COURSE: HYDROGEN STORAGE AND TRANSPORT LOGISTICS

FRAMEWORK FOR SPECIALIZATION IN THE FIELD OF HYDROGEN STORAGE AND TRANSPORT LOGISTICS

In the face of contemporary global challenges, such as disrupted supply chains, armed conflicts, and limited access to key resources, alternative and sustainable energy sources are gaining importance. Among them, hydrogen is emerging as a key energy source of the future. Hydrogen also offers potential not only in the energy sector but also in transport, industry, and many other areas. Hydrogen's potential as a clean fuel will not be fully realized without several important, effective, and safe solutions, including storage and transportation.

Hydrogen logistics represent a complex challenge, requiring specialized knowledge and skills encompassing both advanced technology and rigorous safety standards. It is in this context that efficient hydrogen storage and transportation logistics are becoming a key element in the transition to a hydrogen economy.

Demand for competencies in the next 10 years:
The demand for hydrogen logistics specialists will increase significantly over the next 10 years. This is due to the following trends and factors:

1. **Energy transition** - the world is moving towards decarbonising its economy, and hydrogen is seen as a key element of this process, particularly in sectors such as transport, industry and energy.
2. **Development of hydrogen technologies** - the intensive development of hydrogen production, storage and transport technologies makes it necessary to have2

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3. **Infrastructure investments** – Governments and businesses around the world are investing in building hydrogen infrastructure, including pipelines, refueling stations, storage terminals, and hydrogen production plants. These investments will require logistics specialists.
4. **Increased demand for hydrogen** - with the development of hydrogen technologies, the demand for hydrogen will grow rapidly, which will translate into a greater need for logistics specialists who will manage supply chains.
5. **New regulations and standards** - as the hydrogen market develops, new regulations and standards will be created, which will require specialized knowledge and skills in their interpretation and implementation.
6. **Sustainable development** - growing environmental awareness and the need to minimize environmental impact will result in the need to employ specialists who will implement sustainable logistics solutions.
7. **Education and training** - the increasing demand for hydrogen logistics specialists and storage specialists will require the intensification of educational and training programs.

Hydrogen storage and transport logistics specialists will be in high demand in the coming decade. Their knowledge and skills will be crucial to the development of the hydrogen economy, not only in achieving climate goals. They will be able to find employment in energy, logistics, and transportation companies, as well as in public administration and research organizations.
The labor market for specialists in this field will develop dynamically and place high requirements on competences, which makes this qualification an attractive choice for people looking for future-oriented qualifications – professional competences.
Description of qualifications in the scope: Hydrogen storage and transport logistics - includes effects preparing specialists to effectively and responsibly manage hydrogen supply chains from storage to transport to the end user.

Combining aspects of hydrogen storage and transport:

- **Storage technology:** Storing hydrogen at high pressure (350-700 bar) in cylinders or tanks is common, but has capacity and weight limitations. Storing hydrogen in liquefied form (LH2) is more volume-efficient but requires very low temperatures (-253°C) and is energy-intensive. Methods of storing hydrogen in chemical compounds (e.g., ammonia, methanol) are also being explored, allowing for safer transportation but requiring additional conversion processes.

- **Transport infrastructure:** Hydrogen transport requires the development of specialized infrastructure. Hydrogen pipelines are effective over long distances, but their construction is expensive. Road and rail transport require specialized tankers, and maritime transport requires adapted vessels. The development of this infrastructure is crucial for the efficient distribution of hydrogen.
- **Safety:** Hydrogen is flammable and explosive, so safe storage and transportation are a priority. Appropriate standards, procedures, detection, and protection systems are required. The materials used in tanks and pipelines must be corrosion- and stress-resistant.

The table below lists the learning outcomes and assessment criteria for each competency:

COMPETENCY 1: SAFE AND RESPONSIBLE ACTIVITIES IN ORGANIZING HYDROGEN STORAGE AND TRANSPORT	
Applies safety rules for the storage and transport of hydrogen	• Identifies and describes in detail the causes of hydrogen-related explosions and fires. • Is able to list and describe basic safety rules for the storage and transport of hydrogen. • Understands the specific properties of hydrogen, such as its flammability, explosiveness, and storage requirements. • Explains the phenomenon of hydrogen embrittlement and its impact on structural materials. • Can identify potential hazards associated with improper storage or transport of hydrogen. • Characterizes various emergency scenarios (e.g. leakage, rupture, ignition). • Is able to identify risky situations and propose appropriate preventive measures. • Correctly applies hydrogen storage procedures, such as checking container tightness and monitoring pressure and temperature. • Selects and operates appropriate equipment and materials, e.g. high-pressure or cryogenic tanks.

