis, engineering and management decision-making regarding the rational use of hydrogen in energy and as a motor fuel.

Program learning outcomes:

use theoretical knowledge to solve practical tasks of engineering support for the rational application of technological processes of hydrogen production, its accumulation and storage; automate technological processes; to establish the relationship between the physical-chemical, operational and environmental properties of hydrogen; analyze technological processes, optimize them through automation; determine the most important, optimal technological parameters and justify optimal technological processes, as well as operational conditions for the rational use of hydrogen and form the infrastructure for the rational operation of technological equipment .

2. Pre-requisites and post-requisites of the discipline (place in the structural and logical scheme of training according to the relevant educational program)

Prerequisites: the discipline is based on students' knowledge of basic concepts in physics, mathematics, economics, philosophy, sociology, ecology and professional training disciplines, aimed at acquiring the skills of a systematic approach to the study and solving of current and prospective problems of energy, rational use of energy resources and engineering and technological methods in solving specific practical situations, as well as the ability to correctly assess the local and remote consequences of management and engineering decisions regarding the use of hydrogen.

Post-requisites. Competences that will be acquired by students during the study of this discipline should be applied by them during the execution of the master's thesis, as well as future engineering tasks in the field of energy, in particular, electrical engineering, renewable energy sources, alternative energy in general, etc.

3. Content of the academic discipline

Part 1. Regulatory, technical and organizational principles of engineering support for the rational use of energy resources:

Topic 1.1. The place and role of the science of rational use of energy resources in the complex system of knowledge. Basic terms and concepts.

Topic 1.2. Classification and characteristics of commercial energy carriers. Legislative basis and basics of technical regulation.

Topic 1.3. Technological bases of production of commodity energy carriers and technological equipment for their storage and use.

Topic 1.4. Modern technology and innovative technologies.

Part 2. Properties and technologies of production, accumulation, storage and use of hydrogen:

Topic 2.1. Basic properties and classification of hydrogen as an energy carrier.

Topic 2.2. Basic technological processes of hydrogen production.

Topic 2.3. Hydrogen storage technologies.

Topic 2.4. Hydrogen transportation technologies.

Topic 2.5. Hydrogen storage technologies.

Topic 2.6. Technologies of hydrogen use in energy and transport.

4. Educational materials and resources

Basic literature:

1. Andriishyn M. P., Marchuk Y. S., Boychenko S. V. Natural gas, fuel and oil: Monograph. – Odesa: Astroprint, 2010. – 232 p.

2. Fundamental problems of hydrogen energy: a monograph / [Andriichuk I.L. et al.]; under the editorship V. D. Pokhodenko, V. V. Skorokhoda, Yu. M. Solonin; NAS of Ukraine. - K.: KIM, 2010. - 495 p.

3. Boychenko VILLAGE. IN. RATIONAL use of hydrocarbon fuels. - K.: NAU, 2001. - 216 p.

4. Bratychak M. M., Hryshiny O. B. Oil and gas technology. - Lviv: Lviv Polytechnic National University, 2002. - 179 p.

5. Alternative energy resources: a study guide / S. V. Boychenko, A. V. Yakovleva, O. O. Vovk, Kazimyr Leyda, S. Y. Shamanskyi; in general edited by Professor SV Boychenko. - K.: NAU, 2021. - 397 p. (URL: https://ela.kpi.ua/handle/123456789/49236).

6. Kudrya S.O., Kuznetsov M.P., Morozov Y.P., etc. // Renewable energy sources, Monograph: Edited by. S.O. Curls. - Kyiv: Institute of Renewable Energy of the National Academy of Sciences, 2020. - 392 p.

7. Energy sources. Workshop [Electronic resource]: study guide for students, specialties 144 "Heat power" and 141 "Electric power, electrical engineering and electromechanics" / KPI named after Igor Sikorskyi; edited by: V. V. Dubrovska, V. I. Shklyar. – Electronic text data (1 file: 1.49 MB). – Kyiv: KPI named after Igor Sikorskyi, 2019. – 71 p. (URL: https://ela.kpi.ua/handle/123456789/41491).

8. Malyarenko V. A. Synopsis of lectures on the discipline "Power generation technology" / V. A. Malyarenko, S. I. Dotsenko, I. O. Temnokhud; Hark. national city university farm named after O. M. Beketova. - Kh.: XNUMG, 2014. - 164 p.

