Training Guidelines

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Management Summary

Europe is in full swing to transform towards a European hydrogen economy. In order to become a global leader in hydrogen, Europe needs to enable its strong innovative SME's and stimulate Investments. To give the European hydrogen market a boost, the Hy2Market project was established through funding of the I3 instrument. Hy2Market is an EU-funded project running from 2023 to 2026. Its aim is to accelerate the European hydrogen economy by connecting European regions with strong production potential to those with growing demand, and by advancing the full value chain from production and transport to industrial and mobility applications. Alongside its technical and infrastructural work, the project also addresses regulatory barriers and supports capacity building. Within this framework, training and knowledge exchange play an important role in equipping Europe's workforce and stakeholders with the skills needed for a safe and effective hydrogen transition.

Acquiring the right knowledge for the hydrogen transition is required to ensure a smooth process. To achieve this, it is important to create an overview of existing training material and to check if this matches the demand by the market. As such, this deliverable on "Training & Guidelines" has the goals to generate market data by comparing existing material with experiences from partners active in the hydrogen field. The Hy2Market Consortium has been thoroughly asked as part of this research. From this corporation we got extensive information on desired education through a survey among its 38 partners at the time of research, the programs already out there, experts' opinions on current state gathered through different Consortium meetings, that can conclude on: 1. How to organize your trainings best; 2. Identify gaps; 3. Improvements of hydrogen education/training.

For the scope of this research, it was decided to do a combination of quantitative research and qualitative research. Desk research has been conducted with a specific focus on the regions of The Netherlands, Austria, and Greece to map out the existing material on hydrogen training and education. A quantitative analysis was done through a survey with all the partners of the Hy2Market project asking for the required knowledge for 14 different positions that potentially play a role within an organization working on hydrogen. The analysis was compared with the desk research and identified gaps between the current offerings and the actual demand from the market for available training material. Lastly the Consortium was asked for best practices and what needs to change regarding training formats.

Key Insights

Whilst the report offers a detailed overview over the survey, research results and sticky notes from the consortium, this paragraph will point out the key findings.

- **Importance of On-the-job Learning** - Many organizations and respondents in the survey are engaged in sectors like hydrogen production, transport, and use, which heavily rely on practical knowledge and experience. Therefore, facilitating hands-on, real-time learning on the job will be crucial. Companies dealing with technical projects development are especially suited for implementing task rotations and mentorship schemes to enhance practical learning.
- **Heavy reliance on Previous Education** - A significant proportion of respondents highlighted that formal education—both undergraduate and graduate programs—forms the foundation of knowledge for hydrogen-related roles. This reliance suggests that formal educational institutions are providing a solid base of theoretical knowledge. However, it also indicates that there may be gaps in practical, real-world applications that need to be addressed through additional training.
- **External Training and Workshops are equally important** - Data suggests that external training and workshops are crucial for staying updated on broader industry trends. These external workshops and training programs are vital for maintaining up-to-date knowledge in fast-evolving areas like hydrogen technologies. External programs, particularly those focused on new innovations in renewable energy and safety, will play a significant role in employee development.
- **Learning from peers plays a crucial role** - Based on the survey results, peer learning also plays a critical role in fostering innovation and knowledge exchange. Employees sharing technical knowledge and advice about specific challenges and aspects related to hydrogen transport, production, or use can significantly enhance organizational and employee performance. This emphasizes the importance of peer networks and knowledge-sharing initiatives within teams.
- **Learning Preferences and Gaps** - In general, responses suggest that while previous education forms a strong base, there is a significant emphasis on on-the-job learning and external training programs and workshops to bridge gaps in technical skills related to the hydrogen value chain. This underscores the importance of facilitating and fostering specialized, role-specific trainings, both within companies and through external providers. Addressing these gaps will be essential for scaling up hydrogen operations in the future.
- **Engineering & Technical Roles** (Mechanical, Chemical, Electrical, Quality & HSE) demand **strong knowledge in engineering, safety,** and **operational aspects**.
- **Managerial and Business-Oriented Roles** (Finance, HR, Purchasing, Top-Level Management) focus more on **economic, market,** and **legal knowledge**.
- **Cross-functional roles** (R&D, Mid-Level Management, and Logistics) require a mix of technical and strategic knowledge.
- Across all positions within a company **Safety-**, **Legal-** and **Economic Knowledge** have been deemed **most relevant**.
- **Learning-by-doing As the Core Driver of Hydrogen Skills Development** - Consortium feedback from the sticky notes shows that most hydrogen-related competencies are gained "on-the-job" rather than through formal

education. This highlights a clear gap between academic training and the practical skills needed for implementation, underscoring the need for hybrid learning models that combine theoretical instruction with structured field experience.

- **Upskilling the existing workforce is critical for accelerating hydrogen deployment** - Consortium feedback highlights that many professionals currently engaged in hydrogen projects lack formal, sector-specific training. Targeted upskilling programs and training strategies are essential to ensure competence and skills acquisition.
- **Accessibility of courses and misalignment between available training and real-world hydrogen competencies -** The availability of affordable and accessible hydrogen training programs emerged as a key concern among the consortium. Many courses remain overly theoretical, offering limited hands-on experience and failing to meet real project needs. This misalignment highlights the need for field-based learning that directly connects training content with operational tasks and workforce requirements.
- **Preference for Practical, Collaborative, and Industry-Led Learning Models -** Consortium input highlighted strong support for company-led training, mentorship and peer exchange as the most effective ways to build hydrogen competencies, valuing technical workshops and knowledge platforms.

TABLE OF CONTENTS:

1 Introduction

To explore the current job situation as well as the demand for skills in the hydrogen market, Hy2Market has carried out a survey amongst its 38 participating organizations from France, Greece, Italy, Netherlands, Romania, Portugal, Spain and Austria. Furthermore, desk research on existing training materials was performed. The survey has produced several findings, which allowed for the development of the current Training Guidelines, as a manual for the knowledge and skills landscape in the hydrogen area. The study provides insights in which types of knowledge different roles/positions in the organizations should have in the field of hydrogen and in which way they should acquire it. These results are mirrored to the existing training programs from the Desk Research to show how current training programs need to be modified or added in order to match market demands.

1.1 Hy2Market vision

The Hy2Market project brings together regions throughout Europe that work on different innovations to boost the production, transport, and use of green hydrogen. The project builds on European frontrunner regions like Northern Netherlands, Upper-Austria, and Rhone-Alpes, and the first European Hydrogen Valley in Northern Netherlands to share knowledge and create innovations in the Hydrogen value chain. In the Hy2Market project, which is funded by the European I3 Instrument, 38 partners at the time of writing in 10 regions work together. In these regions companies and (knowledge) institutions collaborate on innovations, studies, and investments to reach a robust and innovative hydrogen value chain.

The Hy2Market project aims to identify and overcome barriers in production, transport, use in industry and use in mobility. This with the goal to realise a broad integration with standards, legislation, and common practices so that hydrogen plays an important role in reaching Fitfor55 and 2050 decarbonization goals. To achieve this, a European approach is a must and in Hy2Market the partners will invest heavily in transfer of the existing expertise, and the knowledge build up during the project.

This guideline for training (Task 6.3 Cooperation in Know-How and Skills Development) is part of Work Package 6 – Knowledge exchange platform. In this work package, all partners learn from the work carried out in other work packages and collaborate to build strong hydrogen value chains across Europe. This way, learnings and best practices from one region, help to speed-up Hydrogen initiatives in other regions.

1.2 Significance for the hydrogen sector and best practices

With Hy2Market being an enabler of hydrogen innovations and many important implementations, the Consortium already has seen some major projects coming of the ground during the timeline of the overall project. These initiatives underline the importance of a skilled workforce and serve as best practices from those who already had to tackle the challenge for a new workforce. Some of our partners from Greece, Spain, and Portugal shared experiences to show the relevance for Hydrogen Training and Guidelines:

1.2.1 Cluster of Bioeconomy and Environment of Western Macedonia (CluBE)

“In Western Macedonia, the transition from lignite to clean energy has created both opportunities and gaps in the workforce. While many workers have strong energy backgrounds, almost none had prior exposure to hydrogen technologies. Through Hy2Market and other initiatives we launched targeted upskilling training programs with universities and training centers, helping to build a regional hydrogen skills ecosystem. The project has been key in linking local training to European market needs.” ~ N. Ntavos, Co-Founder & Manager, CluBE

1.2.2 EDP Renewables

"In our case, the activities carried out have been primarily engineering-focused, rather than involving manual labor or construction work. To support this, we promote continuous training through webinars and internal sessions led by our colleagues in regulation and strategy, specifically oriented towards hydrogen. Additionally, we have strengthened training in project management—such as PMP certification—and communication skills to enhance dissemination efforts across our projects." ~ S. Fernandez Garcia, H2 Project Developer & Manager, EDPR

1.2.3 MédioTejo21

MedioTejo21 considers that it is essential to ensure stakeholder involvement in the project and in the implementation of hydrogen mobility solutions in the region. Considering that having a new bus with new characteristics could pose a challenge for drivers and security forces, we organised training sessions for drivers with two modules focused on the characteristics of the bus and a more practical one on driving the bus. As for the security forces, we held a training session focused on the best procedure in the event of an accident involving the bus. ~ M. Lima, Project Manager, MédioTejo21

1.3 Scope of Research study

Addressing the hydrogen education and training for a whole continent is a big task. Focussing on what is within the reach of Hy2Market is therefore an important exercise. Within this deliverable, the research team opted for a combination of quantitative research and qualitative research. Qualitative research was done in the form of desk research, mapping out the existing training materials on hydrogen education. The Desk Research focusses on categorizing the existing material in different regions based on the type of training being teached e.g. 1-day Masterclass, Multiple week program, full time study program. Additionally, programs have been categorized based on the needed Due to the available resources within the project, it was opted to focus on the regions of The Netherlands, Austria, and Greece. It is important to note that, although generating a preliminary overview, other European regions have not been analysed to the same extent as the previous mentioned regions. To still be able to draw meaningful conclusions, overarching European programmes were considered and analysed such as the Green Skills for Hydrogen project and the European Hydrogen Observatory.

A quantitative analysis was done in the form of a survey where the Hy2Market Consortium was questioned thoroughly on their experiences and needs when it comes to hydrogen training and education. With the al the Consortium members consisting of 38 parties at the time of research responding to the survey, a sufficient number of answers was gathered to draw meaningful conclusions. The survey was spilt in the different job positions in the hydrogen sector, the required knowledge, and the preferred training formats. The Desk Research and the Survey was complemented by asking the partners during a Consortium in Lipari about their best practices and what they think should change in the field of hydrogen training during.

Before examining the type of hydrogen-related knowledge required for different positions in a company, it's important to recognise that not all positions see a need for expertise in this area.

For positions in Human Resources, Legal Management, Operational Logistics, Purchasing, Logistics and Supply Chain, the need for knowledge is considered to be very low. On the other hand, for positions in R&D, top, middle and first level management, the need is considered to be high. This makes sense, as the latter are also the positions responsible for the future direction of the company.

2 Desk research on existing material

There is already a wide range of hydrogen education available in Europe. Establishing an overview of the existing options allows for a better understanding of the current state of hydrogen education. By creating an overview, gaps in our education systems can be identified and mirrored against actual demand for hydrogen education as experienced by the market. This chapter delves into a summary of the Desk Research conducted by Hy2Market partners NEC, Biz-up, and CLUBE. The full desk research can be found in Appendix B.

2.1 NEC's desk research summary

The desk research conducted by the New Energy Coalition (NEC) presents a detailed overview of the current hydrogen education landscape in the Netherlands, with a particular focus on Northern regions such as Groningen and Drenthe. The findings illustrate that while educational offerings are expanding in response to the energy transition, most existing programs remain at the introductory or generalist level. Courses provided by the New Energy Business School (NEBS), for example, are often structured around broad overviews of the hydrogen value chain, designed primarily for leadership, management, and policy-oriented participants. Similarly, collaborations such as the NEBS–Brunel University initiative reflect a growing demand for cross-border, entry-level training that bridges scientific knowledge and policy awareness.

At the vocational level (MBO), initiatives such as *Waterstof Werkt* signal a positive shift toward more applied education, with new MBO-level programs emerging at institutions like Drenthe College, Noorderpoort, and Alfa College. These developments are complemented by broader strategic projects such as *HyDelta 2.0*, which investigates the evolving skill requirements at University of Applied Science (HBO), University (WO), and postgraduate levels. Together, these efforts aim to ensure that future professionals in hydrogen transport and infrastructure are equipped with relevant and timely expertise.

Despite these developments, NEC's research highlights several critical gaps. Notably, there is a pressing need for specialized training focused on hydrogen safety, operational risk, and system maintenance. Skills related to high-pressure hydrogen handling, regulatory compliance (e.g. HAZOP studies, ATEX certification), and system diagnostics are largely absent from mainstream curricula. Participants across various sectors frequently cited hydrogen safety as an area of concern that is insufficiently addressed in existing courses. This reveals a disconnect between the growing complexity of hydrogen infrastructure and the current state of technical education. Another significant observation concerns the lack of structured retraining programs for professionals transitioning from traditional fossil fuel-based industries. Given the strategic importance of hydrogen to the Dutch and European energy transition goals, there is a missed opportunity to tap into the transferable expertise of these professionals through targeted reskilling initiatives.

In conclusion, the NEC desk research underscores that while the foundation for hydrogen education in the Netherlands is steadily taking shape, it remains in an early developmental stage. The emphasis to date has been on building awareness and providing accessible entry points into the hydrogen sector. Moving forward, however, there is a clear imperative to deepen the technical and regulatory content of these programs, to scale up specialized training in safety and operations, and to institutionalize reskilling pathways that can support a more inclusive and workforce-ready hydrogen economy. Table 3 shows the findings of the desk research of NEC.

Aspect	Details
Main Focus of Training	Training landscape for hydrogen production, transport, industrial use, and mobility
Key Training Providers Identified	New Energy Business School (NEBS), NEC Projects, Brunel University
Types of Training Offered	Masterclasses, intensive 3–4-day courses, 16-day directive courses, postgraduate modules
Target Audience	Management, re-skilling professionals, policy makers, technical staff (MBO, HBO, WO levels)
Key Skills Emphasized	Broad foundational knowledge, hydrogen safety, system overview, introductory technical modules
Gaps Identified	Lack of specialized and deep technical training; limited focus on safety (HAZOP, ATEX); need for upskilling from other energy sectors
Regional/National Initiatives	Waterstof Werkt (vocational education initiatives in Northern Netherlands), HyDelta 2.0 (skill requirements for HBO, WO, and postgraduate levels)
Conclusions	Hydrogen education is growing but still introductory; specialized, technical, and safety-focused training urgently needed

Table 1 NEC findings

2.2 Biz-up’s desk research summary

Business Upper Austria (Biz-Up) conducted desk research to identify existing training opportunities related to hydrogen and to assess frameworks that support skills development in the region and beyond. A central element of the research was a five-day online course developed by the Energy Training Centre. This course targeted adult learners seeking foundational knowledge on green hydrogen, including its applications across various industries and strategies for organizational adaptation. The course aimed to equip participants with the ability to evaluate whether hydrogen integration could benefit their respective sectors and how to position themselves within the evolving hydrogen economy.

The course was structured around five thematic modules. The first day introduced green hydrogen, addressing types, environmental benefits, and current limitations. The second day examined infrastructure and economic conditions necessary for large-scale deployment. The third module focused on strategic preparedness and market implications. The fourth session explored innovation, sustainability considerations, and production strategies. The final module presented international case studies, illustrating ongoing investments and practical applications across different countries and industries.

In addition to the course, Biz-up referenced several international resources and best practices. A prominent example is the *Queensland Hydrogen Industry Workforce Development Roadmap* (2022–2032), which emphasizes data-driven planning, workforce adaptability, and early STEM education. This roadmap was presented as a potential model for future European initiatives. Further resources were also highlighted, including technical training content from the Hydrogen Academy, fact sheets published by Hydrogen Europe, and school-level educational materials from the NEED Project. The European Hydrogen Observatory was noted for its open-access materials covering safety standards, life-cycle assessment, and techno-economic evaluation. TÜV Austria's specialized training programs were also referenced as an example of industry-relevant education. These programs address key topics such as hydrogen safety regulations, system testing, electrolysis and fuel cell technologies, and issues related to material compatibility, including hydrogen embrittlement and high-temperature corrosion.

In conclusion, the Biz-up desk research reveals a rapidly expanding but still fragmented hydrogen training landscape. While a variety of training opportunities exist, there is a clear need for greater harmonization, more technically advanced content, and improved alignment with industry requirements across Europe. The findings underscore the importance of developing coordinated, applied, and safety-focused educational frameworks to support the growing hydrogen sector. Table 4 shows the findings of the desk research of Biz-up.

Aspect	**Details**
Main Focus of Training	Identification and assessment of hydrogen-related training programs and skill development frameworks in Upper Austria and internationally
Key Training Providers Identified	National: Energy Training Centre, Hydrogen Academy, TUV Austria, New Energy Business School (NEBS) International: Queensland Hydrogen Industry Hydrogen Europe, European Hydrogen Observatory
Types of Training Offered	Online modular courses, safety training, case study-based programs, certification courses, technical modules on electrolysis, storage, fuel cells, material compatibility, and leadership-focused modules
Target Audience	STEM students, professionals entering the hydrogen economy, and current industry staff requiring technical, safety or regulatory upskilling

Key Skills Emphasized	Hydrogen safety, infrastructure requirements, strategic readiness, innovation in hydrogen applications, regulatory and material science knowledge
Gaps Identified	Need for harmonized and applied training across Europe; early-stage educational content for technical learners still limited; limited integration of hydrogen topics in standard engineering curricula
Relevant Strategic Resources	Queensland Hydrogen Roadmap, Hydrogen Europe resources, NEED Project for educational content, TUV Austria certification courses, New Energy Business School, EU Hydrogen Strategy, REPowerEU
Conclusions	While training offers are increasing and diversifying, there is a continued need for European-wide alignment, deeper specialization, and better integration into formal education systems

Table 2 Desk research findings by Biz-up

2.3 CLUBE's desk research summary

The desk research conducted by CLUBE (Cluster of Bioeconomy and Environment of Western Macedonia) highlights various hydrogen training initiatives in Greece, developed in collaboration with Advent Technologies and the University of Western Macedonia. The research responds to the urgent need for reskilling and upskilling in regions affected by the energy transition—especially in Western Macedonia—and provides insights into how these needs are being addressed through targeted educational programs.

CLUBE coordinated four key training initiatives:

1. "Masterclass: One-Day Hydrogen" – Aimed at introducing professionals (inside and outside the energy sector) to the hydrogen value chain.
2. "Hydrogen Summer ScH2ool" – A training program focused on hydrogen technologies, directed at university students.
3. "Engineering Our Future: Developing Hydrogen Skills" – Targeted towards engineers impacted by the energy transition, focusing on developing competencies related to hydrogen applications.
4. "2nd Hydrogen Summer ScH2ool" – A continuation of the earlier summer school, indicating sustained interest and engagement.

These training programs provided hands-on learning, industry exposure, and knowledge transfer through expert-led sessions. The target audience comprised undergraduate and postgraduate students, engineers, and technicians, many of whom are expected to transition into hydrogen roles as regional industries shift away from fossil fuels.

The research also referenced the broader European training context, noting that Greece has relatively few hydrogen programs compared to other countries. Nevertheless, its recent initiatives are seen as proactive and well-aligned with European trends, especially the 40% increase in reskilling programs observed between 2022 and 2023.

CLUBE's desk research includes a strong emphasis on practical learning and collaborative development. The educational offers covered topics such as:

- Introduction to hydrogen and fuel cell technologies
- Structure and applications of fuel cells
- Basics and principles of electrolysis
- System safety and regulatory responsibilities
- Material compatibility with hydrogen, including hydrogen embrittlement and corrosion
- Real-world system design, operation, and testing protocols

In conclusion, CLUBE's contribution demonstrates a proactive regional model for hydrogen education in a transitioning economy, emphasizing technical readiness, regulatory awareness, and practical application. Table 5 shows the findings of the desk research of CLUBE. Table 6 shows an overview of the 3 together.

Aspect	**Details**
Main Focus of Training	Development and evaluation of hydrogen training programs to support skill development in Western Macedonia during the energy transition
Key Training Providers Identified	CLUBE, Advent Technologies, University of Western Macedonia
Types of Training Offered	One-day masterclasses, hydrogen summer schools, engineering focused reskilling courses
Target Audience	University students, engineers, technicians, and professionals transitioning from fossil fuel sectors
Key Skills Emphasized	Hydrogen value chain fundamentals, electrolysis, fuel cells, material compatibility, safety protocols, system design and operation
Gaps Identified	Limited national-level programs in Greece; need for broader reach and institutional embedding
Regional Focus	Training initiatives organized directly by CLUBE and academic partners
Conclusions	Strong regional model emphasizing hand-on, practical hydrogen education with strategic alignment to reskilling demands in energy transition regions

Table 3 Desk Research findings by CLuBE

Combined Tables

Aspect	NEC	Bizup	CLUBE
Main Focus of Training	Training landscape for hydrogen production, transport, industrial use, and mobility	Identification and assessment of hydrogen-related training programs and skill development frameworks in Upper Austria and internationally	Development and evaluation of hydrogen training programs to support skill development in Western Macedonia during the energy transition
Key Training Providers Identified	New Energy Business School (NEBS), NEC Projects, Brunel University	National: Energy Training Centre, Hydrogen Academy, TUV Austria, New Energy Business School (NEBS) International: Queensland Hydrogen Industry Hydrogen Europe, European Hydrogen Observatory	CLUBE, Advent Technologies, University of Western Macedonia
Types of Training Offered	Masterclasses, intensive 3–4-day courses, 16-day directive courses, postgraduate modules	Online modular courses, safety training, case study-based programs, certification courses, technical modules on electrolysis, storage, fuel cells, material compatibility, and leadership-focused modules	One-day masterclasses, hydrogen summer schools, engineering focused reskilling courses
Target Audience	Management, re-skilling professionals, policy makers, technical staff (MBO, HBO, WO levels)	STEM students, professionals entering the hydrogen economy, and current industry staff requiring technical, safety or regulatory upskilling	University students, engineers, technicians, and professionals transitioning from fossil fuel sectors
Key Skills Emphasized	Broad foundational knowledge, hydrogen safety, system overview, introductory technical modules	Hydrogen safety, infrastructure requirements, strategic readiness, innovation in hydrogen applications, regulatory and material science knowledge	Hydrogen value chain fundamentals, electrolysis, fuel cells, material compatibility, safety protocols, system design and operation

Aspect	NEC	Bizup	CLUBE
Gaps Identified	Lack of specialized and deep technical training; limited focus on safety (HAZOP, ATEX); need for upskilling from other energy sectors	Need for harmonized and applied training across Europe; early-stage educational content for technical learners still limited; limited integration of hydrogen topics in standard engineering curricula	Limited national-level programs in Greece; need for broader reach and institutional embedding
Regional/National Initiatives	Waterstof Werkt (vocational education initiatives in Northern Netherlands), HyDelta 2.0 (skill requirements for HBO, WO, and postgraduate levels)	Queensland Hydrogen Roadmap, Hydrogen Europe resources, NEED Project for educational content, TUV Austria certification courses, New Energy Business School, EU Hydrogen Strategy, REPowerEU	Training initiatives organized directly by CLUBE and academic partners
Conclusions	Hydrogen education is growing but still introductory; specialized, technical, and safety-focused training urgently needed	While training offers are increasing and diversifying, there is a continued need for European-wide alignment, deeper specialization, and better integration into formal education systems	Strong regional model emphasizing hand-on, practical hydrogen education with strategic alignment to reskilling demands in energy transition regions

Table 4 Overview NEC/ Biz.up/ CLUBE

3 Positions and their requirements

This chapter delves into the diverse roles within the burgeoning hydrogen sector, outlining the essential knowledge domains and preferred training formats for each based on the survey that has been conducted within the project. From the technical expertise of Operations and Maintenance and various Engineering disciplines to the strategic insights required for Finance and Accounting, Purchasing, Logistics, and Supply Chain, IT, R&D, Quality and HSE, and Management (Mid-level, First-level, and Top-level), we explore the specialized skills needed to drive this industry forward. While some roles, like HR and Operational Logistics, show limited current involvement, the comprehensive analysis highlights the critical need for tailored knowledge acquisition to ensure a skilled and adaptable workforce for the future of hydrogen.