COMPETENCY 1: SAFE AND RESPONSIBLE ACTIVITIES IN ORGANIZING HYDROGEN STORAGE AND TRANSPORT

Applies safety rules for the storage and transport of hydrogen	• Applies the principles of safe hydrogen transport, including securing containers, compliance with labelling and transport regulations (e.g. ADR). • Predicts/identifies the impact of external conditions (e.g. temperature, vibrations) on transport safety. • Analyzes hydrogen detection methods and alarm systems. • Responds in an emergency, e.g. in the event of a hydrogen leak, in accordance with applicable procedures. • Selects individual and group protective measures to be used in hazardous situations. • Applies applicable legal regulations and standards regarding the storage and transport of hydrogen. • Identifies information in technical documentation and regulations relating to hydrogen.
Determines the physical and chemical properties of hydrogen	• Distinguishes between isotopes of hydrogen. • Explains what orthohydrogen and parahydrogen are and how this affects storage. • Justifies the density of hydrogen in various states of aggregation (gas, liquid, solid). • Indicates key temperatures for hydrogen (boiling, critical, triple point). • Describes the explosive range and flammability limits of hydrogen in a mixture with air. • Explains hydrogen diffusivity and its safety implications. • Analyses the corrosive properties of hydrogen and its effect on various materials. • It describes hydrogen as a flammable and explosive gas, giving lower and upper explosive limits in a mixture with air. • This explains the high chemical reactivity of hydrogen, especially in reactions with oxygen, halogens and metals.

COMPETENCY 1: SAFE AND RESPONSIBLE ACTIVITIES IN ORGANIZING HYDROGEN STORAGE AND TRANSPORT

Determines the physical and chemical properties of hydrogen	• Explains the role of hydrogen as a reducing agent in chemical reactions, e.g. in the chemical industry or metallurgy. • Describes the occurrence of hydrogen in nature in molecular form (H_2) and the importance of atomic hydrogen in chemical reactions. • Lists the isotopes of hydrogen (protium, deuterium, tritium) and their basic properties, giving examples of their applications. • Explains the high thermal conductivity of hydrogen and its importance in industrial applications. • It describes the behavior of hydrogen under extreme conditions, such as very high temperatures or pressure, where it can decay into protons and electrons.
Identifies emergency and critical situations related to hydrogen	• Can conduct risk analysis for various hydrogen-related logistics scenarios. • Can develop emergency plans and preventive procedures. • Explains procedures for emergency situations (e.g. leak, fire, explosion). • Apply the principles of first aid in case of hydrogen poisoning or burns. • Explains the mechanisms of critical situations, such as hydrogen ignition due to sparking, overheating or leaks in the installation. • Recognizes typical hazards associated with hydrogen, including the risk of explosion in enclosed spaces and the effects of hydrogen's low molecular weight, which leads to the gas spreading rapidly. • Characterizes the impact of high pressure and temperature on hydrogen storage and transport, including the risk of damage to pressure vessels.

COMPETENCY 1: SAFE AND RESPONSIBLE ACTIVITIES IN ORGANIZING HYDROGEN STORAGE AND TRANSPORT

Identifies emergency and critical situations related to hydrogen	• It lists examples of hydrogen-related failures, such as hydrogen embrittlement in materials and the consequences of misuse of hydrogen infrastructure. • Explains emergency response procedures, including leak control, evacuation of hazardous areas, and ignition neutralization. • Analyses the impact of hydrogen on safety in industry, including in relation to systems for storage, transport and use of hydrogen in technical devices. • It proposes risk minimization strategies such as using materials resistant to hydrogen embrittlement, controlling pressure and temperature, and monitoring the atmosphere for the presence of hydrogen.

COMPETENCY 2: ORGANIZING HYDROGEN STORAGE

Hydrogen storage is a technology that allows us to store this gas in a safe and efficient way.

Hydrogen is the lightest element in nature, and its structure allows it to store enormous amounts of energy in a small volume.
Moreover, it is one of the most abundant elements in the universe, which theoretically makes it an infinite source of energy.

• Organizes compressed gas storage or • Stores compressed gas	• Describes the different types of pressure vessels (type I, II, III, IV) and their construction. • Explains the hydrogen compression process and related technologies. • Applies guidelines for the safety and operation of pressure vessels. • Analyzes the costs associated with storing compressed hydrogen.

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COMPETENCY 2: ORGANIZING HYDROGEN STORAGE

	• Supports hydrogen compressors and compressed gas storage systems. • Monitors the operating parameters of devices and systems. • Performs basic service and maintenance activities.
• Organizes the storage of liquid hydrogen or • Stores liquid hydrogen	• Describes the hydrogen liquefaction process and cryogenic technologies. • Characterizes cryogenic tanks and their construction (including vacuum insulation). • Applies/selects guidelines for the safety and operation of cryogenic tanks. • Analyzes the phenomenon of evaporation (boil-off) and ways to minimize it. • Supports cryogenic pumps and liquid hydrogen storage systems. • Analyzes the costs associated with storing liquid hydrogen. • Performs basic service and maintenance activities.
• Organizing the storage of chemically bound hydrogen or • Modern forms of hydrogen storage	• Lists and characterizes hydrogen storage materials (e.g. metal hydrides, ammonia, methanol). • Explains the process of hydrogen absorption and desorption in storage materials. • Analyses the advantages and disadvantages of individual materials from the point of view of storage and their further transport. • Identifies technological challenges related to hydrogen storage.