9. Study of the operation of the electrolyzer and fuel cell. Laboratory work [Electronic resource]: teaching. manual for students specialty 144 "Heat power" / V.V. Dubrovska, V.I. Shklyar, V.I. Deshko, D.V. Biryukov; KPI named after Igor Sikorsky. – Electronic text data (1 file: 0.83 MB). – Kyiv: KPI named after Igor Sikorskyi, 2022. – 35 p. (URL: https://ela.kpi.ua/handle/123456789/48279).

Supporting literature:

1. Motor fuels: properties and quality. Textbook / Serhii Boychenko, Andriy Pushak, Petro Topilnytskyi, Kazimir Leyda; in general ed. Prof. S. Boychenko. - K.: "Center of educational literature". 2017. – 324 p. (URL: https://ela.kpi.ua/handle/123456789/49646).

2. Vorrath S. BNEF: Renewable hydrogen can replace gas in power generation. (URL: https://ieefa.org/bnefrenewable-hydrogen-can-replace-gas-in-power-generati on / (accessed 09/01/20).

3. Fundamentals of system analysis: a textbook for universities / M.Z. Zgurovskyi, N.D. Pankratova. - K.: Ed. BHV group, 2007. – 544 p.

4. Fundamental aspects of renewable hydrogen energy and fuel cell technologies / edited by Yu.M. Corned beef - K.: "KIM", 2018. - 260 p.

5. Atlas of the energy potential of renewable energy sources of Ukraine / by general ed. S.O. Curls. – Kyiv: Institute of Renewable Energy of the National Academy of Sciences of Ukraine, 2020. – 82 p.

6. Shabani B., Andrews J. Hydrogen and fuel cells // Energy Sustainability through Green Energy. New Delhi: Springer, 2015. – P. 453–491.

7. M. V. Yatskov, N. M. Korchyk, O. A. Prorok. Basic technological schemes of basic inorganic productions: training. manual. – Rivne: NUVHP, 2020. – 212 p.

8. Chunshan S., Wei P. Tri-reforming of methane: a novel concept for catalytic production of industrially useful synthesis gas with desired H ₑ/CO ratios. - Catalysis Today, 2004. - p. 128–131.

9. Dubrovska, V. V. Technology of production of electric energy [Electronic resource]: a textbook for students studying in specialty 141 "Electroenergetics, electrical engineering and electromechanics" / V. V. Dubrovska, V. I. Shklyar; KPI named after Igor Sikorsky. – Electronic text data (1 file: 6.59 MB). – Kyiv: KPI named after Igor Sikorskyi, 2022. – 316 p. (URL: https://ela.kpi.ua/handle/123456789/48258).

Information resources:

1. Distance course "Infrastructure of technologies for the production and accumulation of hydrogen for energy and transport" - *https :// classroom . google . com / c / NTg 0 MDc 0 NTA 4 NDc 3*
https://classroom.google.com/c/NTgzMzk2MDk2NTc3 (External form of education)

Literature, the bibliography of which is provided with a link, can be found on the Internet or in the electronic library of KPI named after Igor Sikorsky. Literature, the bibliography of which does not contain references, can be found in the library or on the Internet, or in the library of the department.
Basic literature [1-3,6-9] is mandatory for reading. All other literary sources are optional, it is recommended to familiarize yourself with them

Educational content

5. Methods of mastering an educational discipline (educational component)

The method of teaching the discipline combines visual teaching methods with explanation. Teaching is conducted in the form of lectures, practical and laboratory (practicum) classes. The problem-search method and cause-and-effect analysis are used during the calculation work.

Lecture

No s/p	Name of the topic of the lecture and a list of main questions (reference to the literature)
1	**Topic 1.1.** The place and role of the science of rational use of energy resources in the complex system of knowledge. ***Literature**: 1, 3, 5, 9.*
2	**Topic 1.2.** Classification and characteristics of commercial energy carriers. Legislative basis and basics of technical regulation. ***Literature**: 1, 3, 5, add. lit. 1.5.*
3-4	**Topic 1.3.** Basics of modern energy technologies. Basic knowledge of technological equipment for their storage and use of the main types of energy carriers. ***Literature**: 2-7, dod. lit. 1,5,6,8.*
5-6	**Topic 1.4.** Modern technology and innovative technologies. ***Literature**: 2, 3, 5-9, add. lit. 2,3,5-7.* *Modular control work*
7-8	**Topic 2.1.** Basic properties and classification of hydrogen as an energy carrier. ***Literature**: 2, 6, 9, add. lit. 2,5,7.*
9-10	**Topic 2.2.** Basic technological processes of hydrogen production. ***Literature**: 2,3,5,7,9, additional lit. 2,3,5,7,9.*
11-12	**Topic 2.3.** Hydrogen storage technologies. ***Literature**: 2, 6, 7, 9, add. lit. 5.7.*
13-14	**Topic 2.4.** Hydrogen transportation technologies. ***Literature**: 2, 6, 9, add. lit. 5.7.*
15-16	**Topic 2.5.** Hydrogen storage technologies. ***Literature**: 2, 6, 9, add. lit. 5.7.*
17-18	**Topic 2.6.** Technologies of hydrogen use in energy and transport. ***Literature**: 2, 6, 7, 9, add. lit. 5.7.* *Modular control work*