3.1 Operation and Maintenance

Core Knowledge: 4.5 Safety Knowledge, 4.1 Operational Knowledge, 4.3 Engineering Knowledge

An Operation and Maintenance (O&M) professional in the hydrogen sector ensures the safe, efficient, and reliable functioning of hydrogen production, storage, distribution, and utilization systems. The Task of an O&M professional includes monitoring, troubleshooting, maintaining, and optimizing hydrogen-related equipment and processes. Thus, it makes sense, that Safety, Engineering and Operational-Knowledge are deemed most relevant. This role is supposed to bridge the gap between engineering, operations and safety. Providing this position with the mentioned knowledge, ensures that the system design is safe (Engineering), reliable operation and maintenance structures are in place (Operational), Risks are minimized, and emergency preparations are present (Safety). Furthermore, this position requires a broad and deep understanding of the area (Previous Education), a specific knowledge regarding the company's operations (Internal Training Programmes) and up-to-date knowledge (External Trainings and Workshops) to operate safely. Hands-on experience (on-the-job learning) is the dominant training method, underlining that practical skills are more critical than theoretical knowledge in this field.

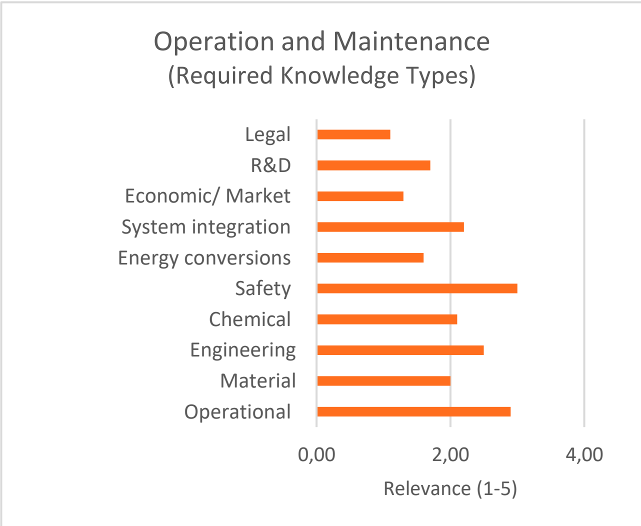


Figure 1 Sources of Knowledge and Training Methods for Operation and Maintenance

Preferred Training Formats: On-the-Job Learning, Previous Education*, Internal Training Programs,* External Training and Workshops

Training Recommendations:

- Implement hands-on safety drills and equipment-specific training for operational staff
- Develop mentorship programs pairing senior engineers with junior staff.
- Offer external workshops to keep Knowledge regarding safety up to date

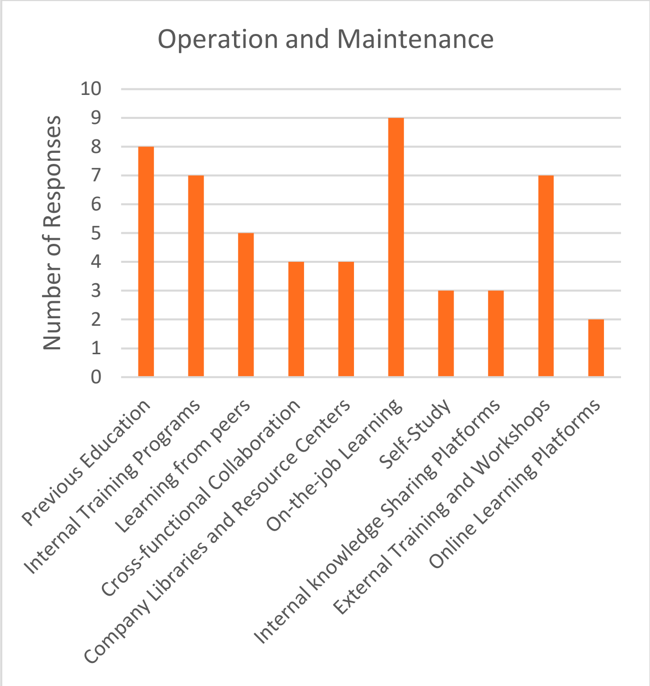
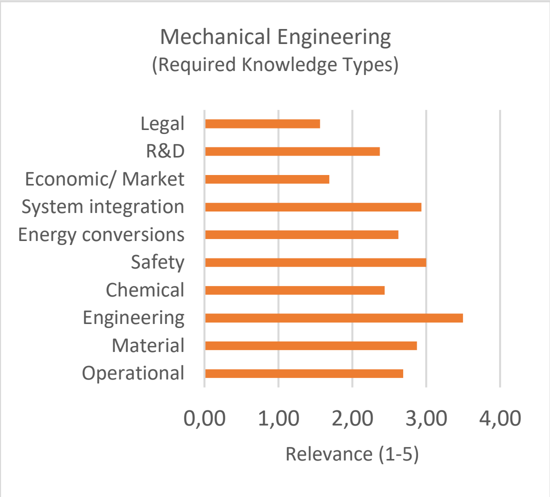


Figure 2 Required Knowledge Types for Operation and Maintenance

3.2 Mechanical Engineering

Core Knowledge: 4.3 Engineering Knowledge, 4.5 Safety Knowledge, 4.7 System Integration Knowledge,



4.2 Material Knowledge.

A Mechanical Engineer in the hydrogen sector plays a crucial role in the design, development, and maintenance of hydrogen technologies—from production systems to storage tanks, pipelines, and integration into broader energy infrastructures. This role requires not only strong technical competencies, but also a well-rounded understanding of cross-disciplinary knowledge domains. According to the chart, the most relevant knowledge areas for Mechanical Engineers are **Chemical Knowledge**, **Safety Knowledge, System Integration, Engineering Knowledge, and Operational Knowledge**. These priorities reflect the role's central function in ensuring technological robustness, safe system performance, and integration across the hydrogen value chain. Engineering Knowledge ensures that hydrogen systems are structurally sound, efficient, and capable of withstanding technical and environmental stressors.

Chemical Knowledge is essential for understanding hydrogen's physical properties, material compatibility, and risks like embrittlement or leakage. Safety Knowledge allows Mechanical Engineers to embed risk-mitigation strategies into system design and daily operations. System Integration Knowledge enables them to align mechanical systems with electrical, chemical, and digital components—especially in hybrid energy systems.

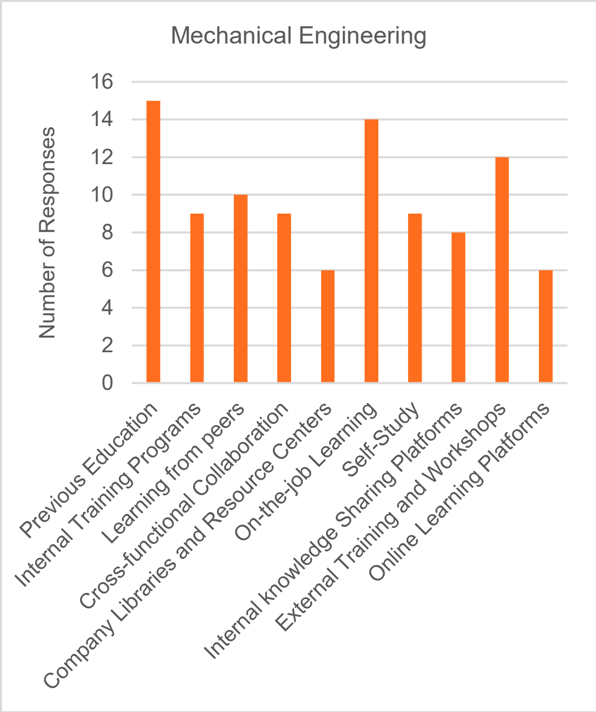


Figure 4 Sources of Knowledge and Training Methods for Mechanical Engineering

Preferred Training & Education Formats

The data shows that Mechanical Engineers prefer a balanced blend of formal education and hands-on learning. Previous education is rated highest, reflecting the importance of a strong academic foundation in mechanical and technical principles. On-the-job learning follows closely, highlighting the value of applying skills in real-world environments. External training, self-study, and peer learning are also well regarded, suggesting a proactive approach to skill development. Internal training programs and cross-functional learning support collaboration and knowledge flow within organizations, while online platforms and company libraries are used less frequently, likely due to a preference for applied, role-specific learning formats.

Preferred Training Formats: Previous Education, On-the-Job Learning, External Training and Workshops

Training Recommendations:

3.3 Chemical Engineering

Core Knowledge: 4.6 Energy Conversion Knowledge*,* 4.4 Chemical Knowledge*,* 4.7 System Integration Knowledge*,* 4.9 R&D Knowledge

Chemical Engineers are essential to the hydrogen value chain, where they support the design, optimization, and scaling of hydrogen production and conversion processes such as electrolysis, reforming, ammonia cracking, and synthetic fuel production.

According to the data, Chemical Engineers must possess a **broad and interdisciplinary knowledge** base that reflects the complexity of hydrogen systems and the need for cross-functional integration. **System Integration Knowledge** is particularly important, as it enables engineers to connect chemical processes with mechanical, electrical, and digital systems—especially at the scale of industrial hydrogen production. Chemical Knowledge forms the foundation of their expertise, allowing for deep understanding of reaction kinetics, catalysts, material compatibility, and the unique safety considerations associated with hydrogen handling. In addition, Engineering Knowledge is essential for translating lab-scale concepts into scalable, economically viable processes that can operate reliably within commercial facilities. Safety Knowledge also plays a critical role, equipping engineers to identify and mitigate risks, prevent issues such as hydrogen embrittlement, and ensure the safety of both systems and personnel. Finally, Economic/Market and Operational Knowledge support techno-economic assessments and cost optimization, while ensuring that chemical process design aligns with practical realities on the ground.

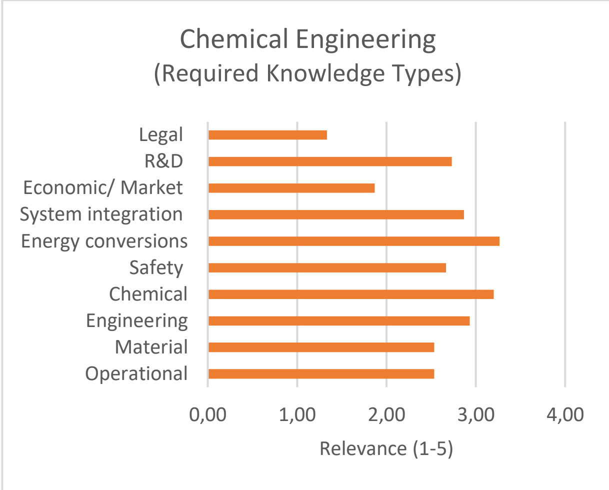


Figure 5 Required Knowledge Types for Chemical Engineering

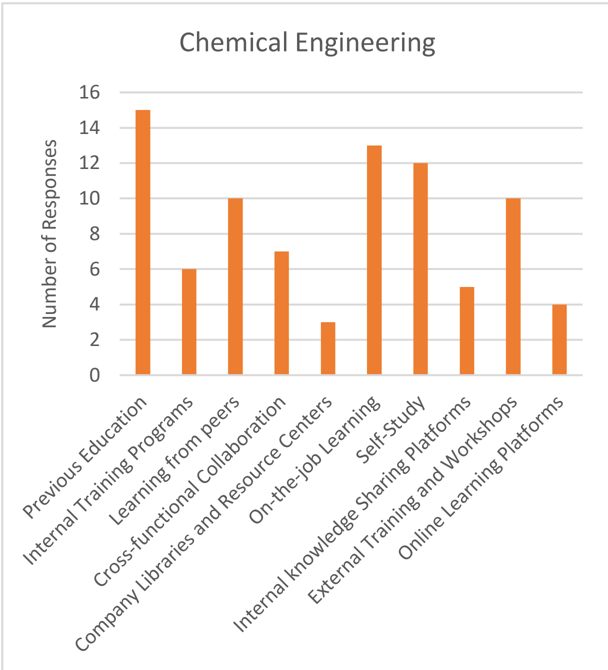


Figure 6 Sources of Knowledge and Training Methods for Mechanical Engineering

Preferred Training & Education Formats

The survey responses indicate that Chemical Engineers prefer a balanced mix of formal education and applied, self-directed learning. There is a strong reliance on previous education and self-study, highlighting the value placed on academic foundations and personal initiative in staying current. On-the-job learning is also prioritized, reflecting the need to apply theoretical knowledge in real industrial settings. Meanwhile, internal training programs and peer learning facilitate knowledge transfer and experience sharing within organizations. Although less dominant, external workshops and online platforms complement this learning ecosystem by providing updates on technical standards and adjacent topics such as certification or regulation.

Preferred Training Formats: Previous Education*,* On-the-Job Learning*, Self-Study*

3.4 Electrical Engineering

Core Knowledge: 4.3 Engineering Knowledge*,* 4.7 System Integration Knowledge*,* 4.1 Operational Knowledge

Electrical Engineers are essential for the design, integration, and control of electrical systems in hydrogen production, storage, conversion, and utilization. Their responsibilities include managing the electrical infrastructure of electrolysis systems, energy management, control systems, power electronics, and grid integration of hydrogen-based technologies. Electrical Engineers in the hydrogen sector are systems thinkers and integrators, operating at the interface of energy infrastructure, automation, and market logic. Their success depends on a mix of engineering depth, economic awareness, and system integration expertise.

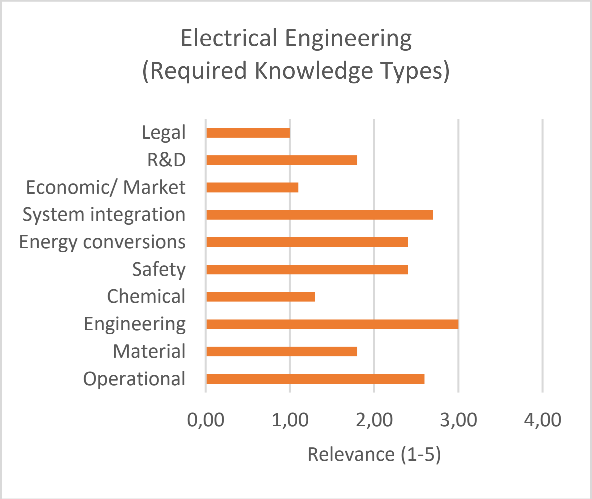


Figure 7 Required Knowledge Types for Electrical Engineering

Based on the knowledge chart, Electrical Engineers require a broad technical foundation combined with interdisciplinary awareness. **Engineering Knowledge** is central to the role, enabling the design of circuits, control systems, and power infrastructure tailored to hydrogen technologies. System Integration Knowledge is equally critical, particularly for linking hydrogen production systems—such as electrolysers—with renewable energy sources, storage technologies, and the electrical grid. A solid grasp of **Economic and Market Knowledge** is increasingly important, reflecting the need to understand hydrogen-related business models, grid services, and electricity market dynamics. **Operational Knowledge** ensures that electrical designs align with real-world conditions, including reliability, maintainability, and performance. Lastly, **Energy Conversions Knowledge** supports comprehension of power-to-gas and gas-to-power processes, which are central to hybrid energy systems involving hydrogen.

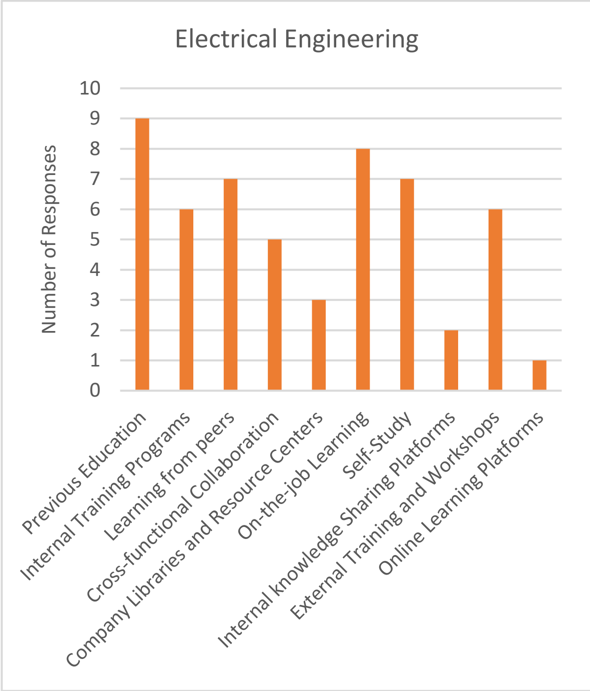


Figure 8 Sources of Knowledge and Training Methods for Electrical Engineering

Preferred Training & Education Formats

The training chart shows that Electrical Engineers favour a mix of formal education and practical, self-directed learning. Previous education ranks highest, underlining the value of strong theoretical grounding. On-the-job learning and self-study are also key, reflecting the need to adapt to evolving hydrogen technologies. Internal training and peer learning support knowledge exchange within teams, while cross-functional learning and external workshops are moderately preferred. Online platforms and libraries are less favoured, likely due to the hands-on, context-specific nature of electrical engineering work. This profile reflects an engineering culture focused on core education, real-world application, and peer collaboration, with less reliance on generic digital content.

Preferred Training Formats: Previous Education, On-the-Job Learning

3.5 Finance and Accounting

Core Knowledge: 4.8 Economic Market Knowledge, 4.10 Legal Knowledge

Finance and Accounting professionals are playing an increasingly strategic role in the hydrogen sector, especially as the industry scales from R&D and pilot phases to commercially viable infrastructure and markets. These professionals ensure that hydrogen investments are economically sound, transparently reported, and aligned with regulatory, sustainability, and taxonomic requirements. Their role spans financial modelling, budgeting, funding acquisition, reporting, compliance, and strategic evaluation of hydrogen project pipelines.

The knowledge chart highlights that **Economic/Market Knowledge** and Legal Knowledge areas for finance professionals. These reflect the importance of understanding funding frameworks, subsidy regulations, electricity and carbon markets, and trade policies that impact hydrogen's economic feasibility. In addition, **System Integration Knowledge** is also highly ranked, indicating the need to comprehend how hydrogen fits into broader energy and industrial systems, especially when evaluating capital expenditures or revenue streams related to power-to-gas, hydrogen mobility, or synthetic fuel applications. R&D Knowledge is surprisingly high as well, likely due to the financing of innovation-driven pilot projects and pre-commercial technologies, which require an understanding of technical development stages, TRLs, and eligibility criteria for innovation funding. Safety and Engineering Knowledge, while less emphasized, are still relevant for risk management, insurance evaluation, and project due diligence.

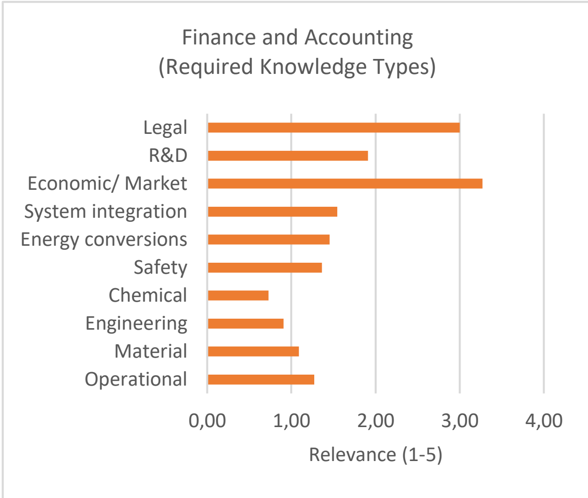


Figure 7 Required Knowledge Types for Finance and Accounting

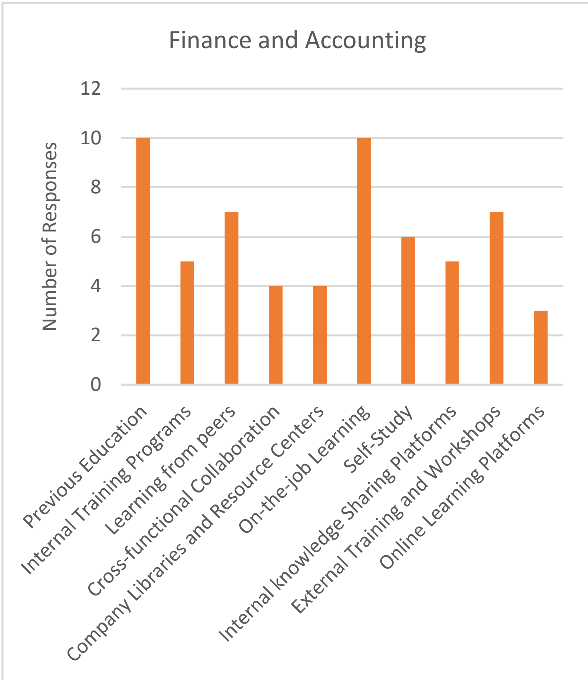


Figure 8 Sources of Knowledge and Training Methods for Finance and Accounting

Preferred Training & Education Formats

When it comes to preferred training and education formats, the data suggests that Finance and Accounting professionals rely on a mix of foundational education and applied, independent learning. Previous Education and On-the-job Learning are the most preferred formats, indicating the importance of both a solid academic foundation and real-world exposure to hydrogen projects, markets, and finance models. Self-Study also scores highly, which likely reflects the fast-evolving nature of the sector and the need to stay up to date with policy shifts, ESG reporting standards, and financial innovation.

Overall, finance professionals in the hydrogen industry operate at the intersection of policy, risk, and investment. To be effective, they must combine a solid understanding of the economic and legal landscape with the agility to interpret technical project data and regulatory implications.

Preferred Training Formats: Previous Education, On-the-Job Learning

3.6 Purchasing, Logistics and Supply Chain

Core Knowledge: 4.8 Economic Market Knowledge, 4.10 Legal Knowledge

In the hydrogen economy, professionals in Purchasing, Logistics, and Supply Chain are essential to ensuring the smooth, cost-effective, and compliant flow of materials, components, and services across all phases of the hydrogen value chain, from procurement of electrolyser units and storage systems to transportation of hydrogen molecules and coordination with suppliers, ports, and technology vendors.