COMPETENCY 3: ORGANIZING HYDROGEN TRANSPORT

• Organizes pipeline transport of hydrogen	• Describes the construction of pipelines for hydrogen transport and the materials from which they are made. • Applies principles related to hydrogen transmission through pipelines (e.g. hydrogen embrittlement, leaks). • Explains pipeline monitoring and control methods. • Analyzes the costs associated with the construction and operation of pipelines.
• Organizes pipeline transport of hydrogen	• Describes the construction of pipelines for hydrogen transport and the materials from which they are made. • Applies principles related to hydrogen transmission through pipelines (e.g. hydrogen embrittlement, leaks). • Explains pipeline monitoring and control methods. • Analyzes the costs associated with the construction and operation of pipelines.
• Organizes transport by road and rail tankers or • Transports hydrogen by road and/or rail tankers	• Characterizes the construction and technical requirements of tanks for the transport of hydrogen (compressed and liquid). • Applies safety guidelines and procedures for loading and unloading tanks. • Analyses road and rail transport costs. • It applies ADR regulations (European Agreement concerning the International Carriage of Dangerous Goods by Road) in the context of hydrogen transport. • Operates hydrogen tank loading and unloading systems. • Monitors the operating parameters of tanks during transport. • Uses transport monitoring systems.

COMPETENCY 3: ORGANIZING HYDROGEN TRANSPORT

• Organizes Maritime Transport or • Transports hydrogen by sea	• Characterizes different types of hydrogen transport vessels (e.g. LH2 tankers, ammonia transport vessels). • Applies technical and operational requirements for maritime transport of hydrogen. • Analyses the costs of sea transport and its profitability for various scenarios.

A very important competence in this process is:

COMPETENCY 4: DESIGNING HYDROGEN STORAGE AND LOGISTICS

This competence will definitely be at a higher level

• Develops hydrogen logistics schemes for a specific project	• Develops a hydrogen logistics scheme for refueling stations, • Develops a hydrogen logistics scheme for the warehouse. • Selects appropriate storage and transport methods depending on the specific nature of the project. • Creates transportation schedules and storage schedules. • Planning for hydrogen demand. • Identifies potential threats at every stage of hydrogen logistics. • Develops a risk matrix and identifies key risk factors. • Creates preventive procedures.
• Designs the cost structure of hydrogen storage and transport for various variants.	• Calculates the costs of storing and transporting compressed gas. • Calculates the costs of storing and transporting liquid hydrogen • Calculates the costs of storing and transporting chemically bound hydrogen • Compares the costs and effectiveness of different solutions. • Monitors key performance indicators (KPIs) for hydrogen storage and transportation.

COMPETENCY 4: DESIGNING HYDROGEN STORAGE AND LOGISTICS

• Characterizes the costs of storing and transporting hydrogen	• Calculates the costs of storing and transporting hydrogen for various variants. • Compares the costs and effectiveness of different solutions.
• Identifies the processes involved in hydrogen production	• Lists and characterizes the main methods of hydrogen production (e.g. steam reforming of methane, water electrolysis, biomass pyrolysis). • Analyzes the impact of a given production method on the purity, costs and logistics of hydrogen distribution. • Understands the concept of "green hydrogen" and its importance in the context of sustainable development.

PERSONAL COMPETENCES

- Communicates clearly and precisely with other team members and clients.
- Prepares reports and documentation in the field of hydrogen logistics.
- Works effectively in a team.
- Shares knowledge and experience with other team members.
- Resolves conflicts constructively.
- Implements activities supporting local communities in developing the hydrogen economy.
- Builds and develops relationships with representatives of the industrial, local government and scientific sectors.
- Adapts work to the requirements of the global market and cultural differences.

Personal competencies with additional verification criteria

1.Communicates clearly and precisely with other team members and clients.

Verification criteria:

- Conducts effective conversations with clients and the team within simulated scenarios (e.g., discussing a logistics plan).
- Creates clear and precise messages, adapting the style to the recipient (e.g., technical details for the team, simplified information for the customer).
- Uses communication support tools such as presentations, visual reports, and summary documents.

2. Prepares reports and documentation in the field of hydrogen logistics.

Verification criteria:

- Prepares a report on the implementation of a logistics project, including technical data, risk analysis and recommendations.
- Develops clear instructions and procedures for the operation of logistics equipment.
- Prepares documentation in accordance with legal requirements and industry standards (e.g., reports compliant with ADR standards).

3.Works effectively in a team.

Verification criteria:

- Actively participates in simulated group tasks (e.g. joint development of a logistics plan).
- Supports team members in solving technical or organizational problems.
- Provides constructive feedback and suggestions to improve team work.

4.Shares knowledge and experience with other team members.

Verification criteria:

- Conducts a short training or presentation for the team on a selected aspect of hydrogen logistics.
- Shares developed materials (e.g. reports, checklists) with other team members.
- Engages in mentoring or coaching less experienced team members.

5.Resolves conflicts constructively.

Verification criteria:

- Simulates conflict resolution within a team (e.g., disagreements over a transportation plan).
- It identifies the causes of conflict and proposes realistic solutions.
- Uses negotiation and mediation techniques in difficult team situations.

6.Implements activities supporting local communities in developing the hydrogen economy.