Practical (seminar) classes

The main tasks of the cycle of practical classes consist in consolidating the knowledge obtained in lectures, familiarization with individual sections.

Also, for students to acquire the skills and experience to operate with modern concepts in the field of rational use of energy resources, which are necessary for the correct perception of the direction of social progress and ensuring safe conditions for the existence of humanity in the future.

No s/p	Tasks assigned to practical classes
1	*Practical lesson 1.* Introduction to the discipline. Subject of discipline. Energy strategy of Ukraine: main provisions
2	*Practical class 2.* Alternative technologies for the production of electrical energy: basic concepts and definitions.
3	*Practical lesson 3.* Technology of electricity production at wind power plants and geothermal power plants.
4	*Practical class 4.* Technology of production of electrical energy by electrochemical sources.

5	*Practical lesson 5.* Technology of production of electric energy by fuel cells. Study of the operation of the fuel cell.
6	*Practical lesson 6.* Study of the operation of a fuel cell in industry and transport (on the example of a transport mechatronic system based on Toyota Mirai car.
7	*Practical lesson 7.* Cogeneration technologies of energy production. Heat pump technologies of energy production and accumulation
8	*Practical lesson 8.* Study of the operation of an electrolyzer.
9	*Practical lesson 9.* Hydrogen technology of electricity storage.

6. Independent work of the student

The student's independent work includes such elements as preparation for current surveys, preparation for practical classes, in particular, preparation of a report and joint report, electronic short informational reports within the deadline specified by the teacher, preparation for a modular control work.

The student's independent work involves:
preparation for classroom classes - 86 hours;
preparation for the modular control work - 4 hours;
preparation for the test - 6 hours

Control works

The purpose of conducting a modular control work is to identify the degree of assimilation of knowledge of the discipline by students, obtained during lectures and practical classes.

The main goal of the MKW is to form students a comprehensive idea of the organization of systematic measures of rational nature management in the context of the doctrines of sustainable development in Ukraine.

Policy and Control

7. Policy of academic discipline (educational component)

During the course, students are obliged to adhere to the general moral principles and rules of ethical behavior specified in the Code of Honor of the National Technical University of Ukraine "Ihor Sikorskyi Kyiv Polytechnic Institute".

Violation of the Code of Academic Integrity of the National Technical University of Ukraine "Ihor Sikorsky Kyiv Polytechnic Institute" is a serious violation, even if it is unintentional. The code is available at the following link: https://kpi.ua/code.3 .

In particular, adherence to the Code of Academic Integrity means that all work on exams and tests must be done individually. During independent work, students can consult with teachers and other students, but must solve tasks independently, guided by their own knowledge, abilities and skills. References to all resources and sources (for example, in reports, independent papers or presentations) should be clearly identified and properly formatted. In the case of joint work with other students on individual tasks, you should indicate the degree of their participation in the work.

Academic Integrity: The policy and principles of academic integrity are defined in section 3 of the Code. Norms of ethical behavior: Norms of ethical behavior of students and employees are defined in section 2.

Requirements for a student of the discipline:

- attending lectures and practical classes is a mandatory component of studying the material, the teacher records attendance at classes;
- the teacher uses *Google classroom* to teach the material of the current lecture, additional resources, practical classes, etc.;
- the teacher uses his own presentation material at the lecture; who, after the lecture, teaches in *Google classroom* on the relevant discipline, where there is a flow of students;
- during lectures, it is forbidden to distract the teacher from presenting the material to students, all questions, clarifications, etc. students ask at the end of the lecture in the time allotted for this;
- MKR is completed during a lecture session and sent to *Google classroom or the teacher's e-mail*;

- in accordance with the "Code of Honor" of the ICR, RR, Tests and Reports students perform independently;
- incentive points are awarded for: active participation in lectures; preparation of reviews of scientific works; presentations on one of the topics, creation of educational and methodical materials; etc. According to the Regulation on the system of evaluation of learning results, the sum of all incentive points cannot exceed 10% of the rating scale;
- penalty points are issued for: late submission of MKR, rewriting of MKR.