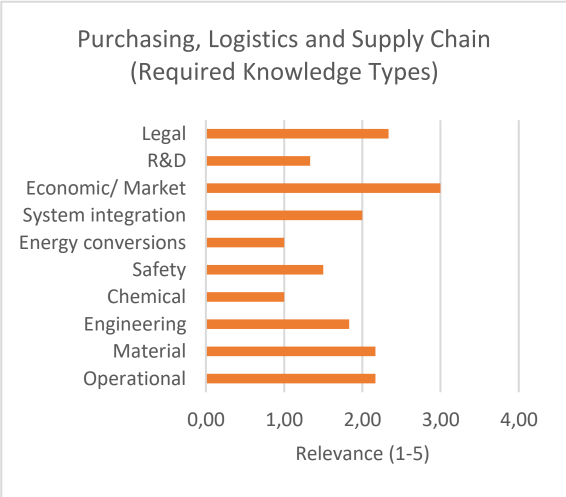


Figure 9 Required Knowledge Types for Purchasing, Logistics and Supply Chain

The knowledge chart highlights that Economic/Market Knowledge is particularly critical for professionals in this function. This aligns with the need to understand hydrogen pricing trends, supply-demand dynamics, and the global trade environment that affects procurement strategies and contracting terms. Legal Knowledge is also highly valued, reflecting the legal sensitivity around procurement frameworks, international transport regulations, and contractual risk management. Material Knowledge, Engineering Knowledge, and System Integration Knowledge are all notably important as well. These competencies enable professionals to understand the technical requirements of hydrogen systems and engage effectively with engineering teams and suppliers. Having a solid grasp of Chemical and Operational Knowledge further supports compatibility and safety in handling hydrogen-related materials, while Safety and Energy Conversion Knowledge—though less prominent—remain relevant, especially in logistics or storage contexts.

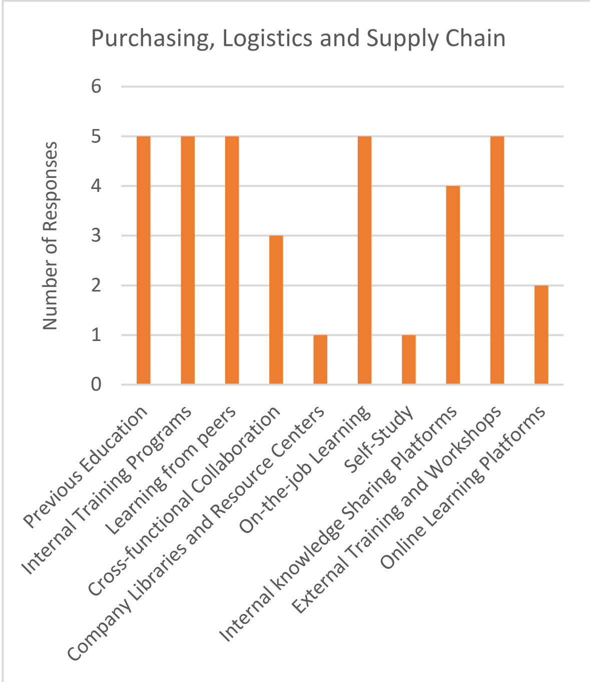


Figure 10 Sources of Knowledge and Training Methods for Purchasing, Logistics and Supply Chain

Preferred Training & Education Formats

When it comes to training and education preferences, professionals in Purchasing, Logistics, and Supply Chain show a strong inclination toward a balanced mix of formal and experiential learning. Previous Education, Internal Training Programs, Peer Learning, On-the-job Learning, and External Training are equally favoured, each scoring relatively high. This suggests that these professionals value both foundational education and direct exposure to day-to-day challenges. Self-Study and Cross-functional Learning also score reasonably well, indicating the need for continuous self-upskilling and better alignment with technical and operational colleagues.

Overall, supply chain professionals in the hydrogen field must combine commercial insight, legal precision, and technical literacy to manage complex procurement strategies, ensure compliance, and keep projects on schedule and within budget.

Preferred Training Formats: No preferred formats

3.7 IT

Core Knowledge: 4.9 R&D Knowledge

In the emerging hydrogen economy, IT professionals are vital enablers of digital infrastructure, cybersecurity, automation, and data-driven decision-making. Their work supports everything from sensor integration in hydrogen plants and IoT-based monitoring to energy management systems, digital twins, and secure data flows across hydrogen supply chains. As hydrogen operations become more interconnected and digitally governed, the role of IT expands from support to strategy.

According to the knowledge chart, IT experts in the hydrogen sector require a broad cross-functional understanding. Most notably, Legal Knowledge stands out as particularly relevant reflecting the increasing importance of data protection, regulatory compliance (e.g., NIS2, GDPR), and secure IT operations in critical hydrogen infrastructure. Lead by R&D Knowledge, which likely points to collaboration with engineers and researchers on emerging digital tools for system design, modeling, and performance optimization. Other highly rated areas include System Integration, Economic/Market Knowledge, and Energy Conversions Knowledge, underscoring the importance of understanding how IT interfaces with technical systems and commercial operations. While Engineering and Operational Knowledge rank slightly lower, their presence suggests that IT professionals still need enough technical fluency to work alongside plant engineers, automation experts, and operations teams.

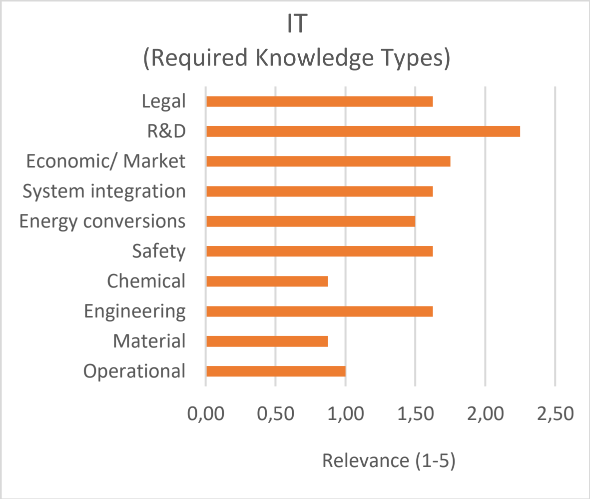


Figure 11 Required Knowledge Types for IT

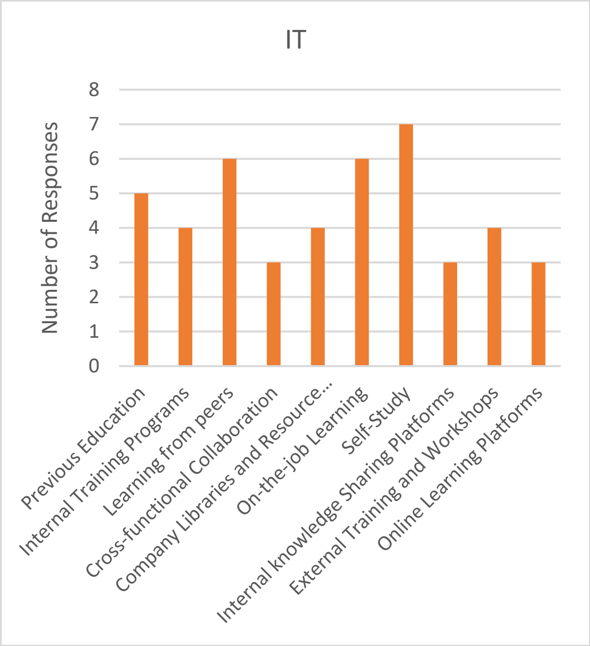


Figure 12 Sources of Knowledge and Training Methods for IT

Preferred Training & Education Formats

The training and education preferences for IT professionals indicate a clear lean toward flexibility, autonomy, and peer-based learning. Self-Study and On-the-job Learning are most preferred, emphasizing the fast-paced and self-directed nature of IT work, where technologies evolve rapidly and learning needs are often immediate and contextual. Learning from Peers and Previous Education also score highly, reflecting the value of foundational knowledge combined with informal and community-based learning. Formats such as Internal Knowledge Sharing, Online Platforms, and Cross-functional Learning are moderately valued, suggesting openness to structured content, especially when tailored to internal systems or use cases. Interestingly, External Training and Company Libraries are among the least preferred, possibly due to their lack of customization or real-time relevance in the IT-domain.

Preferred Training Formats: Self-Study, Learning from peers, On-the-job learning

3.8 R&D (Research and Development) / Innovation

Core Knowledge: 4.9 R&D Knowledge, 4.6 Energy Conversion Knowledge

The R&D and Innovation function is at the heart of the hydrogen transition, driving the development of new technologies, systems, and materials that enhance efficiency, safety, scalability, and cost-effectiveness across the hydrogen value chain. Professionals in this area are not only expected to deliver scientific and engineering breakthroughs but also to contribute to business model innovation, cross-sectoral collaboration, and the translation of lab-scale solutions into commercial products and processes.

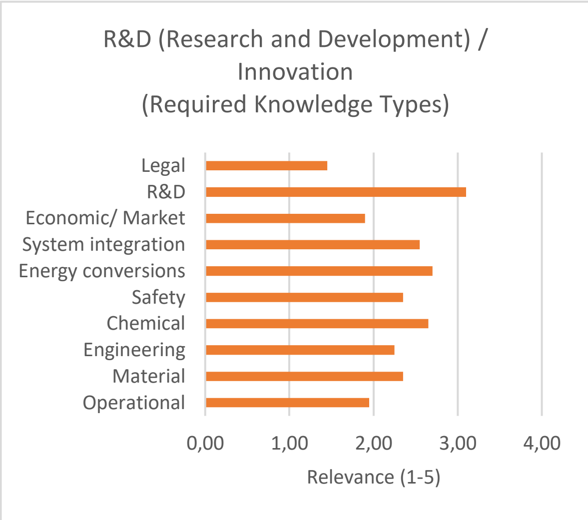


Figure 13 Required Knowledge Types for R&D

According to the knowledge chart, R&D professionals must draw from a highly interdisciplinary knowledge base. R&D Knowledge understandably ranks highest, reflecting the need for familiarity with technology readiness levels (TRLs), pilot project dynamics, intellectual property management, and innovation funding schemes. This is closely followed by Safety Knowledge, Energy Conversions, System Integration, and Chemical Knowledge. All of which are essential for designing experiments, modelling system interactions, and understanding the fundamental thermodynamics and risks involved in hydrogen production, transport, and usage. Engineering and Material Knowledge are also valued, supporting practical prototyping and integration efforts. Notably, Economic/Market Knowledge is well-positioned, showing the growing demand for innovation experts who understand market viability, policy incentives, and cost-performance trade-offs.

Preferred Training & Education Formats

The training and learning preferences of R&D professionals demonstrate a strong orientation toward applied, flexible, and peer-based learning. On-the-job Learning is by far the most preferred mode, reflecting the iterative, experimental nature of innovation work where learning is embedded in real-time project development. Self-Study also scores very highly, aligning with the need for researchers and engineers to stay up to date on scientific literature, technology trends, and emerging tools. Formal and structured formats such as Previous Education, Internal Training Programs, Learning from Peers, and External Training are also well-represented highlighting the importance of foundational knowledge and active knowledge exchange within and beyond the organization. Cross-functional Learning and Internal Knowledge Sharing show moderate preference, supporting collaboration across disciplines and departments.

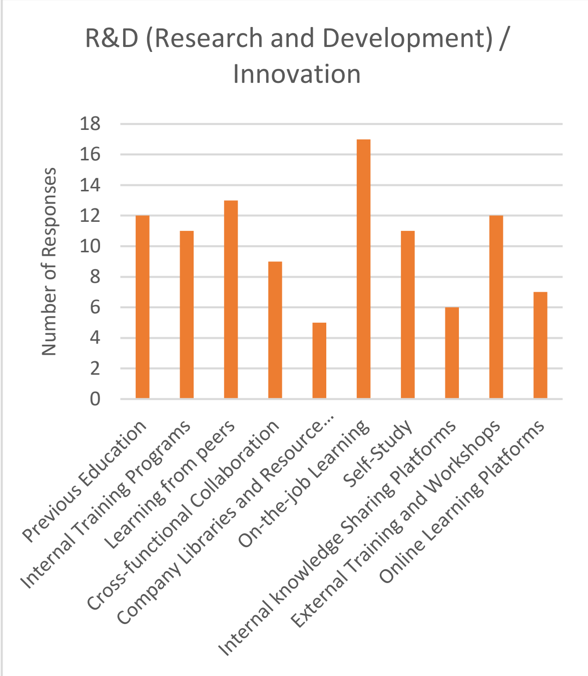


Figure 14 Sources of Knowledge and Training Methods for R&D

Preferred Training Formats: On-the-Job Learning*, Learning from peers*

3.9 Quality and HSE (Health, Safety and Environment)

Core Knowledge: 4.5 Safety Knowledge*,* 4.10 Legal Knowledge*,* 4.1 Operational Knowledge

The analysis of both charts highlights the key knowledge areas required for HSE professionals in the context of hydrogen, as well as how this knowledge should ideally be acquired. **Safety** stands out as the most critical area, understandably, given hydrogen's high-risk nature. **Operational knowledge** and **legal understanding** are also rated as important. Knowledge in **chemistry**, **materials**, and **engineering** is seen as beneficial, though not essential. **R&D** and **economic/market knowledge** are considered less relevant, as they fall outside the typical scope of HSE roles.

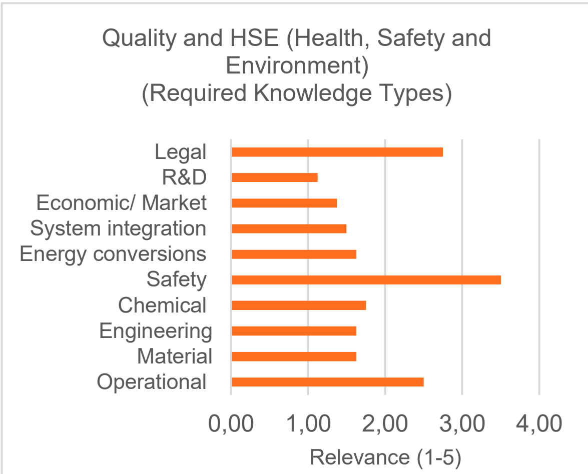


Figure 15 Required Knowledge Types for Quality and HSE

It's worth noting that only 8 out of 37 companies reported that their HSE staff are currently, or will soon be, involved in hydrogen-related activities. However, these companies still indicate a strong need for in-depth knowledge in safety and operational matters.

When it comes to learning methods, companies clearly favour **practical approaches**: **previous education**, **on-the- job learning**, and **peer exchange** are the top choices. Internal training, self-study, and online learning platforms also play a significant role. In contrast, **external training and workshops** were rated lower, perhaps reflecting a preference for organization-specific knowledge transfer.

In summary, for HSE professionals working with hydrogen, a solid foundation in safety and operations is essential. Companies prioritize hands-on, internal learning methods to develop these competencies and prepare their teams for the unique challenges of hydrogen-related work.

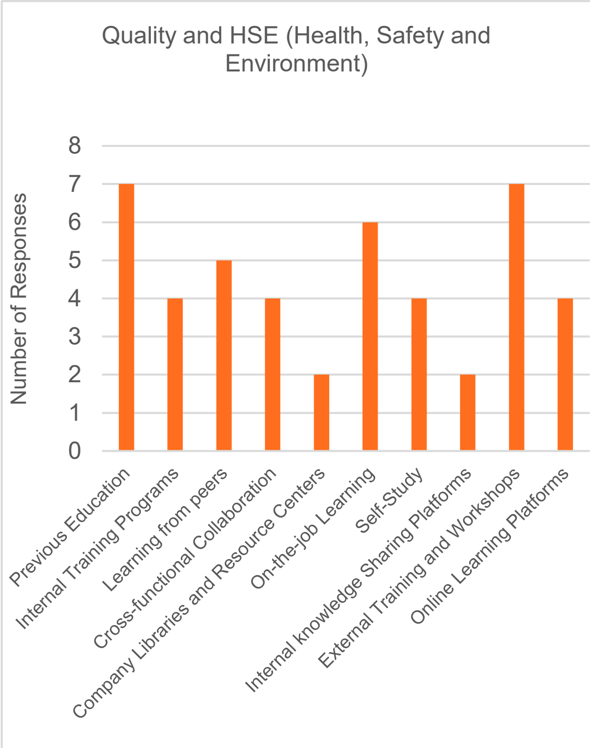


Figure 16 Sources of Knowledge and Training Methods for Quality and HSE

Preferred Training Formats: Previous Education, External Training and Workshops

Training Recommendations:

3.10 Mid- and First-Level Management

Core Knowledge: 4.8 Economic Market Knowledge*,* 4.10 Legal Knowledge*,* 4.9 R&D Knowledge

An analysis of the data reveals clear expectations for Mid- and First-Level Management in hydrogen-related activities. The first graph shows that Economic and Market knowledge is the most relevant, with a score close to 3, indicating its importance for understanding emerging markets, government subsidies, and business models. Other areas like Operational knowledge, Material science, Engineering, Safety, Energy Conversions, System Integration, R&D, and Legal knowledge also have moderately high ratings, suggesting a need for interdisciplinary understanding. Chemical knowledge is the least relevant, with a score around 1.5.

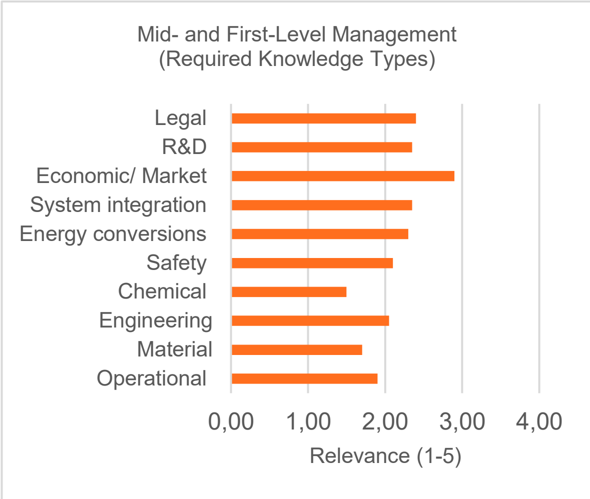


Figure 17 Required Knowledge Types for Mid- and First Level Management

The second graph highlights preferred learning methods. Most companies favour informal and experience-based learning, such as on-the-job learning (15 mentions), learning from peers (14), previous education (13), cross-functional collaboration, and self-study (both around 13). Formal methods like internal training programs, external training, and online learning platforms are less favoured.

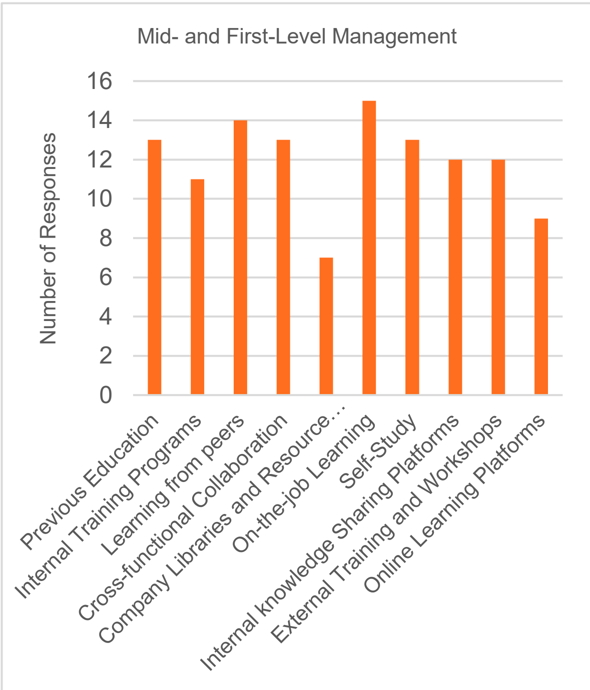


Figure 18 Sources of Knowledge and Training Methods for Mid- and First Level Management

Comparing the two graphs shows alignment between the emphasis on Economic and Market knowledge and hands-on learning methods. Technical topics are important but not at an expert level, aligning with the preference for informal learning. Legal knowledge is moderately important but lacks structured training, which could be risky. Online learning platforms are less favoured, possibly due to concerns about content relevance.

In conclusion, companies expect managers to understand key hydrogen-related topics through direct experience, collaboration, and self-directed learning. Case-based workshops may help fill knowledge gaps, especially in legal compliance and system integration. Enhancing online learning offerings could also be beneficial.

Preferred Training Formats: On-the-Job Learning*, Learning from peers*

3.11 Top-Level Management

Core Knowledge: 4.8 Economic Market Knowledge, 4.10 Legal Knowledge

Of all the roles evaluated, Top-Level Management was the one for which most companies considered knowledge of the hydrogen sector to be required. 21 of 37 companies stated that this position should be informed regarding hydrogen.
The strongest demand is in the area of Economic- and Market knowledge, which received an overall rating of 4 (Comprehensive Knowledge). This is followed by legal knowledge, with an overall rating of 3 (Extensive Knowledge).

Comprehensive knowledge of the Economic/Market field is vital for making informed investment decisions, identifying market opportunities, and developing sustainable business strategies. Legal knowledge is crucial for navigating the regulatory landscape, ensuring compliance, and mitigating risks associated with hydrogen technologies.
A good overview of R&D, system integration, and energy conversions enables top-level management to understand the technological aspects of hydrogen projects, assess feasibility, and make strategic decisions related to innovation and deployment.
Given that this role focus on strategy, finance, and overall business operations, it is plausible to assume that in-depth technical knowledge is not essential.
As for the sources of knowledge, the most popular options were self-study, online learning platforms, and previous education. Thus, top-level management primarily relies on self-directed learning methods such as self-study and online learning platforms to acquire knowledge about hydrogen-related activities. The emphasis on economic/market and legal knowledge aligns with the importance of self-study and online learning platforms. Top-level management likely uses these resources to stay updated on market trends, regulations, and emerging business models.

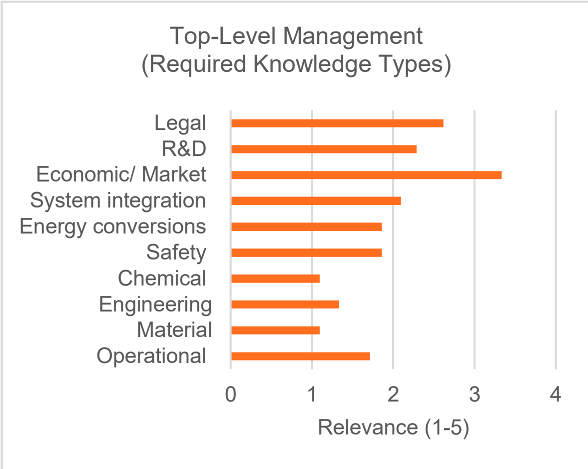


Figure 19 Required Knowledge Types for Top-Level Management

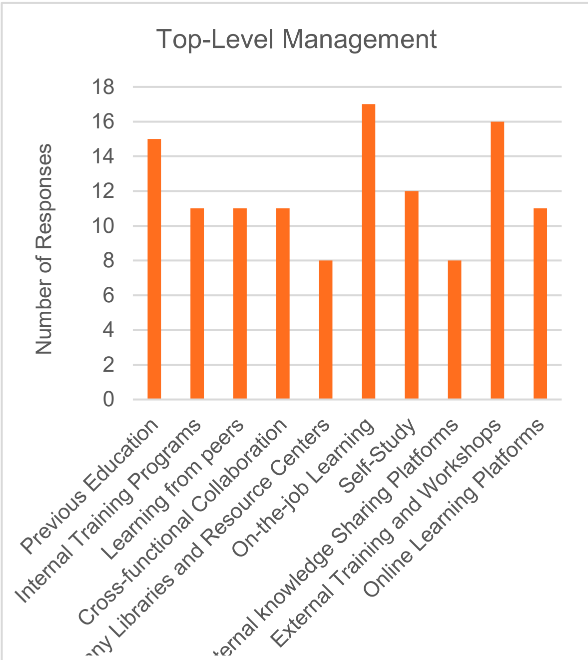


Figure 20 Sources of Knowledge and Training Methods for Top-Level Management

Preferred Training Formats: On-the-Job Learning, External Training and Workshops, Previous Education

3.12 HR (Human Resources)

Core Knowledge: 4.8 Economic Market Knowledge*,* 4.10 Legal Knowledge

Only one of the Project companies or participants considered it as advisable for employees in this role to have good knowledge of the hydrogen sector. Thus, the findings regarding which hydrogen topics might be relevant for an HR role or which knowledge sources to use are not representative. Of the questioned institutions, 16 mentioned there is no such position, and 20 stated there is such a position but no involvement in this area for this role.