Verification criteria:

- Initiates and participates in educational projects on hydrogen aimed at local communities.
- Collaborates with local organizations and institutions to promote knowledge about hydrogen technologies.

- Prepares promotional materials (e.g. brochures, presentations) regarding the benefits of the hydrogen economy for local communities.

7.Builds and develops relationships with representatives of the industrial, local government and scientific sectors.

Verification criteria:

- It organizes meetings and workshops with representatives from various sectors to exchange knowledge and experiences.
- Creates reports summarizing the needs and expectations of various stakeholders in the context of the hydrogen economy.
- It implements joint initiatives such as pilot or demonstration projects in the field of hydrogen logistics.

8. Adapts work to the requirements of the global market and cultural differences.

Verification criteria:

- Conducts negotiations and cooperation with foreign partners, taking into account cultural and legal differences.
- Prepares project documentation and reports in English.
- Participates in international industry events (conferences, fairs, training) and uses the knowledge acquired in local projects.

SOCIAL COMPETENCIES

- He is responsible for his own safety and that of others.
- He carries out his tasks conscientiously.
- Takes actions consistent with professional ethics.
- Independently plans and carries out assigned tasks.
- Shows initiative in searching for new solutions.
- Can make decisions in crisis situations.
- He is aware of the need to constantly improve his qualifications.
  - Follows technological innovations and changes in regulations.
- Participates in training courses and conferences.
- It is involved in initiatives aimed at promoting sustainable solutions in hydrogen logistics.
- Initiates activities for cooperation between the public, private and scientific sectors in the context of hydrogen logistics.
- He is involved in international logistics projects, playing an active role in the management and coordination of activities.

Social competences with verification criteria

1.Is responsible for his own safety and that of others.

Verification criteria:

- Simulates a situation requiring a response to a security threat.
- Identifies potential threats in the logistics process and proposes preventive measures.
- Monitors compliance with safety rules among team members.

2.Carries out his/her tasks conscientiously.

Verification criteria:

- Provides regular reports and documentation according to established schedule.
- Performs tasks with due diligence, meeting project guidelines.
- Commits to achieving team goals by supporting other team members.

3.Takes actions consistent with professional ethics.

Verification criteria:

- Analyzes the scenario for compliance with professional ethics.
- Makes decisions that take into account the well-being of the team and clients.
- Assesses the consequences of professional activities from the perspective of social responsibility.

4. Independently plans and carries out assigned tasks.

Verification criteria:

- Creates a work schedule for the selected logistics task.
- Completes the task within the agreed time, reporting on progress and any difficulties encountered.
- Makes adjustments to the plan based on changing design conditions.

5. Shows initiative in searching for new solutions.

Verification criteria:

- It proposes innovative approaches to the logistical challenges associated with hydrogen.
- Identifies improvements in existing logistics processes.
- Presents recommendations at team meetings, supported by data analysis.

6.Can make decisions in crisis situations.

Verification criteria:

- Simulates the response to a crisis situation (e.g. hydrogen leak, transport failure).
- Evaluates possible action scenarios and selects the optimal option.
- Implements decisions quickly and effectively, minimizing losses and threats.

7.Is aware of the need to constantly improve qualifications.

Verification criteria:

- Prepares a professional development plan, including training and certifications.
- Assesses own skills in the context of labor market needs.
- Regularly updates knowledge about new technologies and logistics solutions.

8. Tracks technological innovations and changes in regulations.

Verification criteria:

- Presents new technologies and recipes during team meetings.
- Prepares notes or reports on regulatory changes in hydrogen logistics.
- Uses newly learned tools or technologies in practical tasks.

9. Participates in training courses and conferences.

Verification criteria:

- Regularly participates in selected industry training courses (documented certificates).
- Prepares short summaries and conclusions from participation in conferences.
- Applies acquired knowledge in implemented logistics projects.

10. Engages in initiatives aimed at promoting sustainable solutions in hydrogen logistics.

Verification criteria:

- Participates in the organization of events promoting hydrogen technologies (e.g. open days, demonstrations).
- Develops proposals for pro-ecological measures in hydrogen logistics, such as reducing greenhouse gas emissions.
- Monitors and reports the environmental impact of logistics activities in local and international projects.

11.Initiates activities for cooperation between the public, private and scientific sectors in the context of hydrogen logistics.
Verification criteria:

- Develops cross-sectoral cooperation strategies at regional and national levels.
- Participates in the preparation and implementation of research and development projects in the field of hydrogen technologies.
- Creates databases of stakeholder contacts and monitors their involvement in projects.

12. Engages in international logistics projects, playing an active role in the management and coordination of activities.

- Organizes and conducts online meetings and workshops with foreign partners.
- Follows and implements international standards (e.g. ISO standards, EU regulations) in implemented projects.