Google classroom course on the "Sikorsky" platform open on the device from which he works (the access code to the course is provided at the first lesson according to the schedule). Syllabus; lecture material; tasks for each practical session; variants of modular control work; methodical recommendations for practical work; variants of the credit test are posted on the "Sikorsky" platform and in the "KPI Electronic Campus" system.

All students, without exception, are obliged to comply with the requirements of the Regulations on the Academic Plagiarism Prevention System at the National Technical University of Ukraine "Ihor Sikorskyi Kyiv Polytechnic Institute".

Students who have scored during the semester the number of points (R ≥ 60 points) can get a grade without a credit test. In case of a desire to increase the grade, the student completes a credit test, based on the results of which a grade is assigned.

Students who scored a rating in the discipline Rc < 60 during the semester are required to write a final test.

For participation in the All-Ukrainian Olympiad (competition of scientific works), a student is awarded 5 (I round) or 10 (II round) points. For writing an article and publishing it, the student is awarded 10 points (publication included in Scopus or Web of Science) or 6 points (professional edition of Ukraine). 3 points for publication of report abstracts at a scientific conference. The total amount of incentive points cannot exceed 10 points.

8. Types of control and rating system for evaluating learning outcomes (RSO)

Current control: URL: https://kpi.ua/document_control

Surveys at lectures, participation in seminars, reports (presentations), joint reports, MKW.

Calendar control: is conducted twice a semester as a monitoring of the current state of fulfillment of the syllabus requirements. The condition for a positive first and second calendar control is to obtain at least 50% of the maximum possible rating at the time of the corresponding calendar control.

Semester control: Test.

The size of the RSO scale is 100 points, which is formed during the semester based on the results of the following works:

– survey during lectures (18 points);

– active work in a practical session (participation in the seminar) (9 practical sessions × 2 points = 18 points);

– preparation of a report (presentation) and presentation at a seminar (19 points for 1 report);

– joint presentation (opposition) at the seminar (3 practical classes × 3 points = 9 points);

– writing MKW (2 parts × 18 points = 36 points).

$$RC_{(max)} = 18\ 1 + 9\ 2 + 19 + 3\ 3 + 36 = 100 \text{ points.}$$

The survey is conducted directly during the lecture session. A complete answer is valued at 1 point, the absence of an answer - 0 points.

Active participation in the practical session (participation in the work of the seminar) is assessed at 2 points, less active participation, incorrect questions and comments that indicate the student's unpreparedness for the class reduce the grade for the work in the seminar to 1 point or to 0 points.

Tasks within the framework of the practical session are evaluated in 2 points according to the following criteria: "excellent" - a fully completed task (at least 90% of the required information), the computer workshop was completed with the necessary modeling and answers to questions - 2 points; "good" - the task is sufficiently completed (at least 75% of the required information), the computer workshop is completed with the necessary modeling and answers to questions, but there are minor inaccuracies - 1 point;

"satisfactory" - the task is incompletely completed (at least 60% of the required information), the computer workshop is completed with the necessary modeling and answers to questions, but there are some errors - 0.5 points; "unsatisfactory" - the practice was not completed - 0 points.

A report on a given topic is usually accompanied by a presentation (up to 10 slides).

Evaluation criteria: "excellent": creative disclosure of the task, fluency in the material, appropriate presentation materials - 18-19 points; "good": in-depth disclosure of the task, relevant information - 14-16 points; "satisfactory": reasonable disclosure of the task - 10-12 points; "unsatisfactory": the topic is not disclosed - 0 points.

During the semester, each student acts as a co-speaker (opponent) three times.

Evaluation criteria: "excellent": fluency in the material, well-founded and reasoned questions, remarks and comments - 3 points; "good": good mastery of the material - 2 points; "satisfactory": weak mastery of the material - 1 point; "unsatisfactory": the student does not master the material, does not participate in the work - 0 points.

During the semester, one MKW is held, consisting of two parts. Each part of the MKW contains three complex questions of the theoretical, calculation or open type, valued at 6 points. The MKW part contains three questions to which the student must provide a written answer.