The highest level of expertise (Extensive Knowledge) is required in Legal- and Economic/ Market knowledge. At the same time an average level of expertise (Good Knowledge) is needed within the Safety area. This is logical, as HR is typically responsible for ensuring compliance with regulations, managing labour law requirements, and aligning workforce planning with market conditions. Safety knowledge is also important but not as extensive – HR needs to know safety protocols for workforce well-being. For all the other knowledge areas an Insight is deemed enough.

As for the second graph, all knowledge sources are deemed equally important, making it difficult to conclude. It might be legitimate to say that this indicates a flexible approach to knowledge acquisition.

Preferred Training Formats: No preferred formats

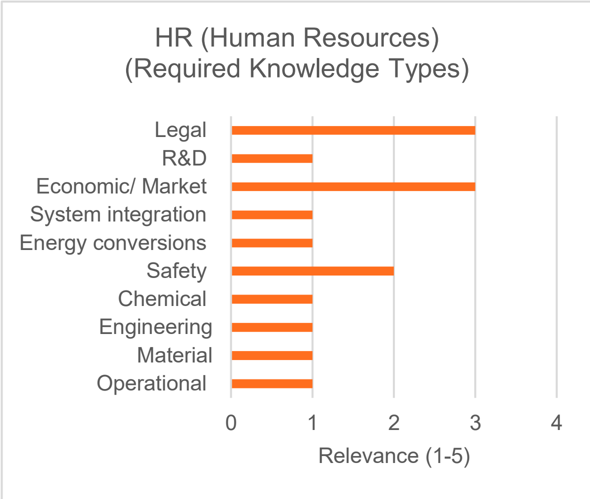


Figure 21 Required Knowledge Types for HR

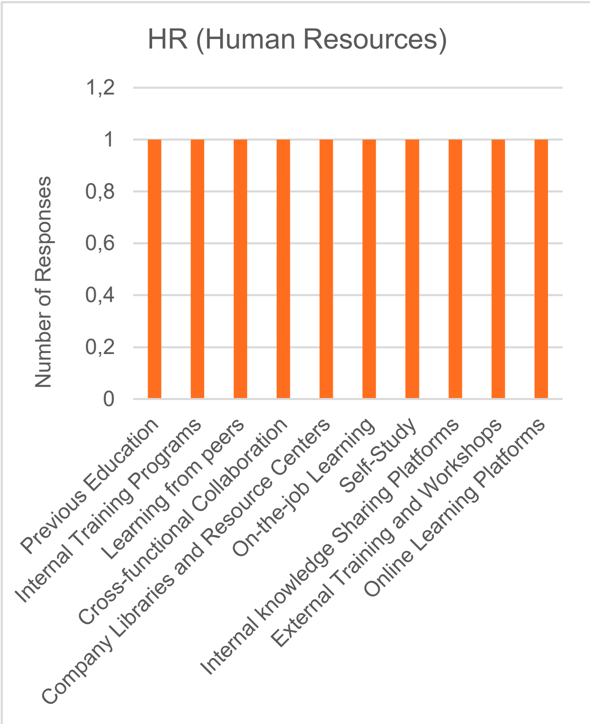


Figure 22 Sources of Knowledge and Training Methods for HR

3.13 Legal Management

Core Knowledge: 4.10 Legal Knowledge

The role of the legal expert in hydrogen is essential for ensuring regulatory compliance, mitigating risks, and safeguarding business operations through robust legal frameworks.

Their expertise is essential for navigating the complex and evolving landscape of hydrogen regulations, safety laws, international agreements, and government incentives. In general, legal management was one of the roles for which the need for knowledge in hydrogen was required to be the highest. The three knowledge areas which were deemed most relevant for this role are Legal, Economic/ Market and Safety knowledge. This is well-founded, as strong expertise in these areas ensures that a hydrogen company operates both in compliance and on a sound economic basis. It is important to possess the knowledge of the regulatory framework to act compliant and safe (Legal), to stay informed about subsidies, trade policies, and competitive strategies for enhancing market viability (Economic/Market), and to adhere to safety standards to minimize liability risks and foster a secure working environment (Safety).

Legal expertise is typically gained through formal education (law degrees, regulatory courses). *On-the-job learning* is also crucial for understanding industry-specific legal applications of processes and technologies. Since legal professionals often deal with various regulations, it is justifiable, that they engage in *self-study and external trainings* to stay updated. Legal management often requires collaboration with engineering, finance, and operations teams to ensure compliance, which makes *cross-functional collaboration* to be an important source of knowledge. However, it is not evaluated as a key resource, yet.

Preferred Training Formats: No preferred formats

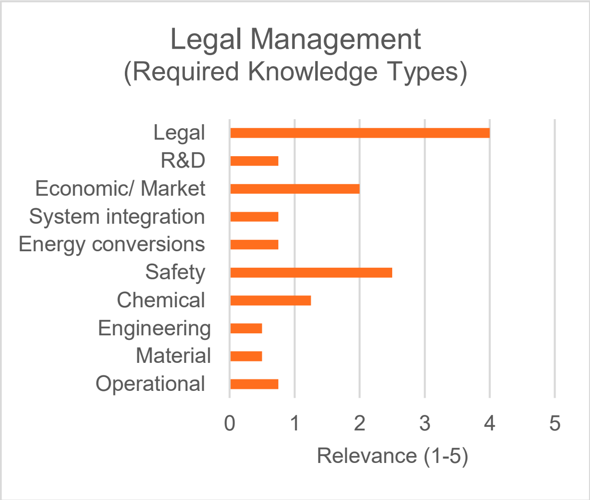


Figure 23 Required Knowledge Types for Legal Managament

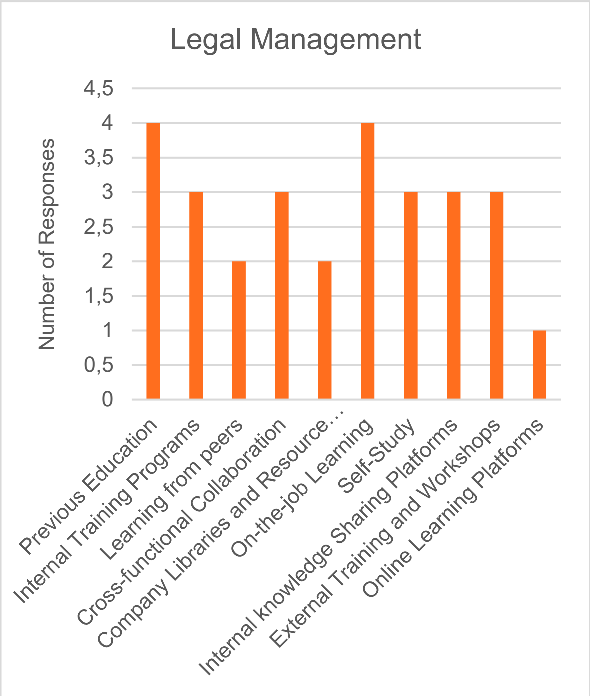


Figure 24 Sources of Knowledge and Training Methods for Legal Management

3.14 Operational Logistics

Core Knowledge: No Core Knowledge Areas identified

As with the HR role, only one of the companies/participants considered knowledge of the hydrogen sector necessary for employees in this position. Thus, the results as to the topic's importance for this position or the results of the sources that should be used to gain knowledge in the hydrogen sector are far from being representable. It is important to mention that more than half (20) of the organisations surveyed stated that there is no such position in the company.

However, for the sake of completeness, the survey results are still presented and discussed here, albeit subject to the limitations outlined above. The company that has answered the question stated that in the areas of Legal-, Safety-, Engineering-, Material- and Operational knowledge only Insight but not more in-depth expertise is required. According to this company, knowledge should be collected through Learning from peers and on-the-job learning. Both knowledge sources are low-threshold and require little to no additional effort. This aligns well with the correlating minor need for knowledge for this position.

The role is supportive rather than technical, which makes this result unsurprising. As hydrogen adoption is still at an early stage, it may not yet be reflected in such supportive functions. Nevertheless, a basic level of knowledge is important to ensure safety and foster cross-departmental collaboration.

Preferred Training Formats: No preferred formats

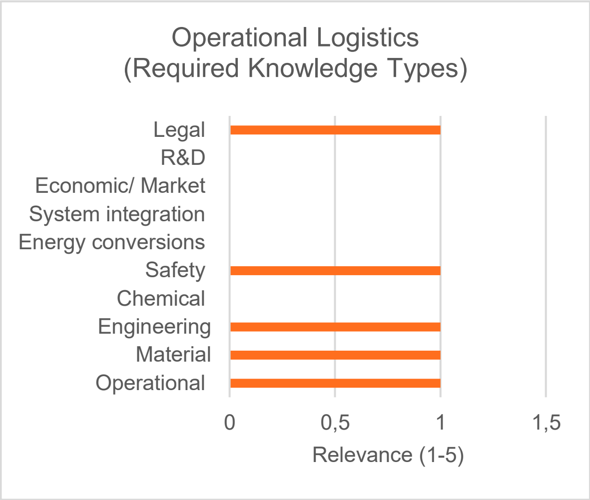


Figure 25 Required Knowledge Types for Operational Logistics

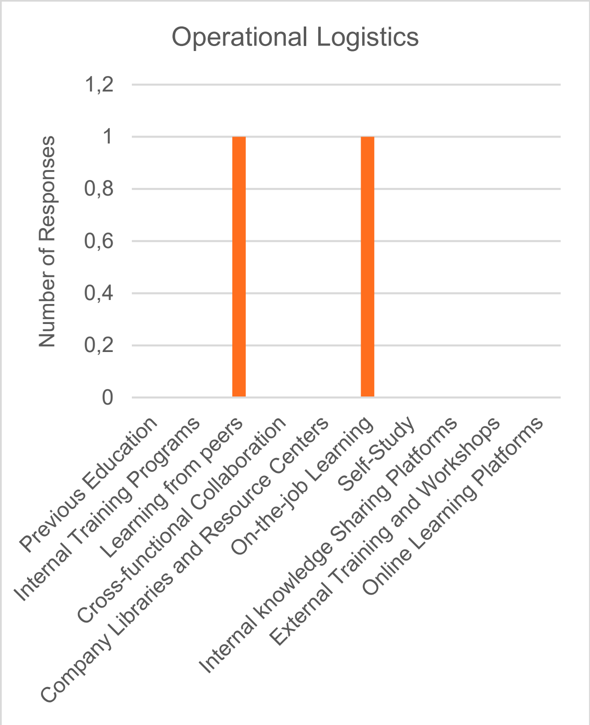


Figure 26 Sources of Knowledge and Training Methods for Operational Logistics

The two heatmaps offer an overview for the types of knowledge relevant for certain roles and the preferred training formats.

	Operational	Material	Engineering	Chemical	Safety	Energy conversions	System integration	Economic/ Market	R&D	Legal	Sum
Operation and Maintenance	3	2	3	2	3	2	2	1	2	1	21
Mechanical Engineering	3	3	4	2	3	3	3	2	2	2	27
Chemical Engineering	3	3	3	3	3	3	3	2	3	1	27
Electrical Engineering	3	2	3	1	2	2	3	1	2	1	20
Finance and Accounting	1	1	1	1	1	1	2	3	2	3	16
Purchasing, Logistics and Supply Chain	2	2	2	1	2	1	2	3	1	2	18
IT	1	1	2	1	2	2	2	2	2	2	17
R&D / Innovation	2	2	2	3	2	3	3	2	3	1	23
Quality and HSE (Health, Safety and Environment)	3	2	2	2	4	2	2	1	1	3	22
Mid- and First-Level Management	2	2	2	2	2	2	2	3	2	2	21
Top-Level Management	2	1	1	1	2	2	2	3	2	3	19
HR (Human Resources)	1	1	1	1	2	1	1	3	1	3	15
Legal Management	1	1	1	1	3	1	1	2	1	4	16
Operational Logistics	1	1	1	0	1	0	0	0	0	1	5

Figure 29 Heatmap Position vs. Knowledge type (0= No knowledge required, 4= Comprehensive Knowledge required)

	Previous Education	Internal Training Programs	Learning from peers	Cross-functional Collaboration	Company Libraries and Resource Centers	On-the-job Learning	Self-Study	Internal knowledge Sharing Platforms	External Training and Workshops	Online Learning Platforms
Operation and Maintenance	8	7	5	4	4	9	3	3	7	2
Mechanical Engineering	15	9	10	9	6	14	9	8	12	6
Chemical Engineering	15	6	10	7	3	13	12	5	10	4
Electrical Engineering	9	6	7	5	3	8	7	2	6	1
Finance and Accounting	10	5	7	4	4	10	6	5	7	3
Purchasing, Logistics and Supply Chain	5	5	5	3	1	5	1	4	5	2
IT	5	4	6	3	4	6	7	3	4	3
R&D / Innovation	12	11	13	9	5	17	11	6	12	7
Quality and HSE (Health, Safety and Environment)	7	4	5	4	2	6	4	2	7	4
Mid- and First-Level Management	13	11	14	13	7	15	13	12	12	9
Top-Level Management	15	11	11	11	8	17	12	8	16	11
HR (Human Resources)	1	1	1	1	1	1	1	1	1	1
Legal Management	4	3	2	3	2	4	3	3	3	1
Operational Logistics	0	0	1	0	0	1	0	0	0	0
Sum	119	83	97	76	50	126	89	62	102	54

Figure 30: Roles within a Company vs. Preferred Training Formats (number of mentionings)

4 Types of Knowledge

A successful integration of hydrogen into the energy system requires more than just technical expertise, it needs a broad understanding of, amongst others, operational, legal and economic aspects. This chapter gives an overview over key knowledge areas. An extensive version can be found in Appendix A

4.1 Operational Knowledge

Hydrogen can be produced through various methods, each having its own distinct advantages and challenges. Electrolysis, when powered by renewable energy, generates green hydrogen, a key to a sustainable low-carbon future, but its costs remain high compared to other methods. Steam reforming, the most common method, produces hydrogen from natural gas but emits significant amount of CO_2, unless paired with carbon capture to create blue hydrogen. Alternatives like methane pyrolysis offer cleaner options by avoiding CO_2 emissions, while gasification of biomass or ammonia provides flexibility in hydrogen production. Biological methods, such as dark fermentation, can also produce hydrogen, though they are limited to certain types of organic materials. The choice of production methods depends on balancing efficiency, resource availability, and environmental impact, with a growing focus on greener solutions.

Hydrogen storage and transport are equally critical for its widespread adoption in the energy sector. Storage options include compressed gas, liquid hydrogen, cryo-compressed methods, and advanced techniques like metal hydride or adsorption into porous materials. For transportation, pipelines offer an efficient solution for long distances, although they require significant infrastructure investments. For shorter distances, hydrogen is often moved by tank trucks in pressurized or cryogenic form. A well-developed infrastructure with refuelling stations, storage facilities, and distribution centers is essential to support the hydrogen economy and ensure reliable supply across industries.

Full Text: Operational Knowledge
Most relevant for: 3.1 Operation and Maintenance*,* 3.2 Mechanical Engineering*,* 3.3 Chemical Engineering*,* 3.4 Electrical Engineering*,* 3.9 Quality and HSE (Health, Safety and Environment)
Available resources: Long version includes all references

4.2 Material Knowledge

Hydrogen is a highly reactive gas widely used in industrial sectors, and as such that ensures material compatibility is critical for system safety and efficiency. One major challenge is hydrogen embrittlement, which occurs when hydrogen diffuses into high-strength steels and certain aluminium alloys, reducing their toughness and increasing susceptibility to cracks and fractures. This phenomenon is particularly critical for materials used in hydrogen storage systems and pressure vessels, making careful material selection and treatment essential to mitigate its impact

Material selection and monitoring are essential for hydrogen applications. Metals such as stainless steels with high nickel content and nickel alloys demonstrate better resistance to hydrogen embrittlement, while polymers, though sometimes compatible, can face limitations under extreme conditions. Extensive material testing, including mechanical and microscopic evaluations—and strict adherence to established standards are necessary to ensure the long-term stability and safety of materials used in hydrogen systems.

Full Text: Material Knowledge
Most relevant for: 3.2 Mechanical Engineering, 3.3 Chemical Engineering, 3.8 R&D (Research and Development) / Innovation
Available resources: Long version includes all references

4.3 Engineering Knowledge

Hydrogen storage and fuel cell technologies require careful engineering to ensure safety and efficiency. Compressed hydrogen is stored in high-pressure tanks, while liquefied hydrogen is kept at very low temperatures using insulated containers. Another method, metal hydrides, stores hydrogen in metal alloys, which are being developed to improve storage capacity and efficiency. Each storage method has its own challenges, but all are important for safe and effective hydrogen use.

Fuel cells—such as Proton Exchange Membrane Fuel Cells (PEMFCs) for transportation and Solid Oxide Fuel Cells (SOFCs) for power generation—also require advanced engineering expertise. PEMFCs focus on improving performance and durability, while SOFCs must handle high temperatures. Additionally, hydrogen pipelines and refuelling stations require safety features and careful design to ensure safe transportation and distribution of hydrogen.

Full Text: Engineering Knowledge
Most relevant for: 3.2 Mechanical Engineering, 3.3 Chemical Engineering, 3.4 Electrical Engineering
Available resources: Long version includes all references

4.4 Chemical Knowledge

Hydrogen purity is important and comes in several grades, depending on the application. Ultra-high purity hydrogen (e.g. ≥ 99.999% or “five-nines”) is required for highly sensitive uses such as high-performance fuel cells, electronics, or laboratory research, where even trace impurities like CO or sulphur compounds can degrade catalyst or process performance. For broader chemical synthesis such as ammonia or methanol production, hydrogen of ~99.9% purity often strikes a reasonable balance between process needs and cost. In large-scale refining or similar industrial operations, lower grades (for example ~99.0%) may be sufficient where tolerance for certain impurities is higher. The key is matching purity to application sensitivity given cost implications of purification.

Hydrogen is produced using methods like electrolysis, which creates very pure hydrogen by splitting water into hydrogen and oxygen. Another method, steam methane reforming (SMR), produces hydrogen from natural gas, typically at 99.9% purity, but can be purified further using techniques like pressure swing adsorption (PSA). Cryogenic distillation is also used to achieve very high purity, especially for liquid hydrogen. These production methods are chosen based on the purity needed for different applications in industries like electronics, chemicals, and refining.

Full Text:

Chemical Knowledge
Most relevant for: 3.2 Mechanical Engineering, 3.3 Chemical Engineering, 3.8 R&D (Research and Development) / Innovation
Available resources: Long version includes all references

4.5 Safety Knowledge

Hydrogen is a flammable gas with a wide flammability range (4%–75% by volume) and relatively low ignition energy (0.02 millijoules) (McCarty et al. 1981). It has a very low density and therefore must be stored at high pressures (10,000–15,000 psi range) to achieve enough mass for practical use. The ease of ignition and high storage pressure of hydrogen create a large portion of the risk associated with hydrogen usage. Hydrogen also has the ability to attack—and damage to the point of leakage—certain materials that are used for the construction of storage containers, piping, valves, and other appurtenances. This destructive feature is sometimes referred to as hydrogen embrittlement (Cramer and Covino 2003). The mechanisms of hydrogen embrittlement can be complex and vary with several physical parameters including temperature and pressure. Hydrogen's ability to escape through materials based on its destructive abilities and small molecule size also contributes to the risk associated with hydrogen usage.

Full Text: Hydrogen Safety
Most relevant for: 3.1 Operation and Maintenance, 3.2 Mechanical Engineering, 3.9 Quality and HSE (Health, Safety and Environment)
Available resources: Long version includes all references

4.6 Energy Conversion Knowledge

Hydrogen can be used in various energy conversion technologies:

- **Fuel Cells**: These devices convert hydrogen into electricity with water as the only byproduct. They are highly efficient and environmentally friendly, making them suitable for transport and stationary power applications. Types include Proton Exchange Membrane (PEM) fuel cells for vehicles and Solid Oxide Fuel Cells (SOFCs) for stationary power generation.
- **Combustion Engines**: Hydrogen can also power internal combustion engines (ICEs). While less efficient than fuel cells, this technology can utilize existing infrastructure with modifications, providing a transitional solution for reducing emission.

Storing hydrogen efficiently is crucial for its use as an energy carrier and can be performed in the following states:

- **Compressed Gas**: Hydrogen can be stored under high pressure, which is straightforward but requires durable materials and safety measures to prevent leaks and explosions.

- **Liquid Hydrogen**: By cooling hydrogen to cryogenic temperatures, it turns into a liquid, which is more space-efficient, but requires significant energy for cooling and insulation to maintain these low temperatures.
- **Solid-State Storage**: This involves storing hydrogen in metal hydrides or chemical compounds, offering safer, low-pressure options but facing challenges in energy density and release rates.

Full Text: Energy conversion of Hydrogen

Most relevant for: 3.2 Mechanical Engineering*,* 3.3 Chemical Engineering*,* 3.8 R&D (Research and Development) / Innovation

Available resources: Long version includes all references

4.7 System Integration Knowledge

Achieving our decarbonisation targets requires an energy system that is both flexible and decentralised, enabling it to integrate fluctuating renewable generation reliably and without disruption. The future energy system will be very different from the one today, relying much more on the direct use of electricity rather than fuels, and decarbonising hard-to-electrify sectors such as heavy transport and some processes in industry.

Better integration will optimise the energy system as a whole—across multiple energy carriers (electricity, heat, cooling, gas, solid and liquid fuels), infrastructures, and consumption sectors—by strengthening the links between them. The objective is to deliver decarbonised, reliable, and resource-efficient energy services at the lowest possible cost to society. Achieving such objective includes a stronger focus on the electrification of demand (through electric vehicles, heat pumps and industrial processes, for example), flexibility and storage, hydrogen and heating and cooling, which represents half of the EU's energy use.

The EU Strategy for Energy System Integration, published in 2020, emphasises direct electrification of end-use sectors and the enabling role of digitalisation, smart grids, smart meters, and flexibility markets. Launched in parallel, the EU Hydrogen Strategy addresses sectors where direct electrification is less feasible. Taken together, the two strategies reflect a deliberate dual approach: maximising electrification wherever possible, while positioning renewable hydrogen as a complementary solution for hard-to-abate applications.

Full Text: System integration of hydrogen

Most relevant for: 3.2 Mechanical Engineering*,* 3.3 Chemical Engineering*,* 3.4 Electrical Engineering

Available resources: Long version includes all references

4.8 Economic Market Knowledge

Economy of hydrogen

Supply and Demand Gap: Current renewable hydrogen production is only 0.02 million tons per year (Mtpa), far below the EU's consumption targets of 20 Mtpa by 2030. RMI projects regulated demand from existing policy measures to range between 2.2 and 2.8 Mtpa by 2030, driven by mandates in industry and transportation. RMI Accelerated Transition Scenario suggests up to 7.0 Mtpa of demand could materialize. This shortfall underscores the urgent need for a delivery-focused approach to accelerate domestic production and secure stable international supply chains to meet additional demand.