For the above outcomes and verification criteria, the following modules were proposed. These modules could constitute separate mini-learning courses, allowing:

a.it will be easier to absorb them,
b.they will be able to be updated and expanded without disturbing the parts that do not require changes,
c.it will be possible to do them as part of the micro-credentials path leading to obtaining a qualification (if it is submitted),
d.may be a starting point for other (related) qualifications

The currently scheduled modules have the following durations, approximately 160 hours in total, including 140 hours of learning plus exercises, and 20 hours of on-site workshops:

- **Module 1:** Safety and Risk Analysis in Hydrogen Handling – 24 hours
- **Module 2:** Introduction to hydrogen and its properties – 20 hours
- **Module 3:** Hydrogen storage technologies – 24 hours
- **Module 4:** Hydrogen transport methods – 20 hours
- **Module 5:** Hydrogen logistics and sustainable development and ecology – 16 hours
- **Module 6:** Basics of logistics and hydrogen supply chain management – 20 hours
- **Module 7:** Managing logistics projects in the hydrogen economy – 20 hours
- **Module 8:** Law and Regulation in the Hydrogen Economy – 16 hours

- The modules can form the basis for developing a training program that, depending on market needs, can be dedicated to specific target groups.

The proposed module topics are particularly recommended for:

- Logistics and transport specialists who will acquire additional skills in new hydrogen technologies;
- Engineers and technicians from the energy industry expanding their competences to include aspects of hydrogen;
- Employees of transport and logistics companies for whom hydrogen will be a new challenge and a necessity;
- Graduates of technical and natural science universities, as hydrogen is a significant challenge, including for climate and sustainable development aspects.
- People looking for specialist qualifications in new technologies such as hydrogen.

The proposed modules are/will be addressed to people interested in working in the renewable energy sector, logistics, transport, chemistry and related fields, as well as in the automotive industry and many other industries open to new technologies.

After completing the modules, participants will:

- Have in-depth knowledge of the properties of hydrogen and the technologies for its storage and transport.
- Know the legal regulations and standards regarding hydrogen logistics.
- Be able to plan, organize and optimize logistics processes.
- Operate devices and technologies related to hydrogen storage and transport.
- Conduct risk analysis and respond to emergency situations.
  Collaborate effectively in teams and communicate clearly and precisely.
- Be aware of the role of hydrogen logistics in sustainable development.

PROPOSED TOPIC SCOPE OF MODULES

MODULE 1: SAFETY AND RISK ANALYSIS IN HANDLING HYDROGEN

- **Duration:** 24 hours (10 hours of lectures, 8 hours of practical exercises, 6 hours of workshops).
- **Objective:** To acquire knowledge of regulations, norms and standards regarding hydrogen logistics as well as skills in risk analysis and emergency procedures.

Topics:

1. **Current ISO and IEC standards for hydrogen (4 hours):**
   - Discussion of key standards such as ISO 14687 (hydrogen fuel specification) and IEC 60079 (explosion safety).
   - Overview of standards for the transport, storage and use of hydrogen in various industrial sectors.
   - Analysis of the latest guidelines related to the certification of hydrogen devices.
2. **National and international safety and environmental regulations (4 hours):**
   - EU regulations (e.g. Seveso III Directive, ADR, IMDG regulations).
   - National regulations on handling hazardous substances and environmental protection.
   - Case studies: hydrogen-related accidents and their legal consequences.
3. **Emergency procedures (leak, fire, explosion) (4 hours – 2 hours of lectures, 2 hours of exercises):**
   - Mechanics and physics of accidents involving hydrogen.
   - Detailed discussion of procedures for specific situations (e.g., isolating an area, extinguishing hydrogen fires).
   - Interactive simulations of responses to hydrogen leaks, fires and explosions.
4. **First aid rules in case of hydrogen poisoning/burn (2 hours):**
   - Physiological effects of contact with hydrogen and its derivatives (e.g. cryogenic burns, gas poisoning).
   - Standard procedures for providing assistance to injured persons.
   - Practical workshops: simulation of first aid in various scenarios.
5. **Risk analysis methods (4 hours):**
   - Wprowadzenie do metod HAZOP (Hazard and Operability Study) i FMEA (Failure Mode and Effects Analysis).
   - Identification of potential threats in the hydrogen logistics chain.
   - Assessment of the effects and probability of risk events.
6. **Developing emergency plans and preventive procedures (6 hours – 2 hours of lectures, 4 hours of workshops):**
   - Creating comprehensive emergency plans for hydrogen installations.
   - Practical exercises: development of preventive and emergency procedures for hypothetical scenarios.
   - Analysis of plan effectiveness based on crisis simulations.

MODULE 2: INTRODUCTION TO HYDROGEN AND ITS PROPERTIES

- **Duration:** 20 hours (8 hours of lectures, 8 hours of exercises, 4 hours of workshops).
- **Objective:** Understand the basic physical and chemical properties of hydrogen, which are crucial for safe storage and transport.
- **Topics:**