MKW (2 parts) is conducted directly during the lecture session, in the presence of the teacher, in the form of a written work, 18 points (each). At the end of the class, the MKR is handed in and cannot be rewritten or completed at home. MKW is sent to *Google classroom or the teacher's e-mail.*

Students who have met all the admission requirements and have a rating of 60 or more points receive a rating corresponding to the rating without additional tests. The sum of the rating points received by the student during the semester is transferred to the final grade according to the table. If the sum of points is less than 60, but the practical and MKW have been completed and credited, the student completes credit work. In this case, the sum of the points for the practical, MKW and final work is transferred to the final grade according to the table. A student who received more than 60 points in the semester, but wants to improve his result, can take part in credit work. In this case, the final result consists of the points obtained on the assessment work and points for practical and MKW. The credit work is estimated at 63 points. The control task of this paper consists of two theoretical questions from the list provided in the appendix to the syllabus and a practical question. Each question and task is evaluated at 21 points according to the following criteria: "excellent" - a complete answer (at least 90% of the required information), appropriate justifications and a personal opinion are provided - 21 - 19 points; "good" - a sufficiently complete answer (at least 75% of the required information), which is completed in accordance with the requirements for the "skills" level or contains minor inaccuracies - 18 - 16 points; "satisfactory" - an incomplete answer (at least 60% of the required information), completed in accordance with the requirements for the "stereotype" level and containing some errors - 15 - 13 points; "unsatisfactory" - unsatisfactory answer - 0 points.

To assign grades to the examination report, the rating is converted into traditional and ECTS grades according to the table

Scores	Rating
100–95	Perfectly
94–85	Very good
84–75	Fine
74–65	Satisfactorily
64–60	Enough
Less than 60	Unsatisfactorily
MKR is not included	Not allowed
RGR is not included	Not allowed

9. Additional information on the discipline (educational component)

The list of theoretical questions submitted for Current, Calendar and Semester control is given in *Google classroom.*

Distance Learning:

Distance learning in this academic discipline is allowed on the basis of general decisions of the university.

Inclusive education:

This discipline can be taught to most students with special educational needs, except for students with severe visual impairments that do not allow them to complete tasks with the help of personal computers, laptops and/or other technical means.

Learning a foreign language:

Given the specifics of the academic discipline, some concepts and educational material can be studied in English (in fragments).

Taking into account the student-centered approach, at the request of students, it is allowed to study individual topics using appropriate English-language electronic resources (for example, on the Coursera platform "Renewable Energy Technologies and Implementation" - https://www.coursera.org/specializations/renewable-energy , " The Global Energy and Climate Policy" - https://www.coursera.org/learn/globalenergyandclimatepolicy .

Consultations (individual and group) on this academic discipline and independent work of students can be carried out with prior consent in the scientific laboratory, in the scientific and technical library of the university and/or at home, respectively. The educational material provided for assimilation by the student in the process of independent work is submitted to the final control together with the educational material that was studied during the auditable educational classes.

Certificates of completion of face-to-face or distance courses on the subject of the discipline may be included in the rating of the applicant in accordance with the requirements of the Regulations on recognition in KPI named after Igor Sikorsky of the results of training acquired in non-formal/informal education, approved by order No. HOH/157/2023 dated 05/09/2023 (URL: https://kpi.ua/informal-education). At the beginning of the semester, the teacher informs students/students about the possibility of taking appropriate free (or paid) courses at their discretion on the subject of the academic discipline. The applicant can choose an online course independently or on the recommendation of a teacher (for example, on the Prometheus platform "Household waste - act now!" - https://prometheus.org.ua/course/course-v1:IRF+WST101+2019_T2 , "Sustainable and renewable energy" - https://prometheus.org.ua/course/course-v1:Prometheus+ENERG101+2023_T1 , "European Green Course and Ukraine" - https://prometheus.org.ua/course/course-v1: Prometheus+GREEN101+2023_T1 , "The welfare of the planet: what everyone should know and can do" - https://prometheus.org.ua/course/course-v1:WWF+WF101+2023_T1 After the student receives an official certificate of completion of the relevant courses , the teacher has the right to credit the relevant part of the course (or the course as a whole).
1 hour of the course is valued at 1 point. The maximum number of hours that can be credited for the results of non-formal education is 12 hours, accordingly the maximum number of points for such results is 12 points.

Working program of the academic discipline (SYLLABUS):

Compiled by: Doctor of Sciences (Technical), Professor, Boichenko Sergii V.

Approved: by the department of the **EEAMC** scientific and educational institute of energy saving and energy management (protocol № 17 dated May 31, 2023).

Adopted: by the methodological council of the scientific and educational institute of energy saving and energy management (protocol № 9 dated 06.22.23).