Strategic Use of Imports: Imports can complement domestic supply to bridge short-term supply gaps while domestic production scales.

Planning Infrastructure around Demand: Accelerating infrastructure investments for imported and intra-EU traded hydrogen derivatives will ensure the creation of resilient supply chains for key demand markets (NL, FR, BE, DE).

Viability

High costs prevent renewable hydrogen uptake:

Renewable hydrogen produced via electrolysis is 3 to 4 times more expensive than hydrogen produced from natural gas, discouraging early offtake.

Significant electrolysers scale-up and renewable electricity cost reductions are necessary to reduce renewable hydrogen production costs.

Significant infrastructure plans face uncertainties in implementation:

In general, 42,000 km of hydrogen pipelines, numerous storage projects and terminals are planned for the next decade, but only 1% has reached final investment decision, as future hydrogen demand uncertainties pose significant challenges to project promoters.

General market

The European hydrogen market is beginning to take shape, driven by ambitious EU-wide strategies and national policies. This report marks the start of ACER's monitoring work on this emerging sector, in line with the hydrogen and gas decarbonisation package. It takes stock of recent developments and highlights key challenges from a regulatory standpoint.

Full Text: Economic-/ Market-Knowledge

Most relevant for: 3.5 Finance and Accounting, 3.6 Purchasing, Logistics and Supply Chain, 3.10 Mid- and First-Level Management, 3.11 Top-Level Management, 3.12 HR (Human Resources)

Available resources: Long version includes all references

4.9 R&D Knowledge

The global hydrogen economy is at its nascency and will require a range of enabling actions to mature. The hydrogen industry is important not just to achieve stated net zero targets, but also to achieve other priorities that countries have identified such as economic growth and energy security. In its Global Hydrogen Review 2021, the International Energy Agency (IEA) outlined five key enabling actions, one of which is the focus of this report: RD&D.
*(*Research, Development and Demonstration)*

With respect to RD&D and innovation, the IEA found 88% of cumulative emissions reductions to 2050 will need to come from emerging technologies that are still currently under development, including hydrogen technologies
With respect to hydrogen production, RD&D and innovation will be required globally to bring down the cost of production from renewable electrolysis, fossil fuel conversion with CCS, and other clean hydrogen production methods. With respect to hydrogen utilization, global innovation gaps are concentrated in the areas of:

• Hydrogen co-firing in coal or natural gas plants
• Electrolytic hydrogen used for steelmaking and chemicals production including ammonia
• Heavy road transport
• Ammonia and methanol use in shipping
• Hydrogen and hydrogen-derived fuels in aviation

The IEA report estimates that globally, USD 25 billion of public money has been budgeted towards hydrogen RD&D until 2030. However, USD 90 billion globally is required to complete the required development and demonstration of emerging technologies by 2030.

Full Text: Hydrogen RD&D
Most relevant for: 3.3 Chemical Engineering, 3.8 R&D (Research and Development) / Innovation
Available resources: Long version includes all references

4.10 Legal Knowledge

Hydrogen is set to play a key role in the EU's transition to climate neutrality by 2050 and in achieving independence from Russian fossil fuels well before 2030. It is also identified as a strategic priority in the European Commission's New Industrial Strategy, offering significant potential for innovation and high-quality job creation. The European Hydrogen Strategy of 2020 set the target of producing up to 10 million tons of renewable hydrogen within the EU by 2030. The REPowerEU Plan, adopted in 2022, complements this by proposing an additional 10 million tons of renewable hydrogen to be imported, bringing the total ambition to 20 million tons by 2030.

In order to coordinate how clean hydrogen may become a viable solution for decarbonizing European economies, in 2020, the European Commission (the “Commission”) launched a Hydrogen Strategy for Europe. The Strategy sets out a strategic framework which the European Clean Hydrogen Alliance can then use to develop an investment agenda and project pipeline. The strategy envisages that from 2025 to 2030, hydrogen will need to become an intrinsic part of European energy systems. During this period, it is anticipated that demand-side policies will be required to ensure that uptake of hydrogen technologies is realised in industrial settings. The development of hydrogen industrial clusters – where decentralised renewable energy production will be located alongside energy-intensive industries – is a fundamental part of this vision.

Full Text: Legal knowledge
Most relevant for: 3.13 Legal Management*,* 3.5 Finance and Accounting*,* 3.9 Quality and HSE (Health, Safety and Environment)*,* 3.11 Top-Level Management
Available resources: Long version includes all references

5 Training Formats

The training formats outlined below are crucial for developing the necessary skills and knowledge in the hydrogen sector, which is rapidly evolving as a key player in the global transition to sustainable energy. As the industry expands, various training approaches have emerged to address the diverse needs of professionals working across various areas of hydrogen production, storage, transport, and utilization[1]. This section provides an analysis of different training formats that were identified through the survey results within the Hy2Market project, which highlights the most effective methods for equipping individuals with the technical, operational, and regulatory expertise required to thrive in the hydrogen sector.

5.1 Previous Education

Previous education, particularly at the undergraduate and postgraduate levels, forms the foundation for most careers in the hydrogen sector. Formal educational programs, such as degrees in engineering, chemistry, and environmental sciences, provide essential theoretical knowledge that underpins the practical skills required in the field. Graduates with specialized degrees in hydrogen-related areas (such as renewable energy engineering, chemical engineering with a focus on hydrogen production, or environmental science) bring critical expertise to the workforce.

While previous education is critical in providing a theoretical understanding of core principles—such as chemical reactions, energy conversion, or system integration—it often requires supplementation with additional training or on-the-job learning to bridge the gap between theory and practice. Educational institutions are increasingly offering specialized programs related to hydrogen technologies, ensuring that graduates are well-prepared for roles within the rapidly growing green hydrogen economy. These programs are typically structured around both theoretical knowledge and practical application, preparing students to contribute to the energy transition by equipping them with an understanding of hydrogen technologies and their integration into various industrial sectors[2].

5.2 Internal Training Programs

Internal training programs are tailored to the specific needs of an organization, offering a focused approach to developing employees' skills in areas directly related to their job functions. In the hydrogen sector, internal training may include detailed workshops and seminars on company-specific technologies, procedures, and safety protocols.

[1] IEA International Energy Agency (IEA): Global Hydrogen Review 2023. Paris, 2023. https://www.iea.org/reports/global-hydrogen-review-2023

[2] International Journal of Hydrogen Energy: "Knowledge, skills, and attributes needed for developing a hydrogen engineering workforce: A systematic review of literature on hydrogen engineering education." 2024.https://doi.org/10.1016/j.ijhydene.2024.05.380

For example, employees working in hydrogen production facilities may undergo specialized training on the operation and maintenance of electrolysers, compressors, and storage systems. These programs are typically developed by in-house experts who ensure that the content is highly relevant and aligned with the company's operational goals.

The benefit of internal training is that it is directly aligned with the company's strategic objectives, allowing employees to gain specialized skills that are crucial for the organization's operations. It also fosters a deeper connection between employees and the company culture, as it often focuses on fostering internal collaboration and knowledge-sharing. Internal programs can range from formal courses to informal lunch-and-learn sessions, and they may involve practical demonstrations and hands-on exercises. Moreover, organizations can tailor the timing and format of these programs to meet the specific operational schedules and training needs of their workforce[3].

5.3 Learning from peers

Learning from peers is a collaborative approach where employees share their experiences, insights, and expertise with one another, often in informal settings. In the hydrogen sector, this type of knowledge transfer is essential as it enables professionals to learn from the practical experience of others who may have encountered similar challenges in areas such as hydrogen storage, safety measures, or system troubleshooting. Peer learning can take the form of informal discussions, group problem-solving sessions, or formal mentorship programs, where experienced employees guide newcomers or those transitioning to new roles.

This type of learning is particularly beneficial in fields like hydrogen technology, where rapid innovation and evolving best practices require continuous adaptation. It allows employees to quickly gain insights into new techniques, tools, or technologies that may not yet be included in formal training programs. Peer learning also fosters a strong sense of community and cooperation within teams, promoting the sharing of valuable industry-specific knowledge. Furthermore, this format can accelerate innovation within organizations as employees exchange ideas and collaborate on solving common challenges[4].

5.4 Cross-functional Collaboration

Cross-functional collaboration is a training format that involves employees from different departments or areas of expertise working together on shared projects or challenges. In the hydrogen sector, this is particularly valuable as it brings together diverse skill sets—ranging from engineering and chemical knowledge to economic and policy expertise.

[3] Green Skills for Hydrogen: Deliverable D2.2 – European Hydrogen Skills Strategy. 2 November 2023. https://greenskillsforhydrogen.eu/wp-content/uploads/2023/11/D2.2-Skills-Strategy-02-11-2023.pdf

[4] Green Skills for Hydrogen: D2.2 – European Hydrogen Skills Strategy

Collaboration between R&D, operations, safety, and logistics teams, for example, can lead to more effective hydrogen system integration and problem-solving.

This format encourages employees to expand their knowledge beyond their primary domain and to learn about other areas of the business. For instance, an engineer working on the technical side of hydrogen production may collaborate with a colleague in finance to understand the economic viability of different hydrogen production methods. Cross-functional collaboration enhances innovation and promotes a holistic understanding of how hydrogen systems work from production to distribution. Furthermore, it ensures that employees are better equipped to make decisions that consider the technical, economic, and regulatory challenges of the hydrogen industry[5].

5.5 Company Libraries and Resource Centers

Company libraries and resource centers provide employees with access to a wide range of materials such as research papers, industry reports, technical manuals, and case studies that are essential for deepening their understanding of hydrogen technologies. These resources are often curated by the company or made available through partnerships with industry organizations, universities, and research institutions. By offering a central repository of knowledge, resource centers help employees stay informed about industry trends, emerging technologies, and regulatory changes that are crucial to their roles.

Resource centers can take many forms, including physical libraries or digital platforms, allowing employees to access information on-demand. In the hydrogen sector, such resources are particularly valuable due to the rapid pace of technological development. Having easy access to up-to-date literature on hydrogen production, storage, and energy conversion technologies can support continuous learning and innovation. Employees can use these resources to refine their understanding of specific topics, conduct in-depth research, or stay informed about the latest advancements and best practices in the hydrogen industry.

5.6 On-the-job Learning

On-the-job learning is a highly effective training format, particularly in the hydrogen sector, where practical experience plays a crucial role in the development of skills. This format involves employees gaining direct experience in the workplace, learning by performing tasks and solving real-world challenges under the guidance of more experienced colleagues. In the context of hydrogen technologies, this training type allows workers to familiarize themselves with the complex systems of hydrogen production, storage, and distribution. One-the-job learning is beneficial for roles that require a combination of technical knowledge and practical problem-solving, such as operation and maintenance of hydrogen production plants or refuelling stations.

[5] Green Skills for Hydrogen: D2.2 – European Hydrogen Skills Strategy

Key activities in this format include task rotation, mentorship, shadowing, and hands-on workshops, ensuring that employees develop a well-rounded understanding of the technology and processes involved in hydrogen production, transport, and utilization.
On-the-job learning is particularly valuable in the hydrogen sector, where technologies are evolving rapidly. This format allows employees to stay up to date with the latest industry standards and equipment. Furthermore, it provides an opportunity for real-time learning, where employees can apply theoretical knowledge to practical situations, reinforcing their understanding of the technology and increasing job readiness. Continuous feedback from experienced colleagues helps learners fine-tune their skills and develop the critical thinking required to address operational challenges in hydrogen infrastructure.

5.7 Self-Study

Self-study is an individual training format where employees take the initiative to learn new concepts or enhance existing knowledge through independent resources. In the hydrogen sector, self-study might involve reading research papers, watching educational videos, or completing online courses focused on specific aspects of hydrogen technologies. As the hydrogen sector is rapidly evolving, self-study allows employees to stay informed about the latest developments and methodologies at their own pace and convenience.

This format is particularly valuable for employees who want to deepen their expertise in specialized areas of hydrogen technology, such as advanced fuel cell systems or emerging hydrogen production methods. Self-study fosters self-motivation and allows employees to explore subjects that may not be covered in traditional training programs. Moreover, it encourages lifelong learning, which is essential in a sector as dynamic as hydrogen. While self-study may lack the interactivity of other formats, it can be highly flexible and tailored to individual learning preferences, making it an excellent complement to other training methods.

5.8 Internal knowledge Sharing Platforms

Internal knowledge sharing platforms are digital or physical spaces within organizations that facilitate the exchange of information and expertise among employees. These platforms allow workers to share insights, ask questions, and collaborate on problem-solving within the organization. In the hydrogen sector, such platforms can be invaluable for addressing complex technical issues, such as system integration or safety concerns, by enabling teams to access collective knowledge.

Knowledge sharing platforms may include online forums, internal document repositories, or dedicated collaboration tools. By centralizing information and encouraging employees to contribute their experiences, these platforms can significantly improve efficiency and innovation within a company. For example, a team working on a new hydrogen production process can use an internal platform to access troubleshooting guides, technical specifications, or research findings from colleagues in other departments. This fosters a culture of continuous learning and allows employees to find solutions to problems faster, improving overall performance and effectiveness.

5.9 External Trainings and Workshops

External training and workshops offer specialized programs outside of the organization, where professionals can learn from industry experts, academics, and trainers. These programs often focus on cutting-edge technologies or emerging trends in the hydrogen sector, providing employees with the latest insights into new technologies and regulatory frameworks. Workshops and training sessions may be offered by industry associations, universities, or consulting firms, and they typically feature interactive learning, demonstrations, and networking opportunities.

For employees in the hydrogen sector, external workshops are particularly valuable for learning about new hydrogen production methods, energy storage technologies, and industry-specific safety standards. Additionally, these programs provide an opportunity to collaborate with peers from other organizations, fostering broader industry networks and creating opportunities for collaboration on research and development projects. These external learning formats help employees gain a global perspective on hydrogen technologies and ensure that they stay competitive in a rapidly evolving sector.

5.10 Online Learning Platforms

Online learning platforms have become an essential training format, particularly in industries like hydrogen, where rapid technological changes require constant reskilling and upskilling. These platforms offer flexible, self-paced learning opportunities, providing employees with access to a wide range of courses, webinars, and tutorials that cover various aspects of the hydrogen value chain. From introductory courses on hydrogen energy to advanced modules on fuel cell technology, these platforms provide valuable learning resources at the click of a button.

Online learning platforms are highly flexible, allowing employees to study at their own pace and on their own schedule. This is particularly beneficial for workers in the hydrogen sector who may have limited time to attend in-person training sessions. Online platforms also allow for a more diverse learning experience, as employees can access courses offered by universities, industry leaders, or specialized training providers from around the world. Furthermore, many platforms offer certification upon completion, which can enhance professional development and increase career advancement opportunities.

5.11 Practical Recommendations for Enhancing In-House Hydrogen Training

Building on the previously outlined training formats in the hydrogen sector, it is important to translate these insights into practical measures that organizations can adopt. This section focuses on the most frequently mentioned or the most common types of trainings/types of knowledge sources, as identified through the Hy2Market survey results and their processing. More specifically, the training formats that were highlighted most by the survey respondents include: **On-the-Job Learning, Previous Education, External Training and Workshops, and Learning from Peers**. The following section provides concrete and practical ideas and recommendations to help companies/organizations enhance their internal training strategies and make better use of the training formats that have proven most effective in developing hydrogen-related skills and expertise.

On-the-Job Learning

Mentorship and Apprenticeship Programs

One of the most effective ways to implement on-the-job learning is through mentorship or apprenticeship programs, where less experienced employees work closely with more seasoned professionals. These programs should be structured with clear learning objectives, timelines, and measurable outcomes. Mentors can guide employees through real-world scenarios, offering advice, feedback, and demonstrations of best practices. Such programs can significantly accelerate knowledge transfer while building relationships between employees across different experience levels.

Job Role and Task Rotation

Allowing employees to shadow colleagues in different roles or departments can broaden their understanding of how the entire organization functions, beyond their immediate responsibilities. Rotational programs can be developed, where employees spend time in various roles over several months or years. For example, engineers can rotate between different operational departments, gaining practical knowledge of production, maintenance, and design processes.

Task-Based Learning and Stretch Assignments

Structuring tasks or projects that push employees slightly beyond their current skill level (known as “stretch assignments”) can help them grow in their roles. Employees can take on projects that require new skills or knowledge, with oversight from senior staff to ensure the quality of work while learning is taking place. This method can be particularly effective when employees work on innovative projects in the hydrogen sector, learning by solving real challenges.

Project-Based Involvement

Actively involving employees in live hydrogen projects—from research and development to the execution phase—provides a dynamic and hands-on learning experience. Encouraging junior employees to contribute to ongoing projects, either as assistants or co-leads, allows them to apply their theoretical knowledge in a practical context while learning the nuances of hydrogen production, storage, transportation, and safety measures in real time.

Previous Education

Partnerships with Academic Institutions

Companies can actively collaborate with universities and technical schools to influence curriculums that are relevant to the hydrogen sector. This could involve joint research initiatives, guest lectures by industry professionals, and internships or cooperative education programs where students spend time working with companies while earning their degrees. These partnerships ensure that students graduate with the necessary knowledge to enter the hydrogen workforce.

Sponsorship and Scholarship Programs

Organizations can offer scholarships to students pursuing degrees or certifications in fields critical to hydrogen development, such as mechanical engineering and chemical engineering. By sponsoring students, companies not only support education but also secure a pipeline of talent that is already familiar with industry-specific knowledge.

Internships and Cooperative Education

Establish robust internship programs that offer students practical experience while completing their academic qualifications. Interns can be involved in real-world projects, providing a preview of the demands of the hydrogen sector. Cooperative education programs, where students alternate between classroom study and full-time work in their field of study, are also a highly effective way to merge formal education with practical experience.

Workforce Reskilling Programs

For professionals already in the workforce, reskilling programs in partnership with universities and training centers can be offered. These programs are tailored to mid-career professionals looking to pivot into the hydrogen sector or update their knowledge in line with the latest technological advancements.

External Training and Workshops

Partnership with External Experts and Training Providers

Engaging with external consultants or training institutions specializing in hydrogen technology can bring advanced and cutting-edge knowledge into the company. These external training programs can be tailored to address specific gaps in internal knowledge or focus on upcoming trends and innovations in the industry.

Conferences, Seminars, and Industry Workshops

Encouraging employees to attend industry-specific conferences, seminars, and workshops is a keyway to ensure they remain up to date with the latest developments in hydrogen technology. These events also provide valuable networking opportunities, allowing employees to exchange ideas with peers and experts.

Certifications

Employees can be encouraged to pursue certifications from recognized bodies in areas such as safety, engineering, or project management. These certifications add a formal layer of validation to employees' expertise and may be critical for certain regulatory or compliance-driven roles.

Online Workshops and Webinars

Many training providers now offer online courses and webinars that employees can complete remotely. This method of training is flexible and scalable, allowing employees to engage with content at their own pace while still receiving valuable instruction on hydrogen-related topics.

Learning from peers

Internal Knowledge-Sharing Networks

Setting up internal platforms where employees can discuss challenges, share innovations, and offer solutions would help foster a culture of continuous learning. Employees working on similar projects, such as hydrogen production or transport, could benefit from shared expertise across teams. In larger organizations which work across multiple regions or sectors, a formalized knowledge-sharing system can encourage cross-pollination of ideas.

Cross-Team Collaborations

Encouraging employees from different departments (e.g., R&D, engineering, operations) to collaborate on joint projects can lead to a deeper understanding of the hydrogen supply chain, as well as foster an environment where employees naturally share their expertise.

Regular Workshops or Lunch-and-Learn Sessions

Organizing short, informal workshops where employees present on their recent projects, industry developments, or lessons learned can help disseminate knowledge throughout the organization. This method is especially useful for sharing operational best practices, new research findings, or improvements in project management within hydrogen technologies.

Peer Mentoring Programs

Formal peer-to-peer mentoring programs can be beneficial in large organizations where specific expertise might be housed within different departments. For example, new recruits in R&D could learn from engineers who have been working on hydrogen projects for a longer time**.**

6 Hy2Market Consortium Insights on Hydrogen Skills Development

During the General Assembly of the Hy2Market project in Lipari (Sicily), a participatory exercise involving sticky notes was conducted to gather insights from consortium members on the topic of skills development. This input, qualitative and reflective in nature, offers valuable ground-level intelligence that enriches and complements the structured recommendations of this deliverable on Hydrogen Training Guidelines. The analysis below identifies recurring themes, training gaps, preferred learning modes, and forward-looking suggestions, offering guidance for tailoring future educational actions and upskilling efforts across the hydrogen value chain.

6.1 Main Themes in Skills Development

Learning-by-Doing and Knowledge Transfer

Several partners emphasized that much of their hydrogen-related learning occurred organically, through project work, knowledge transfer and direct exposure to practical tasks. This trend was particularly evident among partners who lacked prior hydrogen-specific education. Key reflections included:

- "Learning by doing" and "on-the-job" training are recurring modes of knowledge acquisition.
- Desk research, literature reviews, and frequent engagement with experienced professionals were cited as default strategies.
- The importance of peer-to-peer knowledge exchange, including conferences, partner meetings, and collaboration forums, was underscored as vital for capacity building.
- Collaboration with suppliers and service providers (e.g., bus manufacturers and HRS operators in the case of the MedioTejo pilot).
- Communication with other EU project partners working outside the Hy2Market consortium.
- Attendance at technical workshops, conferences, and online webinars.
- Experience from previous and ongoing pilot projects.

This underscores a significant gap between formal hydrogen education and the skills actually needed in implementation, highlighting a strong need for hybrid learning models combining theory with structured field exposure. Importantly, such models should not only bridge concise theory with applied practice, but also target the most pressing operational competencies. These include commissioning and routine operation tasks such as start-up, shutdown, and purging procedures, the execution of safety drills and risk assessments that are proportionate to specific job roles, and installer or technician-level skills covering piping, welding quality assurance and control (QA/QC), fittings, and leak testing. Incorporating these applied elements within training programs will ensure that the workforce is equipped to meet the day-to-day realities of hydrogen deployment, reinforcing safety, reliability, and efficiency across the sector.

Necessity of Upskilling Existing Workforce

A common observation was that hydrogen education must not only target new entrants (e.g., students) but should prioritize the upskilling of current professionals within the broader energy and industrial sectors. Observations included:

- Existing staff often come from backgrounds such as environmental engineering, project management, or energy without hydrogen-specific expertise.
- Immediate project needs are met by hiring external experts or by intensive self-learning.
- Risk assessment, safety, and practical operation of hydrogen systems are areas where on-site training and upskilling is particularly required.

This affirms the deliverable's central argument: a dual-track training strategy is needed, targeting both initial education and continuous professional development.
Also, a standards alignment throughout Europe is necessary, to ensure training content auditable and transferable.

6.2 Barriers to Hydrogen Education

Accessibility of Courses

The availability of low-cost, accessible hydrogen training programs emerged as a significant concern:

- Many available courses are expensive, often hosted by private providers. (e.g. certified H2 skilled worker 7 day course >€4000,- net in Austria)[6]
- There is a lack of widely available, modular, and open-access learning pathways.
- Even when courses exist, participants expressed doubts about their practical value, with online content perceived as "obsolete" or overly theoretical (e.g., "Google, ChatGPT-level knowledge").