1. **Hydrogen isotopes and their characteristics (1 hour - lectures, 1 hour - classes)**
   - Introduction to hydrogen isotopes: protium, deuterium and tritium – structure, physical and chemical properties.
   - The role of isotopes in industry and technology, including the use of deuterium and tritium in nuclear energy.
   - Comparison of hydrogen isotope properties based on literature and experimental data.
2. **Hydrogen: ortho and para – influence on storage (1 hour - lectures, 1 hour - labs)**
   - Explaining the differences between ortho- and para-hydrogen.
   - The importance of hydrogen isomerism in the context of storage and stability at low temperatures.
   - Calculations of energy changes during ortho- and para-hydrogen transformations.
   - Analysis of liquid hydrogen storage processes depending on the isomer content.
3. **Density of hydrogen in different states of matter (1 hour - lectures, 1 hour - labs)**
   - Density of hydrogen in the gaseous, liquid and solid states – differences and their technological significance.
   - Effect of pressure and temperature on hydrogen density.
   - Calculations of hydrogen density at various pressure and temperature parameters.
   - Analysis of hydrogen phase diagrams.
4. **Key temperatures for hydrogen (boiling, critical, triple point) (1 hour - lectures, 1 hour - labs)**
   - Key temperatures explained: boiling point, critical point, triple point.
   - The importance of these parameters for the storage of hydrogen in the liquid and gaseous state.
   - Analysis of hydrogen phase diagrams.
   - Exercise: Identifying appropriate hydrogen storage conditions based on its thermodynamic parameters.

5. **Explosive range and flammability limits of hydrogen (1 hour - lectures, 1 hour - ex.)**
   - Discussion of the flammability limits of hydrogen and its explosive range in air.
   - Causes and mechanisms of hydrogen explosions.
   - Case analysis of hydrogen-related explosions in industry.
   - Determining safety conditions for working with hydrogen.

6. **Hydrogen diffusivity and its consequences (1 hour - lectures, 1 hour - classes)**
   - High hydrogen diffusivity and its impact on storage and transport safety.
   - Discussion of potential hazards arising from diffusion.
   - Calculations of hydrogen diffusion through various materials.
   - Selecting appropriate materials for hydrogen storage.

7. **Corrosive properties of hydrogen (1 hour - lectures, 1 hour - classes)**
   - The phenomenon of hydrogen embrittlement and its impact on structural materials.
   - Corrosive properties of hydrogen in contact with metals.
   - Analysis of data on the resistance of materials to hydrogen.
   - Exercise: Designing hydrogen-resistant systems.

8. **Hydrogen Hazards: Causes of Explosions and Fires, Brittleness hydrogen (2 hours - workshop)**
   - Case studies of hydrogen-related failures.
   - Designing safety procedures for working with hydrogen.

9. **Hydrogen detection methods and alarm systems (1 hour - lectures, 1 hour - workshops.)**
   - Overview of hydrogen detection technologies, including sensors and alarm systems.
   - The role of detection systems in ensuring security.
   - Configuration and testing of hydrogen sensors.

10. **Overview of hydrogen production methods and the concept of "green hydrogen" (2 hrs - lectures, 1 hour - workshops)**
    - Hydrogen production methods: steam reforming of methane, water electrolysis, biomass pyrolysis.
    - Explaining the concept of “green hydrogen” and its role in the energy transition.
    - Group discussion: assessment of the potential of green hydrogen production in Poland and worldwide.

MODULE 3: HYDROGEN STORAGE TECHNOLOGIES

- **Duration:** 24 hours (10 hours of lectures, 10 hours of exercises, 4 hours of workshops).
- **Objective:** To learn about different hydrogen storage methods, their advantages and disadvantages, and technical requirements.
- **Topics:**

1. **Compressed gas storage (3 hours - lectures, 3 hours - exercises, 1 hour - workshops)**
    - Types of pressure vessels (type I, II, III, IV): construction, construction materials and their use.
    - Hydrogen compression process: compression devices, technical requirements and operating parameters.
    - Safety and operation of pressure vessels: principles of use, risks and protection systems.
    - Compressed hydrogen storage costs: analysis of cost drivers.
    - Analysis of the properties of various types of tanks and their applications in practice.
    - Calculations related to the hydrogen compression process (e.g. compressor operation, energy consumption).
    - Assessment of risks associated with the operation of pressure vessels based on case studies.
    - Simulation of the hydrogen compression and storage process using computer models.

2. Liquid hydrogen storage (3 hours - lectures, 3 hours - exercises, 1 hour - workshops)

- Hydrogen liquefaction process: cryogenic technology, energy requirements and key process parameters.
- Cryogenic tanks: construction, types of insulation and technologies to minimize heat loss.
- Safety and operation of cryogenic tanks: risk of freezing, leaks, safety systems.
- The boil-off phenomenon: causes, impact on operation and methods of minimizing losses.
- Liquid hydrogen storage costs: an economic analysis in the context of cryogenic technology.
- Calculations of energy losses associated with hydrogen liquefaction.
- Analysis of liquid hydrogen leak cases and development of safety procedures.
- Selection of cryogenic tanks for specific industrial applications.

- Designing a liquid hydrogen storage system for a selected scenario (e.g. hydrogen transport to a fuel station).

MODULE 4: HYDROGEN TRANSPORT METHODS

- **Duration:** 20 hours (8 hours of lectures, 8 hours of exercises, 4 hours of workshops).
- **Objective:** To learn about different hydrogen transport methods, their advantages and disadvantages, and technical and regulatory requirements.
- **Topics:**

1. **Pipeline transport (3 hours - lectures, 3 hours - exercises, 1 hour - workshops)**
   - Design and materials of hydrogen pipelines: selection of materials resistant to hydrogen embrittlement, design of transmission systems.
   - Challenges of hydrogen transmission through pipelines: hydrogen embrittlement, leaks, impact of pressure and temperature on operation.
   - Pipeline monitoring and control methods: leak detection systems, technical condition inspection.
   - Pipeline construction and operating costs: an economic analysis for large-scale hydrogen transmission.
   - Case study: analysis of technical problems of hydrogen transmission in existing pipelines.
   - Calculations: the influence of pressure and temperature on the efficiency of hydrogen transmission through pipelines.
   - Simulation of the hydrogen transmission process via pipeline, including leak monitoring.
   - Development of a hydrogen transmission pipeline model, taking into account technical requirements and investment costs.

2. **Transport by road and rail tankers (3 hours - lectures, 3 hours - exercises, 1 - hour - workshops)**
   - Construction of hydrogen tanks (compressed and liquid): technical requirements, construction materials, insulation.
   - Safety, loading and unloading of tanks: operating procedures, safety systems, minimizing hydrogen losses.
   - Road and rail transport costs: analysis of logistics costs and their impact on profitability.
   - ADR regulations (European Agreement concerning the International Carriage of Dangerous Goods by Road): key regulations for hydrogen.
   - Analysis of hydrogen leaks during tanker transport and development of response procedures.

- Calculations related to loading and unloading of tanks under various conditions.
- Designing a logistics system for transporting hydrogen by tanker over selected distances.
- Simulation of the hydrogen transport process by road or rail tanker, taking into account loading, transport and unloading.

3. **Maritime transport (2 hours - lectures, 2 hours - exercises, 2 hours - workshops)**
   - Types of vessels for the transport of hydrogen (LH2, ammonia): construction, cryogenic technologies, safety systems.
   - Technical and operational requirements: specifics of loading, transporting and unloading hydrogen in ports.
   - Costs and profitability of maritime transport: an economic analysis in the context of the global hydrogen market.
   - Comparative analysis of the costs and profitability of transporting hydrogen by sea in various forms (LH2, ammonia).
   - Calculation of hydrogen boil-off losses during sea transport.
   - Case study: developing a concept for hydrogen transport by sea on a selected route, taking into account technical and regulatory challenges.

MODULE 5: HYDROGEN LOGISTICS AND SUSTAINABILITY AND ECOLOGY

- **Duration:** 16 hours (8 hours of lectures, 4 hours of exercises, 4 hours of workshops).
- **Objective:** To understand the environmental impact of hydrogen logistics and learn methods to minimize this impact.
- **Topics:**

1. **Greenhouse gas emissions related to hydrogen logistics (2 hours - lectures, 1 hour - lab, 1 hour - workshop)**
   - Analysis of greenhouse gas emissions at various stages of hydrogen logistics (production, transport, storage).
   - Comparison of CO2 emissions for “green”, “blue” and “grey” hydrogen.
   - Global impact of emissions from logistics processes on climate change.
   - Calculations of CO2 emissions for various hydrogen transport methods over a given distance.
   - Case study: analysis of greenhouse gas emissions associated with hydrogen transport in a selected logistics scenario.
   - Development of a logistics strategy to reduce greenhouse gas emissions for a selected hydrogen distribution model.

2. **The role of logistics in reducing the carbon footprint (2 hours - lectures, 1 hour - exercises, 1 - hour - workshops)**

- Key logistics strategies for reducing the carbon footprint in the hydrogen sector.
- Optimizing transport routes and minimizing emissions.
- Implementation of digital technologies (e.g. IoT, AI) in monitoring the carbon footprint in hydrogen logistics.
- Comparative analysis of the carbon footprint of different hydrogen transport models (pipelines, maritime transport, tankers).
- Simulation of the impact of changing logistics parameters (e.g. route, type of transport) on emission reduction.
- Designing a hydrogen logistics model taking into account carbon footprint minimization and energy efficiency optimization.

3. **Methods of hydrogen recovery and recycling (1 hour - lectures, 1 hour - exercises, 1 hour - workshops)**
    - Hydrogen recovery technologies in industrial and logistics processes.
    - Practical application of hydrogen recycling: reducing losses during transport and storage.
    - Cost-benefit analysis of implementing hydrogen recovery systems in logistics chains.
    - Development of a proposal for implementing a hydrogen recovery system in a selected logistics process.

4. **Technologies for reducing NOx emissions and other pollutants (2 hours - lectures, 1 hour - exercise, 1 hour - workshop)**
    - Sources of NOx emissions and other pollutants in hydrogen logistics.
    - Emission reduction technologies for hydrogen transport (e.g. catalytic filters, combustion optimization).
    - The use of renewable energy sources in hydrogen logistics.
    - Simulation of the impact of using modern emission reduction technologies on the natural environment.
    - Discussion and analysis of case studies of the implementation of emission reduction technologies in hydrogen logistics in various countries.

5. **The role of fuel cells in logistics (1 hour - lectures, 1 hour - exercises, 1 hour - workshops)**
    - Principle of operation of fuel cells and their application in hydrogen transport.
    - Advantages of fuel cells compared to traditional energy sources.