This calls for a systemic intervention, funded, structured, and quality-controlled training ecosystems with strong links to industry and policy.

Skills-Training Mismatch

Another critical barrier identified is the misalignment between available training and real-world project requirements. Specific examples include:

- Grid operators and hydrogen installers often lack dedicated curricula tailored to their operational context.
- Mechanical aspects of hydrogen technology (e.g., welding, assembly, installation) are underrepresented in academic settings.

[6] TÜV AUSTRIA Akademie: Certified Hydrogen Specialist. https://www.tuv-akademie.at/kurs/ausbildung-zertifizierte-wasserstoff-fachkraft-tuevr?tx_onkurse_events%5Bcat%5D=94&cHash=9033ec26559934889adb2414fbaee9f0

- Engineers must often “just figure it out” by consulting experts or sourcing materials independently.

This points to a systemic blind spot: educational offerings must be diversified beyond theoretical and research-oriented content and instead integrated with technical apprenticeships, site rotations and field-based learning.

6.3 Preferred Learning Pathways and Methods

The sticky notes offered insight into practical, real-world learning methods that are currently valued, and which could be institutionalized within the Hy2Market training framework:

- Company-led training modules: Some partners (e.g. Soluforce) already offer structured training in welding, installation, and engineering supervision.
- Working groups and technical workshops: These were considered “precious” and valuable for both knowledge exchange and building social capital across sectors.
- Mentorship and exposure for junior staff: Several comments called for involving younger employees in strategic meetings and cross-functional learning sessions.
- Knowledge platforms and business-to-business (B2B) training: There was strong interest in platforms that link businesses, not just academics, across the hydrogen value chain to share lessons learned and technology-specific know-how.

These modes reinforce the deliverable’s recommendation to combine structured academic training with real-time project-based experiences and professional exchanges.

6.4 Key Takeaways and Recommendations

From the feedback provided by Hy2Market partners, the following actions and conclusions are proposed:

- Develop Sector-Specific Micro-Credentials: Modular, role-specific training (e.g., for installers, bus operators, or plant supervisors) should be promoted. These could be co-developed with technical schools and industry partners.
- Establish On-the-Job Learning Frameworks: Encourage projects to formalize internal learning by mentoring junior staff, offering structured training programs, and organizing frequent internal knowledge-sharing sessions.
- Support an open, Practice-Oriented Knowledge Platform: A digital knowledge hub co-created by consortium members and opened to wider stakeholders (SMEs, public bodies, academia) could be a cornerstone of knowledge transfer within and beyond Hy2Market.
- Promote Affordable and Accredited Training Offers: Engage with hydrogen alliances, public education authorities, and EU skills initiatives to push for subsidized, accredited hydrogen training programs for various technical levels.

- Bridge Vocational and Academic Gaps: Build formal links between universities, vocational schools, and pilot project sites to offer hands-on training embedded in real-life hydrogen demonstrations, thus closing the “knowledge gap” between theory and practice.
- Document and Disseminate Lessons Learned: Encourage each demonstration site or pilot within Hy2Market to produce a short, structured reflection report on training needs, challenges, and successful learning practices. These reflections could be captured and shared across the consortium and integrated into broader EU hydrogen education efforts.

In conclusion, the sticky notes analysis highlights that hydrogen skills development across Europe is currently shaped more by hands-on experiences and informal learning than by standardized educational pathways. While this reflects a stage of rapid growth and adaptation in the sector, it also signals a clear opportunity: to formalize and scale up successful practitioner-driven practices. The strong engagement and self-initiative demonstrated by professionals across the Hy2Market consortium reveal both the commitment and the capacity to drive meaningful learning. This deliverable could leverage these insights to propose a more integrated and practice-oriented approach to hydrogen education (ICSED level 3-5), one that balances academic knowledge with real-world application, supports lifelong learning, and fosters cross-sectoral collaboration.

7 Conclusions and Future research

This report brought together several perspectives: a mapping of existing hydrogen education as well as the gaps and opportunities, the results of a questionnaire identifying which types of knowledge are required and accessed by different professional positions, a general analysis of the various domains of hydrogen expertise (e.g. legal, safety, or technical knowledge) and feedback that was collected within the partner meeting in June 2025. This led to useful insights to further develop the educational aspects of the renewable hydrogen ecosystems. This chapter dives into the conclusions as observed by the involved Hy2Market partners for Task 6.3 on Training & Guidelines.

The findings in the desk research indicate that while training offers do exist, they remain incomplete. In some areas—such as safety—continuing education does not keep pace with the rapid developments of the hydrogen sector. And more broadly, there is a noticeable lack of retraining and upskilling opportunities, and this topic has so far received limited attention, even though it deserves closer examination (e.g. who are the people who could be upskilled/ retrained, what is their current knowledge and what would they need to learn using which training formats). Gaps were also identified in formal education, as knowledge should often be embedded from the start of professional training. At the same time, examples from other regions, such as Queensland's integrated approach, show how comprehensive strategies could serve as inspiration for Europe.

The analysis of different professional roles via the survey further highlights the diversity of knowledge demands across the hydrogen economy. In Purchasing, Logistics and Supply Chain, economic and legal expertise dominate, complemented by technical understanding to ensure efficient and compliant operations. IT professionals are expected to drive digital transformation, balancing R&D, legal and system integration knowledge while relying heavily on flexible and self-directed learning formats. R&D and Innovation specialists require a particularly interdisciplinary profile, with strong emphasis on experimental, applied and peer-based learning to bring new technologies to market. Safety, quality and HSE roles prioritize risk management and regulatory compliance, underlining the centrality of safety knowledge. Management functions at different levels, whether mid, first or top level, combine economic and legal literacy with strategic and cross-sectoral insight, generally acquired through experiential and peer-driven learning. For HR and Legal Management, regulatory and compliance-related knowledge is most relevant, while operational logistics only requires basic awareness to support cross-departmental collaboration. Finally, the categorization of knowledge domains in areas such as operational, material, engineering and chemical underlines the breadth of expertise needed to establish a safe, efficient and market-ready hydrogen economy.

7.1 Conclusions Desk Research

Extensive desk research was done by New Energy Coalition (NEC), Business Upper Austria (Biz-Up), and Cluster of Bioeconomy and Environment of Western Macedonia (CLUBE). Regions such as The Netherlands, Austria and Greece, as well as European platforms such as the European Hydrogen Observatory, were investigated on their known training offerings for hydrogen education. An effort was made to categorize the current offers based on the following categories: Main focus of Training; Key Training Providers; Types of Training Offered; Target Audience; Key Skills Emphasized; Gaps Identified; and Regional/National Initiatives. The desk research showed that hydrogen education options are growing, but that the current offers mainly consist of introductory content with a very general overview in hydrogen.

7.2 Comparing desk research with Consortium survey results

The inputs from the desk research are used as a reference point to see if current hydrogen education is matching the training demand as experienced by the market. By comparing the survey results from the Hy2Market Consortium with the outcomes from the desk research, mismatches between current offers and actual demand becomes visible.

- **Accessibility and cost barriers**: Survey results and the sticky notes confirm that available hydrogen courses are often expensive and run by private providers, limiting uptake. Desk research indicates very few publicly supported, affordable training programs at national or EU level.
- **Safety and operational training gap**: Desk research flagged quite a limited focus on safety, and this is reinforced by survey/sticky notes results that safety, commissioning, and daily O&M tasks (e.g., purging, leak detection, risk assessment) are among the most pressing unmet training needs.
- **Regional differences and fragmentation**: While some regions (e.g., Austria, Netherlands, Greece) are developing promising programs, survey feedback underlines the lack of harmonized standards and consistent quality across Europe, making skills non-transferable between countries.
- **Market need for affordable public courses**: A shared conclusion from the different sources is the need for more publicly supported, modular, and accredited training programs, accessible to SMEs and professionals outside established networks.

7.3 Conclusions and Recommendations based on research observations

After carefully observing the desk research and comparing it with the survey and the sticky notes, the observations are used to draw conclusions on the current hydrogen training offerings versus the market demand. Additionally, recommendations are drawn on behalf of Hy2Market to share knowledge and the gained insights with the rest of Europe. Based on the observations, the following conclusions and recommendations are found:

Conclusions

- Safety and risk management are the most critical gaps across existing training programs.
- Access barriers exist: many courses are costly, privately run, and out of reach for SMEs and regional actors.
- Training demand is dual-track: both new entrants (students, young professionals) and mid-career professionals need targeted pathways.
- Regional disparities risk creating uneven hydrogen workforce readiness across Europe.

Recommendations

- Develop EU-wide modular and role-specific training guidelines to harmonize content and improve transferability of skills.
- Create structured mentorship, apprenticeship, and rotation schemes to formalize workplace learning within European regions.
- Establish accredited EU-level hydrogen safety programs with focus on HAZOP, ATEX, and emergency response.
- Promote public funding and open-access courses, particularly for SMEs and professionals.
- Foster academic–industry partnerships to co-design hydrogen-specific curricula, embed internships, and accelerate curricular integration.
- Set up structured cross-regional peer-learning platforms and digital knowledge-sharing tools.
- Design dual-track training schemes: (1) introductory modules for newcomers and (2) advanced technical/safety courses for reskilled professionals.
- Disseminate regional best practices systematically and push for EU-level alignment to reduce fragmentation and support equal workforce readiness. In terms of re- and upskilling a global look is required – one should check who the people in question for re- and upskilling are, what they currently know, for which positions they could be trained and how this training can be best performed.

7.4 Future research

The research conducted for Task 6.3 on Training and Guidelines for the Hy2Market project has led to many valuable insights. Given the extent of insights gained, some interesting unforeseen outcomes led to more unanswered questions. Whilst outside of the scope for this research, these outcomes serve as a good foundation for future research and/or new projects such as Hy2Market and potential follow up. The following points are questions or insights which require further investigation in order to draw additional conclusions:

- Broader participation across staff levels could enrich future surveys. Including technicians, operators, and early-career professionals may reveal different training preferences compared to management perspectives.
- Expanding the geographical scope beyond Hy2Market partner regions could provide a fuller European view. Adding insights from hydrogen frontrunner countries such as Germany, Denmark, or Norway would help identify additional best practices.
- Investigating cost structures and funding models for training would add value. Understanding how public support, subsidies, or industry-led financing can make courses more accessible could guide policy and program design.
- Evaluating the long-term impact of training programs would be beneficial. Follow-up studies could track how knowledge gained influences safety, efficiency, and career progression within the hydrogen sector.
- Exploring diversity and inclusiveness in hydrogen training could strengthen workforce development. Examining gender balance and broader participation may improve sector attractiveness and retention.
- Certification and accreditation of hydrogen training are emerging themes. Future work could examine how recognized standards and mutual recognition across countries support workforce mobility and trust in skills.
- Digital and immersive training methods (e-learning, VR/AR, simulators) offer opportunities for wider reach. Research could assess their potential for cost-effective, practical training delivery.
- Reskilling pathways for workers from fossil-based sectors remain a promising area. Mapping how transferable skills can be systematically redirected to hydrogen roles would support just transition goals.

Appendix A – Knowledge Database

This appendix provides a more in-depth exploration of the critical knowledge domains essential for various roles within the hydrogen sector, serving as an extended version of the core concepts introduced in previous chapters. It elaborates on Operational Knowledge, detailing hydrogen production methods, storage techniques, and transport infrastructure. Furthermore, it covers specialized insights into Material Knowledge (including hydrogen embrittlement), core principles of Engineering Knowledge (spanning design and safety), and fundamental aspects of Chemical Knowledge (such as purity levels and production methods). The appendix also delves into the crucial area of Hydrogen Safety, outlining properties, hazards, safety measures, and regulatory frameworks. Finally, it examines Energy Conversion, System Integration, and key aspects of Economic/Market Knowledge to provide a comprehensive understanding of the multifaceted expertise required for a thriving hydrogen economy.

Operational Knowledge

Methods of Hydrogen Production

Electrolysis

Electrolysis involves the use of electrical energy to split water (H_2O) into hydrogen (H_2) and oxygen (O_2). This method is particularly attractive when the electricity used comes from renewable energy sources such as wind or solar power, leading to the production of green hydrogen. Electrolysis is scalable and plays a central role in the transition to a low-carbon economy. It offers significant potential for reducing greenhouse gas emissions when powered by clean energy. However, the current costs are higher compared to fossil fuel-based methods, necessitating future cost reductions through technological innovations and economies of scale.

Steam Reforming

Steam reforming of natural gas is currently the most widespread method of hydrogen production. In this process, natural gas (CH_4) is reacted with steam at high temperatures (700–1000 °C) in a reactor to produce hydrogen (H_2) and carbon dioxide (CO_2). Although this method is efficient and cost-effective, it is associated with substantial CO_2 emissions. The hydrogen produced through this method is often referred to as "grey hydrogen." To mitigate the environmental impact, steam reforming can be combined with carbon capture and storage (CCS) technologies, resulting in what is known as "blue hydrogen."[7]

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[7] IRENA (2020), Green Hydrogen: A guide to policy making, International Renewable Energy Agency, Abu Dhabi

Pyrolisis

Methane pyrolysis is a process where methane gas is heated to high temperatures in the absence of oxygen, breaking it down into hydrogen gas and solid carbon. This method produces hydrogen without emitting carbon dioxide, making it a cleaner alternative to other hydrogen production methods. The solid carbon produced can be used in various industrial applications, making the process efficient and environmentally friendly. The three most common methods of pyrolysis are thermal, catalytic and plasma splitting.[8]

Gasification

Solid biomass (e.g. wood or dry waste biomass) can be gasified to produce hydrogen. Hydrogen can also- be produced from ammonia (NH_3). This is broken down into its components at high temperatures. Advantage of H_2 production from ammonia: In contrast to hydrogen, ammonia can be transported with fewer precautions, as it already becomes liquid at -33 °C. It is therefore possible to bind hydrogen in ammonia for transport and then split it back into hydrogen.[9]

Biological hydrogen production

Microorganisms can produce hydrogen through fermentation. Also called, "dark fermentation". Biomass, wastewater and residues are converted into hydrogen and carbon dioxide by means of microorganisms. In complete darkness and temperatures of 30 to 80 °C, anaerobic conditions prevail. However, not all organic compounds can be used in this process. Therefore, they are then converted into methane and carbon dioxide.

The choice of process depends on the availability of raw materials, sustainability and environmental impact.

Storage Techniques

Hydrogen storage encompasses various methods to ensure hydrogen availability for the energy sector. Here are some key approaches:

- Compressed Gas Storage: Hydrogen is compressed and stored in pressure vessels.
- Liquid Hydrogen Storage: Hydrogen is liquefied and cooled for storage in its liquid form.
- Cryo-Compressed Storage: A combination of compressed and liquid storage.

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[8] Gas Connect Austria (2021), Wasserstoffherstellung: Wie geht Pyrolyse?, Wien. https://www.gasconnect.at/aktuelles/news/detail/wasserstoffherstellung-wie-geht-pyrolyse
[9] Wvgw Wirtschafts- und Verlagsgesellschaft Gas und Wasser mbH, https://wvgw.de/h2/wasserstoffherstellung/https://wvgw.de/h2/wasserstoffherstellung/, 16.04.2025

- Metal Hydride Storage: Hydrogen is chemically bonded to metals or alloys.
- Adsorptive Storage: Hydrogen is adsorbed into highly porous materials.
- Chemically Bonded Hydrogen: Hydrogen is converted into other substances through chemical reactions and released later.

These storage methods enable the efficient use of hydrogen in various applications.[10]

Transport and Distribution

Pipelines

Hydrogen can be transported through pipelines specifically designed for this purpose. This method is efficient and safe for moving large quantities of hydrogen over long distances. Hydrogen Europe highlights that building such a pipeline system is crucial for the future hydrogen economy but requires significant investments and infrastructure modifications. Expanding this infrastructure is essential to facilitate large-scale hydrogen distribution and optimize the overall supply chain.[11]

Tank Trucks

For shorter distances and smaller quantities, hydrogen is often transported by tank trucks in pressurized or cryogenic tanks. This method offers flexibility and does not require extensive infrastructure.[12]

Infrastructure for Hydrogen Supply

A well-developed infrastructure is crucial for the hydrogen economy. This includes hydrogen refueling stations for vehicles, distribution centers, and storage facilities. Coordinated planning and investment are necessary to ensure a reliable and efficient hydrogen supply. Developing this infrastructure is essential for supporting the widespread adoption of hydrogen technologies and ensuring that supply meets demand across various sectors.[13]

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[10] EWE, Wasserstoff speichern − ein Portrait, https://www.ewe.com/de/zukunft-gestalten/wasserstoff/wasserstoffspeicherung-im-portrait, 16.04.2025

[11] Hydrogen Europe, Tech. https://hydrogeneurope.eu/wp-content/uploads/2021/11/Tech-Overview_Hydrogen-Applications.pdf, 16.04.2025

[12] Plötz, Wietschel, Döscher, & Thielmann, Status Quo und Zukunft von Wasserstoff im Verkehrssektor, https://www.isi.fraunhofer.de/de/blog/2022/status-quo-und-zukunft-h2-Verkehrssektor.html, 2022

[13] Hydrogen Europe, https://hydrogeneurope.eu/, 16.04.2025 Hydrogen Europe, https://hydrogeneurope.eu/, 16.04.2025

Material Knowledge

Hydrogen is a highly reactive gas widely used in various industrial applications, especially in the energy and chemical sectors. Ensuring material compatibility with hydrogen is crucial for maintaining the safety and efficiency of systems and equipment. Different materials, particularly metals and polymers, exhibit varying behaviours when exposed to hydrogen. The following points provide a detailed examination of material properties and compatibility with hydrogen.

Hydrogen Embrittlement

Hydrogen embrittlement is a significant phenomenon affecting especially high-strength steels and certain aluminium alloys. This process describes the brittleness of metals caused by the diffusion of hydrogen into the metal structure.

- Mechanism: Hydrogen atoms diffuse into the metal and accumulate at grain boundaries or within the metal lattice. This destabilizes the metal lattice structure, leading to increased brittleness and reduced mechanical properties. As a result, the material becomes more prone to cracks and fractures.
- Effects: Hydrogen embrittlement is particularly critical for materials used in hydrogen storage systems or pressure vessels. These materials must be selected and treated to withstand the challenges posed by hydrogen embrittlement.

Material Selection and Monitoring

Selecting appropriate materials for use with hydrogen is essential to ensure the integrity and safety of systems.

- Metals: Stainless steels, especially those with high nickel content, exhibit better resistance to hydrogen embrittlement compared to conventional steels. Nickel alloys and specially alloyed high-strength steels are preferred due to their superior hydrogen compatibility. However, material selection also depends on specific operating conditions such as temperature, pressure, and hydrogen concentration.
- Polymers: Polymers and composite materials are also tested for their hydrogen resistance. Some polymers show good hydrogen compatibility, but they may have limitations under extreme pressure and temperature conditions. Research and development are ongoing to create advanced polymers that meet the high demands of hydrogen applications.

Material Testing and Monitoring

Extensive testing and adherence to standards are necessary to ensure the suitability of materials for hydrogen applications.

- Testing Methods: Mechanical tests, such as tensile and compressive tests, are essential to assess the impact of hydrogen on material strength. Microscopic examinations are conducted to analyze structural changes in the material. Special testing methods are used to measure hydrogen uptake and diffusion, which are crucial for evaluating long-term material stability.
- Standards and Guidelines: There are numerous standards and guidelines that specify the requirements for materials used in hydrogen applications. These standards help classify materials and ensure they meet high safety and reliability standards.

Summary

Material compatibility with hydrogen is a complex issue that requires a detailed examination of material properties and behaviours. Hydrogen embrittlement poses a significant challenge, particularly for metals and some polymers. Careful material selection, comprehensive testing methods, and adherence to standards are crucial for ensuring the safety and efficiency of hydrogen applications.[14]

Engineering Knowledge

Hydrogen Storage Design

Compressed Hydrogen: Hydrogen is stored at high pressures (typically 350-700 bar) in composite or steel tanks. The design considerations include ensuring that tanks can withstand high pressures and are resistant to hydrogen embrittlement. Advanced materials and engineering designs focus on optimizing tank weight, strength, and safety.
Liquefied Hydrogen: Hydrogen can be stored in liquid form at cryogenic temperatures (around -253°C). The design of cryogenic tanks involves complex insulation technologies to minimize heat transfer and prevent hydrogen boil-off. Engineers must ensure that materials can handle extreme temperatures and maintain structural integrity.
Metal Hydrides: This storage method involves hydrogen absorption into metal alloys, forming metal hydrides. The engineering challenges include developing alloys with high storage capacity and efficient hydrogen release and absorption cycles. This technology is promising for high-density hydrogen storage.[15]

[14] Bundesministerium für Wirtschaft und Klimaschutz, Materialeigenschaften und Kompatibilität für Wasserstofftechnologien, https://www.bam.de/Content/DE/Standardartikel/Themen/Energie/Wasserstoff/wasserstoff-materialeigenschaften-kompatibilitaet.html, 16.04.2025

[15] Kohlmann, Metal Hydrids, Encyclopedia of Physical Science and Technology (Third Edition), 2003

Hydrogen Fuel Cell Engineering

Proton Exchange Membrane Fuel Cells (PEMFCs): PEMFCs are widely used in transportation and stationary power generation. Engineering considerations include optimizing the membrane electrode assembly, improving catalyst performance, and enhancing durability and efficiency under varying operating conditions.

Solid Oxide Fuel Cells (SOFCs): SOFCs operate at high temperatures and are used for stationary power generation. Design focuses on materials that can withstand high temperatures and thermal cycling, as well as improving efficiency and reducing degradation[16]

Hydrogen Infrastructure and Safety

Pipeline Design: Hydrogen pipelines must be designed to handle high-pressure hydrogen safely. Considerations include selecting materials resistant to hydrogen embrittlement, implementing leak detection systems, and ensuring robust safety protocols.[17]

Refuelling Stations: Engineering design for hydrogen refuelling stations involves integrating storage, compression, and dispensing systems. Safety features include leak detection, explosion-proof systems, and user interface design for ease of operation.[18]

System Integration and Optimization

System Modelling: Engineering tools and simulations are used to model hydrogen production, storage, and utilization systems. These models help in optimizing performance, reducing costs, and improving safety.

Performance Optimization: Techniques include improving efficiency in hydrogen production processes, enhancing storage system performance, and optimizing fuel cell operation for various applications.[19]

[16] U.S. Department of Energy, Types of Fuel Cells, https://www.energy.gov/eere/fuelcells/types-fuel-cells, 16.04.2025
[17] U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration, https://www.phmsa.dot.gov/, 16.04.2025
[18] International Hydrogen Fuel Cell Association, http://www.ihfca.net/web/index.aspx, 16.05.2025
[19] Parks, Boyd, Cornish & Remick, Hydrogen Storage and Compression, https://www.nrel.gov/docs/fy14osti/58564.pdf, 2014

Purity Levels of Hydrogen

Hydrogen purity is crucial for various applications, including industrial processes, fuel cells, and research. The purity of hydrogen is typically classified into several grades based on its intended use.

- High-Purity Hydrogen (99.9999% or 6N): This grade of hydrogen is used in critical applications such as electronics manufacturing, high-precision laboratory experiments, and some high-performance fuel cells. It is also required for certain chemical synthesis processes where contaminants can significantly impact the final product's quality.

- Technical-Grade Hydrogen (99.9% or 3N): This grade is suitable for general industrial applications, including ammonia production, methanol synthesis, and various chemical processes. It provides a good balance between purity and cost.

- Industrial-Grade Hydrogen (99.0% or 2N): Often used in bulk chemical processing and refining, this grade is appropriate for applications where ultra-high purity is not critical, such as in hydrogenation processes in the food industry.[20]

Production Methods

- Electrolysis: Electrolysis of water produces high-purity hydrogen by passing an electric current through water, splitting it into hydrogen and oxygen. The purity can be very high, typically up to 99.9999%, depending on the purity of the water used and the quality of the electrolyzer. This method is used for applications requiring very high purity hydrogen.[21]

- Steam Methane Reforming (SMR): SMR is a widely used method for producing hydrogen from natural gas. The process involves reacting methane with steam over a catalyst to produce hydrogen and carbon

[20] Hydrogen Tools, https://www.h2tools.org/faq/hydrogen-purity-requirements?, 16.04.2025
[21] IEA (2023), Global Hydrogen Review 2023, IEA, Paris https://www.iea.org/reports/global-hydrogen-review-2023

monoxide. This method generally yields hydrogen with a purity of around 99.9% to 99.95%. It is commonly used for industrial applications but requires additional purification steps for high-purity needs.[22]

- Pressure Swing Adsorption (PSA): This technique is often used in conjunction with SMR or other hydrogen production methods to further purify hydrogen. PSA systems can achieve high-purity hydrogen by selectively adsorbing impurities at high pressure and desorbing them at low pressure.[23]

- Cryogenic Distillation: This method involves cooling hydrogen to very low temperatures to separate it from other gases. It is effective for achieving very high purity levels, typically used in the production of liquid hydrogen.[24]

Applications

- High-Purity Hydrogen: Used in electronics, pharmaceuticals, aerospace, and research where even minute contaminants can affect performance.
- Technical-Grade Hydrogen: Suitable for chemical synthesis, refining, and bulk industrial processes.
- Industrial-Grade Hydrogen: Used in large-scale industrial processes, including petroleum refining and hydrogenation.[25]

Hydrogen Safety

Hydrogen is a flammable gas with a wide flammability range (4%–75% by volume) and relatively low ignition energy (0.02 millijoules) (McCarty et al. 1981). It has a very low density and therefore must be stored at high pressures (10,000–15,000 psi range) to achieve enough mass for practical use. The ease of ignition and high storage pressure of hydrogen create a large portion of the risk associated with hydrogen usage. Hydrogen also has the ability to attack—and damage to the point of leakage—certain materials that are used for the construction of storage containers, piping, valves, and other appurtenances. This destructive capability is sometimes referred to as hydrogen embrittlement (Cramer and Covino 2003). The mechanisms of hydrogen embrittlement can be complex and vary with

[22] Jehle, F., & Meinig, M. (2016). Strategic workforce planning: A practical overview. Procedia CIRP, 57, 607–612.
[23] ScienceDirect. (n.d.). Pressure swing adsorption. In Engineering Topics. Elsevier. Retrieved April 17, 2025, from https://www.sciencedirect.com/topics/engineering/pressure-swing-adsorption
[24] Elsevier. (n.d.). Cryogenic hydrogen. ScienceDirect. Retrieved April 17, 2025, from https://www.sciencedirect.com/topics/engineering/cryogenic-hydrogen
[25] National Renewable Energy Laboratory. (n.d.). *Hydrogen*. U.S. Department of Energy. Retrieved April 17, 2025, from https://www.nrel.gov/hydrogen/

several physical parameters including temperature and pressure. Hydrogen's ability to escape through materials based on its destructive abilities and small molecule size also contributes to the risk associated with hydrogen usage.[26]

Properties of Hydrogen

Flammability and Explosivity: Hydrogen is highly flammable with a flammability range of 4% to 75% by volume in air. Due to this wide range, hydrogen can easily form explosive mixtures with air. It can ignite with a very low ignition energy, such as that from static electricity, and burns with an almost invisible flame, which can pose significant risks.[27]
Low Ignition Energy: Hydrogen has an exceptionally low minimum ignition energy of around 0.02 millijoules. This is significantly lower than that of many other gases, making hydrogen more prone to accidental ignition.[28]
High Diffusivity: Due to its low molecular weight, hydrogen diffuses rapidly in air, which can help disperse leaks. However, this high diffusion also means that it can quickly reach flammable concentrations.[29]
Low Density: As the lightest element, hydrogen rises rapidly when released into the air. This property can assist in the dispersal of the gas, but it also allows hydrogen to accumulate in confined spaces such as under ceilings, potentially leading to dangerous concentrations.[27]

Common Hazards Associated with Hydrogen

Leaks and Ventilation: Hydrogen molecules are very small, which allows them to escape easily from containment systems. This property necessitates the use of robust detection and ventilation systems to prevent the accumulation of hydrogen, which could lead to explosive conditions.[28]

Cryogenic Burns and Frostbite: When hydrogen is in its liquid form, it is extremely cold, with temperatures near -253°C (-423°F). Contact with liquid hydrogen can cause severe cryogenic burns or frostbite to the skin and can also make another materials brittle.[29]

Embrittlement: Hydrogen can cause embrittlement in certain metals, particularly steels, leading to the weakening and potential failure of pipelines, storage tanks, and other components. This phenomenon is a critical consideration in material selection for systems that handle hydrogen.[30]

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[26] Rivkin, Burgess & Buttner, Hydrogen Technology Safety Guide, National Renewable Energy Laboratory, https://www.nrel.gov/docs/fy15osti/60948.pdf, 2015
[27] National Fire Protection Association. (2016). NFPA 2: Hydrogen Technologies Code. National Fire Protection Association
[28] U.S. Department of Energy. (2021). *Hydrogen Safety*. Office of Energy Efficiency & Renewable Energy. Retrieved from https://www.energy.gov/eere/fuelcells/hydrogen-safety
[29] National Institute of Standards and Technology (NIST). (2020). *Properties of Hydrogen*. Retrieved from https://www.nist.gov/
[30] U.S. Department of Energy. (2021). *Hydrogen and Fuel Cell Technologies Office: Hydrogen Embrittlement*. Retrieved from https://www.energy.gov/eere/fuelcells/hydrogen-embrittlement

Static and Electrical Discharge: Hydrogen has a very low ignition energy, meaning it can easily ignite from static discharge or electrical sparks. To mitigate this risk, proper grounding and bonding are essential in any environment where hydrogen is present.[31]

Safety Measures and Best Practices

Detection Systems: Hydrogen detection systems are essential for the early detection of leaks and the prevention of hazardous concentrations. These systems should be integrated into any infrastructure that handles hydrogen to ensure safety.[32]

Ventilation: Adequate ventilation is crucial to preventing the accumulation of hydrogen gas in facilities. Effective ventilation systems should be designed to ensure rapid dispersion of hydrogen, minimizing the risk of reaching flammable concentrations.[33]

Material Selection: Selecting materials that are resistant to hydrogen embrittlement and other hydrogen-related effects is vital. Metals and polymers used in hydrogen systems must undergo rigorous testing and certification to ensure compatibility and safety.[34]

Training and Procedures: Personnel working with hydrogen must be thoroughly trained in its handling, properties, potential hazards, and the appropriate emergency response procedures. This training is critical to ensuring safe operations and quick, effective responses to any incidents.[35]

Emergency Planning: Comprehensive emergency response plans are essential for any facility that handles hydrogen. These plans should include evacuation routes, emergency shutdown procedures, and clear communication channels to ensure the safety of all personnel during an emergency.[36]

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[31] Crowl, D. A., & Louvar, J. F. (2011). *Chemical Process Safety: Fundamentals with Applications* (3rd ed.). Pearson Education.

[32] U.S. Department of Energy. (2021). *Hydrogen Safety*. Office of Energy Efficiency & Renewable Energy. Retrieved from https://www.energy.gov/eere/fuelcells/hydrogen-safety

[33] National Fire Protection Association. (2016). *NFPA 2: Hydrogen Technologies Code*. National Fire Protection Association

[34] U.S. Department of Energy. (2021). *Hydrogen and Fuel Cell Technologies Office: Hydrogen Embrittlement*. Retrieved from https://www.energy.gov/eere/fuelcells/hydrogen-embrittlement

[35] Crowl, D. A., & Louvar, J. F. (2011). *Chemical Process Safety: Fundamentals with Applications* (3rd ed.). Pearson Education

[36] National Fire Protection Association. (2016). *NFPA 2: Hydrogen Technologies Code*. National Fire Protection Association.

Regulatory and Industry Standards

For hydrogen to take a prominent role in the energy sector, safe design of equipment and structures is required along with proper safety controls during their entire life cycle from design to decommissioning. Over-cautious regulatory restraints should be revised to ensure that they address tangible risks.

Existing codes and standards for hydrogen equipment and processes can serve as guidelines for industry and governments. However, national regulations should be developed, or existing provisions amended to permit the safe use of hydrogen. There is a range of practical safety measures which can be applied to hydrogen technologies, as set out in the individual sections covering each scenario. All installations require good standards of design and construction, combined with safe operational practices and maintenance. Fixed installations may also require safe separation distances from vulnerable populations and other high-risk installations.
If adequate safety measures are adopted for hydrogen technologies, the residual risks to safety associated with hydrogen are comparable to that associated with conventional fuels. However, in many countries, there are no specific safety legislative frameworks for hydrogen technologies, although in many cases, existing safety legislation covering gas, energy, transport and heating sectors, can be applied to hydrogen.

In some circumstances specific safety regulations on hydrogen might be required in where there are current safety gaps. Existing European and/or international safety regulations, such as the United Nations Global Technical Regulation No. 13 (GTR #13) (UNECE, 1998) for hydrogen vehicle requirements can be used as a guide. Existing safety regulations might need revision to account for new technology advancements and innovations, while updated research findings could support fewer conservative measures to accelerate the deployment of hydrogen technologies and boost the hydrogen market. In many places hydrogen deployment is very difficult if not impossible because of either complete ban or total uncertainty (there is no clear legal structure of responsible authorities and institutions) or overly conservative safety distances in fixed installations.[37]

Energy conversion of Hydrogen

Hydrogen is a versatile and clean energy carrier, pivotal in transitioning to sustainable energy systems. It plays a significant role in various energy conversion processes, making it essential for both academic and industrial applications. Below is a comprehensive overview of hydrogen energy conversions, including its production, storage, and use as a fuel.

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[37] OECD (2023), Risk-based Regulatory Design for the Safe Use of Hydrogen, OECD Publishing, Paris, https://doi.org/10.1787/46d2da5e-en.

Hydrogen Production

The production methods for hydrogen each have their unique efficiencies and environmental impacts.[38]

- **Steam Methane Reforming (SMR)**: The most common method, SMR involves reacting methane with steam to produce hydrogen and CO_2. It is efficient but has a high carbon footprint unless combined with carbon capture and storage (CCS) technologies. This method is prevalent in the chemical industry due to its cost-effectiveness and scalability.
- **Electrolysis**: This process splits water into hydrogen and oxygen using electricity. When powered by renewable sources, it produces "green hydrogen" with a negligible carbon footprint. The efficiency of electrolysis is highly dependent on the electricity source and system design.
- **Biological Processes**: Methods like bio photolysis and fermentation are under development for sustainable hydrogen production from biomass. These processes are promising for future large-scale applications but are currently limited by technological and economic challenges.[39]

Hydrogen Storage

Storing hydrogen efficiently is crucial for its use as an energy carrier[40]:

- **Compressed Gas**: Hydrogen can be stored under high pressure, which is straightforward but requires durable materials and safety measures to prevent leaks and explosions.
- **Liquid Hydrogen**: By cooling hydrogen to cryogenic temperatures, it becomes a liquid, which is more space-efficient but requires significant energy for cooling and insulation to maintain these low temperatures.
- **Solid-State Storage**: This involves storing hydrogen in metal hydrides or chemical compounds, offering safer, low-pressure options but facing challenges in energy density and release rates.

Hydrogen as a Fuel

Hydrogen can be used in various energy conversion technologies:

- **Fuel Cells**: These devices convert hydrogen into electricity with water as the only byproduct. They are highly efficient and environmentally friendly, making them suitable for transport and stationary power applications.

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[38] Ghosh, P. C., Dutta, K., & Majumdar, G. (2017). Hydrogen fuel and fuel cell technology for cleaner future: A review. Environmental Science and Pollution Research, 24(31), 24232–24244. https://doi.org/10.1007/s11356-017-0260-9

[39] Singla, M.K., Nijhawan, P. & Oberoi, A.S. Hydrogen fuel and fuel cell technology for cleaner future: a review. Environ Sci Pollut Res 28, 15607–15626 (2021)

[40] Singh, R., & Singh, S. P. (2016). Hydrogen fuel and fuel cell technology for cleaner future: A review. Environmental Science and Pollution Research, 23(24), 24364–24384. https://doi.org/10.1007/s11356-016-7631-2

Types include Proton Exchange Membrane (PEM) fuel cells for vehicles and Solid Oxide Fuel Cells (SOFCs) for stationary power generation.

- **Combustion Engines**: Hydrogen can also power internal combustion engines (ICEs). While less efficient than fuel cells, this technology can utilize existing infrastructure with modifications, providing a transitional solution for reducing emission.

Energy Efficiency and Environmental Impact

The efficiency and environmental impact of hydrogen depend on the entire supply chain:

- **Conversion Efficiency**: While fuel cells and electrolysis are generally efficient, the overall efficiency must account for losses in production, storage, and transportation. The choice of technology and process optimization are crucial factors.
- **Carbon Footprint**: The environmental benefits of hydrogen hinge on its production method. Green hydrogen from renewable-powered electrolysis has a minimal carbon footprint, whereas SMR without CCS significantly contributes to greenhouse gas emissions.

Applications and Future Prospects

Hydrogen's versatility extends to various sectors:

- **Transportation**: Fuel cell vehicles (FCVs) provide a clean alternative to traditional vehicles, particularly for heavy-duty transport. They offer long ranges and quick refueling times compared to battery electric vehicles.
- **Energy Storage**: Hydrogen can store excess renewable energy, converting it back into electricity during demand peaks, thus helping to stabilize the power grid.
- **Industrial Use**: Hydrogen is essential in industries like petrochemicals and steel production. Green hydrogen can significantly reduce carbon emissions in these sectors [41]

System integration of hydrogen

To reach our decarbonisation goals, a more flexible and decentralised energy system is needed to smoothly absorb additional renewable generation. The future energy system will be very different from today's, relying much more on the direct use of electricity rather than fuels, and decarbonising hard-to-electrify sectors such as heavy transport and some processes in industry.

[41] Singla, M. K., Nijhawan, P., & Oberoi, A. S. (2021). Hydrogen fuel and fuel cell technology for cleaner future: A review. Environmental Science and Pollution Research, 28(13), 15607–15626. https://doi.org/10.1007/s11356-020-12231-8

Better integration will allow for the optimisation of the energy system, across multiple energy carriers (electricity, heat, cold, gas, solid and liquid fuels), infrastructures and consumption sectors, by creating stronger links between them with the objective of delivering decarbonised, reliable and resource-efficient energy services, at the least possible cost for society. It includes a stronger focus on the electrification of demand (through electric vehicles, heat pumps and industrial processes, for example), flexibility and storage, hydrogen and heating and cooling, which represents half of the EU's energy use.

The EU strategy, published in 2020, promotes a greater direct electrification of end-use sectors and involves various existing and emerging technologies, processes and business models, such as ICT and digitalisation, smart grids and meters and flexibility markets.[42]

Hydrogen integration

Hydrogen, predominantly used in the chemical and petrochemical industries, has localized consumption due to storage and transportation challenges. This has often led to bilateral contracts wherein producers and consumers are located in the same or nearby industrial hubs.[43] The growth of green hydrogen, produced via renewable electrolysis, has expanded its utility across different energy sectors, signalling the need for revamped infrastructure and cross-sectoral coordination.[44]

However, integration of hydrogen into existing energy systems introduces complex challenges, necessitating substantial investments in technological innovation and infrastructure for production, storage, transport, and distribution. This paradigm shift in energy systems incurs uncertainties for stakeholders, particularly concerning design and implementation of an emergent hydrogen supply chain.[45]

However, comprehensive analyses of hydrogen integration, considering inherent interdependencies and stakeholder roles in shaping decision-making, are still limited.[46]

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[42] European Commission. (n.d.). Energy system integration. European Commission. Retrieved April 17, 2025, from https://energy.ec.europa.eu/topics/eus-energy-system/energy-system-integration_en
[43] Abdalla, M., et al. (2024). Unveiling complexity of hydrogen integration: A multi-faceted approach to the Netherlands' energy systems. Renewable and Sustainable Energy Reviews, 176, 113062. https://doi.org/10.1016/j.rser.2023.113062
[44] Smit et al., 2007
[45] Schlund et al., 2022
[46] Abdalla, M., et al. (2024). Unveiling complexity of hydrogen integration: A multi-faceted approach to the Netherlands' energy systems. Renewable and Sustainable Energy Reviews, 176, 113062. https://doi.org/10.1016/j.rser.2023.113062

EU acquis, Hydrogen strategy

In an integrated energy system, hydrogen can support the decarbonisation of industry, transport, power generation and buildings across Europe. The EU Hydrogen Strategy addresses how to transform this potential into reality, through investments, regulation, market creation and research and innovation.

The priority is to develop renewable hydrogen, produced using mainly wind and solar energy. However, in the short- and medium-term other forms of low-carbon hydrogen are needed to rapidly reduce emissions and support the development of a viable market.

To help deliver on this Strategy, the EU Commission has also launched the European Clean Hydrogen Alliance with industry leaders, civil society, national and regional ministers and the European Investment Bank. The Alliance will build up an investment pipeline for scaled-up production and will support demand for clean hydrogen in the EU.[47]

System Integration with Hydrogen: An Overview

System integration involves incorporating hydrogen technologies into existing energy systems and infrastructure. This process is critical for leveraging hydrogen's potential as a clean energy carrier and requires careful planning and execution.[48]

Integration of Hydrogen Production

Hydrogen production facilities, such as electrolysis plants, need to be integrated with renewable energy sources like wind and solar power. This integration is essential for the efficient production of green hydrogen and requires coordination between power generation and hydrogen production systems, often involving smart grid technologies to manage electricity flow and balance supply and demand.[49]

Storage and Distribution Systems

Efficient storage and distribution are vital for hydrogen's role as an energy carrier. This includes integrating hydrogen storage facilities with transportation networks, such as pipelines and refueling stations. Challenges include maintaining infrastructure safety, managing high-pressure systems, and ensuring a consistent supply.[50]

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[47] Abdalla, M., et al. (2024). Unveiling complexity of hydrogen integration: A multi-faceted approach to the Netherlands' energy systems. Renewable and Sustainable Energy Reviews, 176, 113062. https://doi.org/10.1016/j.rser.2023.113062

[48] International Energy Agency (IEA). (2019). The Future of Hydrogen: Seizing Today's Opportunities. Retrieved from https://www.iea.org/reports/the-future-of-hydrogen

[49] U.S. Department of Energy. (2020). *Hydrogen Production and Delivery*. Office of Energy Efficiency & Renewable Energy. Retrieved from https://www.energy.gov/eere/fuelcells/hydrogen-production-and-delivery

[50] National Renewable Energy Laboratory (NREL). (2020). *Hydrogen Storage and Distribution*. Retrieved from https://www.nrel.gov/hydrogen/storage-distribution.html

Hydrogen Utilization in Energy Systems[51]

Integrating hydrogen into existing energy systems involves several applications, such as:

- **Power Generation**: Hydrogen can be used in fuel cells for decentralized power generation or as a fuel in combined heat and power (CHP) plants.
- **Transportation**: Integration includes setting up refuelling infrastructure for fuel cell vehicles (FCVs) and adapting transportation networks.
- **Industrial Processes**: Hydrogen can replace fossil fuels in high-temperature industrial processes, requiring modifications to existing systems.

Regulatory and Safety Considerations

Regulatory frameworks and safety standards are critical in system integration. This includes setting codes for hydrogen production, storage, and distribution, ensuring safety measures are in place, and standardizing technology interfaces to ensure compatibility and safety across different systems.[52]

Economic and Environmental Impacts

Economic feasibility and environmental impact assessments are crucial in planning hydrogen integration. This involves analysing the costs of infrastructure development, potential savings from reduced emissions, and the overall economic benefits of transitioning to a hydrogen-based energy system.[53]

Economic-/ Market-Knowledge

Economy of hydrogen

Supply and Demand Gap: Current renewable hydrogen production is only 0.02 million tonnes per year (Mtpa), far below the EU's unrealistic consumption targets of 20 Mtpa by 2030. We project regulated demand from existing policy measures to range between 2.2 and 2.8 Mtpa by 2030, driven by mandates in industry and transportation. Our Accelerated Transition Scenario suggests up to 7.0 Mtpa of demand could materialize. This shortfall underscores the urgent need for a delivery-focused approach to accelerate domestic production and secure stable international supply chains to meet additional demand.

Strategic Use of Imports: Imports can complement domestic supply to bridge short-term supply gaps while domestic production scales.

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[51] International Energy Agency (IEA). (2019). *The Future of Hydrogen: Seizing Today's Opportunities*. Retrieved from https://www.iea.org/reports/the-future-of-hydrogen

[52] International Organization for Standardization (ISO). (2019). *ISO 19880-1: Gaseous Hydrogen — Fueling Stations — General Requirements*. Retrieved from https://www.iso.org/standard/71940.html

[53] European Commission. (2020). *A Hydrogen Strategy for a Climate-Neutral Europe*. Retrieved from https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

Planning Infrastructure around Demand: Accelerating infrastructure investments for imported and intra-EU traded hydrogen derivatives will ensure the creation of resilient supply chains for key demand markets (NL, FR, BE, DE).[54]

Viability

High costs prevent renewable hydrogen uptake:

Renewable hydrogen produced via electrolysis is 3 to 4 times more expensive than hydrogen produced from natural gas, discouraging early offtake.

Significant electrolysers scale-up and renewable electricity cost reductions are necessary to reduce renewable hydrogen production costs.

Significant infrastructure plans face uncertainties in implementation:

42,000 km of hydrogen pipelines, numerous storage projects and terminals are planned for the next decade, but only 1% has reached final investment decision, as future hydrogen demand uncertainties pose significant challenges to project promoters.[55]

While Europe undeniably needs to scale its renewable hydrogen supply chains, this can be done strategically and pragmatically, focusing on use cases where hydrogen is essential for decarbonization.