- Impact of fuel cell use on sustainable development in hydrogen logistics.
- Analysis of the energy efficiency of fuel cells in the context of hydrogen logistics.
- Designing a logistics system based on the use of fuel cells to power transport infrastructure.

MODULE 6: BASICS OF LOGISTICS AND HYDROGEN SUPPLY CHAIN MANAGEMENT

- **Duration:** 20 hours (10 hours of lectures, 6 hours of exercises, 4 hours of workshops).
- **Objective:** To acquire the knowledge and skills in logistics that are necessary to effectively manage the hydrogen supply chain.
- **Topics:**

1. **Hydrogen supply chain analysis from production to end user (4 hours):**
   - Overview of the stages of hydrogen production, storage, transport and distribution.
   - Identification of key challenges at individual stages (e.g. security, costs, regulatory compliance).
   - Supply chain mapping, taking into account the role of different technologies (e.g. electrolysers, refueling stations).

2. **Planning hydrogen supplies (3 hours):**
   - Methods of forecasting hydrogen demand.
   - A strategic approach to inventory management in the context of hydrogen technologies.
   - Inventory management scenarios in crisis situations (e.g. supply disruptions).

3. **Optimization of transport routes (3 hours):**
   - Specificity of hydrogen transport by various means (tankers, pipelines, sea transport).
   - Route optimization techniques taking into account costs, safety and legal constraints.
   - Use of digital tools for route planning (e.g. GPS systems, optimization software).

4. **Hydrogen storage management (3 hours):**
   - Specification of hydrogen storage facilities (e.g. pressurized, cryogenic).
   - Safety standards and compliance with regulations in warehouse management.
   - Warehouse automation technologies dedicated to hydrogen.

5. **Methods of optimizing logistics processes (3 hours):**
   - Introduction to Lean and Six Sigma methods in hydrogen logistics.
   - Analysis of logistics processes from the perspective of minimizing losses and improving efficiency.
   - Examples of optimizing logistics processes in real projects.

6. **Use of WMS and TMS software (4 hours – exercises and workshops):**
   - Practical application of Warehouse Management System (WMS) and Transport Management System (TMS) in the hydrogen economy.
   - Discussion of the integration of logistics systems with IoT and AI technologies.
   - Workshop: Simulation of hydrogen storage and transport management using WMS and TMS.

MODULE 7: LOGISTICS PROJECT MANAGEMENT IN THE HYDROGEN ECONOMY

- **Duration:** 20 hours (8 hours of lectures, 8 hours of exercises, 4 hours of workshops).
- **Objective:** Acquiring skills in planning, managing and monitoring hydrogen logistics projects in dynamically changing market conditions.
- **Topics:**

1. **Project Management Basics (6 hours):**
   - Creating schedules and plans for logistics projects.
   - Analysis of budgets and cost estimates.
   - Project change management.

2. **Specificity of projects in the hydrogen economy (8 hours):**
   - Infrastructure management: refueling stations, warehouses, pipelines.
   - Management of hydrogen technologies in logistics projects.
   - Discussion of completed logistics projects in the hydrogen economy, their challenges and successes.

3.**Practical workshops (6 hours):**
   - Creating a feasibility study for a hydrogen infrastructure project.

MODULE 8: LAW AND REGULATION IN THE HYDROGEN ECONOMY

- **Duration:** 16 hours (8 hours of lectures, 4 hours of exercises, 4 hours of workshops).
- **Objective:** To familiarize participants with national and international laws and regulations regarding the hydrogen economy and logistics.
- **Topics:**

1.**Basics of legal regulations in hydrogen logistics (6 hours):**
   - Current national legal regulations regarding the hydrogen economy (2 hours):
     - Discussion of Polish regulations regulating the development of the hydrogen economy, including definitions, principles of certification and activities of hydrogen system operators.
   - International standards and regulations (2 hours):
     - Analysis of international norms and standards for hydrogen technologies, such as ISO standards and European Union regulations.
   - Safety in hydrogen transport and storage (2 hours):
     - Overview of safety regulations for the transport and storage of hydrogen, including ADR regulations (European Agreement concerning the International Carriage of Dangerous Goods by Road) and IMDG regulations (International Maritime Dangerous Goods Code).

2. **Environmental and ethical aspects (6 hours):**
   - Principles of environmental responsibility in the hydrogen economy.
   - Analysis of cases of violations of regulations and their consequences.

3.**Practical workshops (4 hours):**
   - Regulatory analysis for a hypothetical transport project, taking into account national and international regulations.

It is also worth considering another process approach, in which, in addition to the above-described ones, the following modules play an important role – they are complementary and part of other training blocks for other professions:

- **Module 9:** Social and economic aspects of hydrogen use in the economy
- **Module 10:** Possibilities and preferences for introducing hydrogen as an alternative source
- **Module 11:** Hydrogen Production

The presented description of the modules, for example, from a process perspective, highlights the complexity and multidimensionality of the challenges associated with the development of a hydrogen economy. It provides an example of how modules can be combined depending on market and process needs, with strict consideration of safety.

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