It's time to retire any lingering misconceptions of hydrogen as a Swiss army knife for economy-wide decarbonization. Hydrogen — when produced renewably — can enable Europe's heavy transport and industrial sectors to decarbonize and will reduce the region's dependence on imported natural gas. However, with renewable fuels and feedstocks both expensive and relatively scarce, policymaker support for hydrogen should focus and direct funding only to hard-to-electrify sectors in parallel with support for electrification and energy efficiency measures. Demand-side investments and policies should prioritize hydrogen applications in steelmaking, e-fuels, fertilizers, and refining to maximize emissions reductions, efficiently leverage public funds and ensure these high-impact industries are empowered to transition to renewable hydrogen.[56]

General market

The European hydrogen market is beginning to take shape, driven by ambitious EU-wide strategies and national policies. This report marks the start of ACER's monitoring work on this emerging sector, in line with the hydrogen and

[54] Homann, Q., Rosas, J., Kerr, C., & Tatarenko, O. (2025, March 10). The case for recalibrating Europe's hydrogen strategy. Rocky Mountain Institute. https://rmi.org/the-case-for-re-calibrating-europes-hydrogen-strategy/

[55] Agency for the Cooperation of Energy Regulators (ACER). (2024). European hydrogen markets 2024 Market Monitoring Report: Monitoring report covering 2023 and H1 2024. Retrieved from https://www.acer.europa.eu/monitoring/MMR/european_hydrogen_markets_2024

[56] Homann, Q., Rosas, J., Kerr, C., & Tatarenko, O. (2025, March 10). The case for recalibrating Europe's hydrogen strategy. Rocky Mountain Institute. https://rmi.org/the-case-for-re-calibrating-europes-hydrogen-strategy/

gas decarbonisation package. It takes stock of recent developments and highlights key challenges from a regulatory standpoint.[57]

Market dynamics

European governments have made low to moderate progress on nine key performance indicators (KPIs) for low-carbon hydrogen. More ambitious policy implementation is needed to kickstart a European hydrogen market.[58]

The total installed capacity of electrolysers in Europe is currently just over 200 MW. Projects accounting for another 1.8 GW of capacity, mostly captive to a single off-taker or industry, are under construction and expected to become operational by the end of 2026. Projects accounting for around 60 GW of capacity announced as being operational by 2030 are waiting for the final investment decision (FID). Although funding instruments are becoming increasingly available, the actual deployment of these projects remains at risk due to sector uncertainties, in particular the evolution of demand and renewable hydrogen cost prospects.[59]

Public funding and investments

Public Funding Gap: Current funding commitments (2025) fall short of what is needed to achieve the EU's hydrogen and climate objectives. Approximately €13,9 billion in public funding will be needed to implement RED III mandates and an extra €31,7 to enable faster decarbonization under the Accelerated Transition Scenario.

Unlocking Private Investment: Public funding could unlock approximately €251 billion in private capital expenditures. This is equivalent to a 7x leverage effect in mobilizing private investment from public funds.

Slow Deployment: Despite €21,4 billion in relevant committed funds from the Commission and Member States, only €3 billion in public funding has been disbursed to renewable hydrogen projects and end-users.

Geographic Focus: A near-term focus on key demand centers can kickstart the decarbonization of major industrial centers, although a more equitable EU-wide distribution of public funding will be required in the long term to effectively scale hydrogen adoption across all Member States.

Public and private investments should be directed to steelmaking, fertilizers, refining, aviation, and shipping; sectors where hydrogen provides the most decarbonization value. Allocating resources to low-impact uses like heating and light-duty vehicles represents inefficient use of scarce public funds and risks delaying necessary transitions through electrification and energy efficiency measures.

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57 Agency for the Cooperation of Energy Regulators (ACER). (2024). European hydrogen markets 2024 — Market Monitoring Report. Retrieved from https://www.acer.europa.eu/sites/default/files/documents/Publications/ACER_2024_MMR_Hydrogen_Markets.pdf

58 ERCST. (2024). 2024 State of the European Hydrogen Market Report. Retrieved from https://ercst.org/2024-state-of-the-european-hydrogen-market-report/

59 Agency for the Cooperation of Energy Regulators (ACER). (2024). European hydrogen markets 2024 Market Monitoring Report: Monitoring report covering 2023 and H1 2024. Retrieved from https://www.acer.europa.eu/monitoring/MMR/european_hydrogen_markets_2024

In 2022, the Commission launched the European Hydrogen Bank to create investment security and business opportunities for European and global renewable hydrogen production. It is not designed to be a physical institution, but is a **financing instrument**, run internally by European Commission services.[60]

While public funding has the potential to catalyse private sector investment, current funding commitments fall short of what is needed to achieve the EU's hydrogen and climate objectives. Despite significant amounts being earmarked by the European Commission and Member States through mechanisms such as Contracts for Difference (CfDs), H2Global, auctions, and the European Hydrogen Bank (EHB), actual funds deployed to date remain limited. It is important to note that the recently proposed Industrial Decarbonisation Bank (aiming for €100 billion in funding) represents the ideal vehicle to support the accelerated transition of Europe's heavy-emitting sectors.[61]

Hydrogen RD&D

The global hydrogen economy is at its nascency and will require a range of enabling actions to mature. The hydrogen industry is important not just to achieve stated net zero targets,1 but also to achieve other priorities that countries have identified such as economic growth and energy security. In its Global Hydrogen Review 2021, the International Energy Agency (IEA) outlined five key enabling actions, one of which is the focus of this report: RD&D.[62]

*(*Research, Development and Demonstration)*

With respect to RD&D and innovation, the IEA found 88% of cumulative emissions reductions to 2050 will need to come from emerging technologies that are still currently under development, including hydrogen technologies.

With respect to hydrogen production, RD&D and innovation will be required globally to bring down the cost of production from renewable electrolysis, fossil fuel conversion with CCS, and other clean hydrogen production methods. With respect to hydrogen utilisation, global innovation gaps are concentrated in the areas of:

- Hydrogen co-firing in coal or natural gas plants
- Electrolytic hydrogen used for steelmaking and chemicals production including ammonia
- Heavy road transport
- Ammonia and methanol use in shipping
- Hydrogen and hydrogen-derived fuels in aviation

[60] European Commission. (2025). European Hydrogen Bank – objective. Retrieved from https://energy.ec.europa.eu/topics/eus-energy-system/hydrogen/european-hydrogen-bank_en#objective

[61] Homann, Q., Rosas, J., Kerr, C., & Tatarenko, O. (2025, March 10). The case for recalibrating Europe's hydrogen strategy. Rocky Mountain Institute. https://rmi.org/the-case-for-re-calibrating-europes-hydrogen-strategy/

[62] Delaval, B., Rapson, T., Sharma, R., Hugh-Jones, W., McClure, E., Temminghoff, M., & Srinivasan, V. (2022). Hydrogen RD&D Collaboration Opportunities: Global Report. CSIRO. Retrieved April 17, 2025, from https://explore.mission-innovation.net/wp-content/uploads/2022/09/H2RDD-Global-FINAL.pdf

The IEA report estimates that globally, USD 25 billion of public money has been budgeted towards hydrogen RD&D until 2030. However, USD 90 billion globally is required to complete the required development and demonstration of emerging technologies by 2030.

Hydrogen RD&D is not only important for meeting global net zero objectives, but also to meet the other objectives driving country strategies. The most cited drivers across many international hydrogen roadmaps and strategies are:

- Environmental: Such as the global drive to reduce carbon emissions or the domestic drive to improve local air quality.
- Industrial strategy and economic growth: Either growing hydrogen exports or leveraging comparative advantages to develop key hydrogen technologies or sectors.
- National technology development: Leading technological advances and exporting energy
- technologies to gain a competitive edge.

Less frequently mentioned drivers, but critical for several countries are:

- Energy security: Diversifying energy supply chains and expanding renewable energy.
- Hydrogen export: Producing hydrogen for the global market, particularly to energy importing nations less endowed with energy resources

Global hydrogen RD&D activity. Research publications by country

Key countries producing the highest levels of hydrogen research output across all areas of the value chain (production, storage and utilisation) are China, the US, Japan, India, Germany, the UK and France. Large countries (i.e. with a high population and GDP) are likely to produce large volumes of research. As such, NCI14 was also used to identify smaller countries with lower publication volumes but producing high quality research. Examples of countries achieving high NCI scores include Australia, Singapore, Saudi Arabia, Hong Kong, Denmark, the UK, Canada and Vietnam.

Patents&Innovations

Technologies motivated by climate change concerns accounted for nearly 80% of all patents related to hydrogen production in 2020.
Hydrogen technology development is shifting towards low-emissions solutions such as electrolysis, according to a joint study of patents by the European Patent Office (EPO) and the International Energy Agency (IEA).
The report is the first of its kind and uses global patent data to provide comprehensive up-to-date analysis of innovation in all hydrogen technologies. It covers the full range of technologies, from hydrogen supply to storage, distribution and transformation, as well as end-use applications.
Hydrogen production technologies accounted for the largest number of hydrogen patents over the 2011-2020 period. While global hydrogen production is currently almost entirely fossil-based, the patenting data shows that low-emissions innovations generated more than twice the number of international patents across all segments of the hydrogen value chain than established technologies.

Technologies motivated by climate concerns account for nearly 80% of all patents related to hydrogen production in 2020, with growth driven chiefly by a sharp increase of innovation in electrolysis. The most innovative regions are now competing to host the first industrial roll-out phase, with the data suggesting that Europe is gaining an edge as a location for investment in new electrolyser manufacturing capacity.

Among hydrogen's many potential end-use applications, the automotive sector has long been the focus for innovation, and patenting in this sector continues to grow, led mainly by Japan. Similar momentum is not yet visible in other end-use applications, despite concerted policy and media attention in recent years on hydrogen's potential to decarbonise long-distance transport, aviation, power generation and heating. National net zero emissions pledges cannot be achieved without addressing unabated fossil fuel use in these sectors. One bright spot is a recent uptick in patenting for the use of hydrogen to decarbonise steel production – possibly in response to the post-Paris Agreement consensus that the sector needs radical solutions to cut emissions quickly.

For established hydrogen technologies, innovation is dominated by the European chemical industry, whose expertise in this sector has also given it a head start in climate-motivated technologies such as electrolysis and fuel cells. Automotive companies are also active, and not just for vehicle technology. Behind them, universities and public research institutes generated 13.5% of all hydrogen-related international patents in 2011-2020, led by French and Korean institutions, with a focus on low-emissions hydrogen production methods such as electrolysis.
"Hydrogen from low-emissions sources can play an important role in clean energy transitions with potential to replace fossil fuels in industries where few clean alternatives exist, like long-haul transport and fertilizer production," said IEA Executive Director Fatih Birol. "This study shows that innovators are responding to the need for competitive hydrogen supply chains, but also identifies areas – particularly among end-users – where more effort is required. We will continue to help governments spur innovation for secure, resilient and sustainable clean energy technologies." [63]

Legal knowledge

Hydrogen will play an important role in the EU's transition to climate neutrality by 2050 and in the objective to become independent from Russian fossil fuels well before 2030. Hydrogen is also one of the strategic areas of the Commission's New Industrial Strategy, with significant potential for quality job creation. The European Hydrogen Strategy[64] from 2020 sets out the objective to produce up to 10 million tons of renewable hydrogen in the EU. The

[63] International Energy Agency (IEA). (2023, January 10). Hydrogen patents indicate shift towards clean technologies such as electrolysis, according to new joint study by IEA and EPO. International Energy Agency. https://www.iea.org/news/hydrogen-patents-indicate-shift-towards-clean-technologies-such-as-electrolysis-according-to-new-joint-study-by-iea-and-epo
[64] European Commission. (2020). *European hydrogen strategy for a climate-neutral Europe*. European Commission. Retrieved April 17, 2025, from https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

RePowerEU plan[65] proposes to complement this goal by facilitating 10 million tons of renewable hydrogen imports by 2030.[66]

In an effort to coordinate how clean hydrogen may become a viable solution for decarbonising European economies, in 2020, the European Commission (the “Commission”) launched a Hydrogen Strategy for Europe. This sets out a strategic framework which the European Clean Hydrogen Alliance can then use to develop an investment agenda and project pipeline. The strategy envisages that from 2025 to 2030, hydrogen will need to become an intrinsic part of European energy systems. During this period, it is anticipated that demand-side policies will be required to ensure that uptake of hydrogen technologies is realised in industrial settings. The development of hydrogen industrial clusters – where decentralised renewable energy production will be located alongside energy-intensive industries – is a fundamental part of this vision. [67]

The market rules for clean hydrogen production are currently being negotiated and defined. In Europe, following the official adoption of the Hydrogen and Decarbonised Gas package in May 2024, the European Commission must prepare a delegated act on low-carbon fuels within a year. This is a key milestone for the industry.

It is important to ensure that the EU’s future hydrogen production is genuinely low-carbon and aligns with EU climate objectives**.** The Renewable Energy Directive (RED III) requires renewable hydrogen to have a greenhouse gas (GHG) emission saving of at least 70 per cent compared to a fossil fuel comparator, i.e., a maximum threshold of 3.38 kg CO2eq per kg of hydrogen. However, to be consistent with the EU’s net-zero emission target, the carbon intensity threshold would gradually need to decrease to around 1kg CO2eq by 2050. Any positive emissions would lead to additional difficulties in accomplishing net-zero objectives. The application of a gradually decreasing threshold could save up to 230 MtCO2eq of emissions by 2050. The production and market share of fossil gas-based low-carbon hydrogen will then be determined by the extent to which gas suppliers can adopt the most effective technologies to cut upstream emissions. [68]

For policymakers, developing the EU low-carbon hydrogen certification scheme requires a balanced and deliberate approach. The Delegation Act (DA) needs to consider the specificities of each potential low-carbon production route and fit within the existing regulatory framework, aligning with EU industrial, energy, and environmental goals. It must also navigate the diverse energy landscapes of member states, each with unique power mixes, energy resources, infrastructures, and policies. Additionally, it should provide clarity and stability for hydrogen economy stakeholders while remaining adaptable to future uncertainties. The critical considerations for the upcoming DA are:

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[65] European Commission. (2023, March 16). Legal provisions of COM(2023)156 - European Hydrogen Bank. European Commission. Retrieved April 17, 2025, from https://www.eumonitor.eu/9353000/1/j4nvhdfcs8bljza_j9vvik7m1c3gyxp/vm1gqtxd70z0

[66] European Commission. (2023, March 16). Legal provisions of COM(2023)156 - European Hydrogen Bank. European Commission. Retrieved April 17, 2025, from https://www.eumonitor.eu/9353000/1/j4nvhdfcs8bljza_j9vvik7m1c3gyxp/vm1gqtxd70z0

[67] CMS. (2024, December 21). What role can hydrogen play in industrial processes? CMS Law. Retrieved April 17, 2025, from https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/what-role-can-hydrogen-play-in-the-industrial-processes

[68] Deloitte. (2024). The impact of low-carbon hydrogen regulation in the EU. Retrieved April 17, 2025, from https://www.deloitte.com/de/de/issues/sustainability-climate/impact-of-eu-low-carbon-hydrogen-regulation.html

- Establishing an appropriate and comprehensive regulatory framework must provide a clear and consistent vision to get market players moving.
- Gradual adoption of decreasing emission thresholds, in line with the objective of climate neutrality in 2050.
- A dynamic grid emission accounting methodology with a sufficiently precise granularity to align electrolyser operations with power system needs, while creating market opportunities.
- The carbon footprint of fossil gas-based hydrogen should be closely monitored, with careful consideration of the origin and upstream emissions of the fossil gas feedstock.

The upcoming Delegated Act on low-carbon fuels is an opportunity to reassess priorities and balance the short-term needs of the hydrogen industry with national and EU strategic, economic and sustainability goals. Recognizing and addressing these complexities could lay the foundation for a sustainable and resilient hydrogen economy in the EU.[69]

[69] Deloitte. (2024). The impact of low-carbon hydrogen regulation in the EU. Retrieved April 17, 2025, from https://www.deloitte.com/de/de/issues/sustainability-climate/impact-of-eu-low-carbon-hydrogen-regulation.html

Appendix B – Desk Research Previous Education

The hydrogen sector is a quickly evolving aspect of the energy transition which results in an increasingly higher demand for proper training and education. The training offerings should be sufficient to the demand from the market. In order to draw up conclusions how the current market offers compare to the demand for education, desk research was conducted on the existing training materials. This Appendix shows the found programs along with interviews generating insights from experts in the hydrogen field.

Desk research NEC

WP6.3 Desk research

Deliverable:

"Within this task a guideline for training will be developed. New Energy Coalition will take the lead in this task and develop a whitepaper that will provide guidelines related to the competencies and knowledge that are required from employees at different levels in the hydrogen fields. The guidelines will be implemented in the knowledge platform. BEN will support the development of the white paper."

Looking for existing training materials for:

- Hydrogen Production.
- Hydrogen Transport.
- Industrial Use of Hydrogen.
- Mobility Use of Hydrogen.

Within New Energy Coalition (NEC)

The New Energy Coalition (NEC) works together with industry partners as well as innovation hubs and educational institutes. Together with these partners, projects and programs have been developed over time or are still under development which include parts of the hydrogen value chain. Relevant information for Hy2Market from within the market is provided via the New Energy Business School as well as projects that the NEC works on or had worked on.

New Energy Business School (NEBS)

As part of the New Energy Coalition, the New Energy Business School (NEBS) is a department within the organization of NEC. However, goals are different as the NEBS has the goal to selling training and education whereas NEC has its goals in project development/execution.

New Energy Business School programs

Main take aways based on qualitative interview[70]

- 1 day Masterclass hydrogen to learn people the very basics about the hydrogen economy and how the hydrogen system looks like from a broad overview.
- Intensive hydrogen course which lasts for 3 to 4 days where the most common technologies for H_2 production are elaborated and newest trends are discussed.
- Directive hydrogen course which is around twice 8 days. The focus is here is on a very high level and targeted audience is mainly leadership positions.
  - **Note:** All courses are still about hydrogen from an overview perspective. No dived into very detailed or specific parts of hydrogen e.g. full focus on production or full focus on distribution etc.

New Energy Business School x Brunel – Post-Applied Science hydrogen course

Main take aways based on qualitative interview[71]

- More from a policy making perspective.
- Overall overview on the whole hydrogen value chain.
- Includes a technical module about the different electrolysers.
- Includes a module focused on hydrogen policies rolled out by the EU.
- More intended for the management area.
- The program is right now at a very basic/introductory level.
  - Focused on further training from a different background and retraining.
- Based on feedback of the participants so far, safety of hydrogen seems to be a topic that reoccurs often. → (Is hydrogen safe? What if it explodes?) (ignorance)

New Energy Coalition Projects

Waterstof Werkt

- In English Hydrogen Works, is focused on developing education programs.
- 6 study programs being developed on the vocational training level by:
  - Drenthe College.
  - Noorderpoort.
  - Alfa College.
- New project H2CoVe in development.

[70] N. Bakker, "Hydrogen training offerings at the New Energy Business School," Feb. 27, 2024, Groningen.

[71] H. Dieben, "Interview about course with Brunel facilitated by the New Energy Business School," Feb. 27, 2024, Groningen.

HyDelta (2.0) – Deliverable 11.1 The future requirements for HBO, WO and postgraduate personnel in the hydrogen industry

"The goal of this study was to qualitatively examine the skills and competences needed for trained personnel in the HBO (applied sciences education), WO (scientific education), and postgraduate education (retraining of professionals) levels in the Netherlands, in order to work in the hydrogen transport sector; this was done with a focus on the skills and training needed for the gas network operation sector [72]

- Research focusses on Applied sciences (HBO), Academics (WO).
- 19 interviews done with 14 different organizations.
- Based on the interviews, 12 skills were identified for HBO and WO.
  - *Business/commercial skills*:
    Multidisciplinary understanding of the technical, economic, and regulatory aspects of the hydrogen industry.
  - *Information & Communication Technology skills (IT)*:
    To implement digitalization in network management, analyse data that can be used to optimize operations, and develop and implement cybersecurity measures.
  - *Research and scientific skills*:
    Needed to research and develop new and more efficient methods for producing, transporting, and utilizing hydrogen.
  - *Educational skills*:
    Educators will need to be knowledgeable about hydrogen technology and its potential applications, as well as have expertise in learning strategies.
  - *Legal skills*:
    Understand the applicable laws and regulations in order to obtain the necessary permits.
  - *Sociology skills*:
    Identifying and addressing potential social and cultural barriers to the adoption of hydrogen technologies.
  - *Engineering skills*:
    Knowledge of the safety aspects around hydrogen.
  - *Policy and regulatory skills*:
    Needs to be skilled in understanding what the current political framework around hydrogen is, as well as what are the instruments that exist.

[72] J. C. Garcia-Navarro, M. Hulsing, and A. Serna Tamez, "The future requirements for HBO, WO and postgraduate personnel in the hydrogen industry," Aug. 2023.

- *Supply chain management skills*:
  Necessary to manage the entire process, from sourcing and production to logistics and distribution of technologies.
- *Finance/economy skills*:
  Effective risk management skills are necessary.
- *Project management/development skills*:
  Critical to plan, coordinate, and execute these projects.
- *Trading and energy market skills*:
  Need to have a comprehensive understanding of market dynamics and the geopolitical factors that influence a potential global market.

- Additionally, 40 vacancies exclusively to the hydrogen market were analysed to determine their required skills for the job. The four most needed skills were:
  - Engineering (40%)
  - Sales/Business development (13%)
  - Research (10%)
  - Consultancy (10%)
- Recommendations for educational institutions:
  1. A focus on multidisciplinary and systems studies should be a priority.
  2. Emphasizing the job prospects and potential career advancement opportunities in hydrogen related jobs, as well as the potential for competitive salaries and the transferability of skills to other fields.
  3. Incorporating assignments, exercises, or projects related to hydrogen into existing energy transition related studies.
  4. Showcasing hands-on learning opportunities can help attract students to technical studies.
  5. Highlighting partnerships between educational stakeholders and industry, as well as the potential for job prospects, can help students recognize the career opportunities available to them.
  6. Incorporating new technologies and teaching methods that meet the demands of modern students.
  7. Providing comprehensive student support services is crucial to ensuring student success.
  8. Lowering tuition fees or offering study scholarships for technical studies can incentivize students to pursue these programs.
  9. Higher education curricula could benefit from incorporating more soft skills training.

From different parties

Enerdata – Green Skills for Hydrogen deliverable D2.2 "European Hydrogen Skills Strategy"

"The European Hydrogen Skills Strategy aims to investigate the skills needs in the FCH industry and provide insights into the current landscape of education and training programmes available to develop these skills in Europe. By identifying the specific skills required for a career in this domain, we seek to bridge the gap between industry demands and educational offerings. Furthermore, the study aims to feed into the European Net Zero Industry Act proposed by the European Commission on 16 March 2023." [73]

- Project was created as result of the RePowerEU program.
- Desk research in 10 countries with 45 documents analysed (Annex 2).
    - Weakness stated in every country studied for synthesis of desk research *"Study is at a really high level and does not make possible to highlight needs related to specific sectors such as hydrogen"*
- Interview campaign with 93 interviews across 19 countries.
- 913 occupational profiles identified over the whole value chain based on interviews.
    - Country with most interviews counts 10 interviews – maybe too few interviews overall to draw conclusions for a whole country/continent? +400 million people in EU
- The Occupational profiles are categorized using the ESCO codes.
    - With hydrogen being a developing industry, some hydrogen occupational profiles don't have a suitable ESCO code yet (Annex 6).

Important definitions for our scope

- ***ESCO***:
  ECSO is the multilingual classification of European Skills, Competencies, and Occupations. The ESCO classification identifies and categorises skills, competencies, and occupations relevant for the EU labour market, education and training. This standard unified system allows different actors to use ESCO for services like matching jobseekers to jobs based on their skills, suggesting trainings to people who want to reskill or upskill etc.
- ***Occupational profiles***:
  An occupation is a grouping of jobs involving similar tasks and which require similar skills set. Occupations should not be confused with jobs or job titles. While a job is bound to a specific work context and executed by one person, occupations group jobs by common characteristics.

[73] "European Hydrogen Skills Strategy," Jul. 2023. Accessed: Mar. 22, 2024. [Online]. Available: https://greenskillsforhydrogen.eu/wp-content/uploads/2023/11/D2.2-Skills-Strategy-02-11-2023.pdf

- ***Skills***:

  Skills means the ability to apply knowledge and use know-how to complete tasks and solve problems.

- ***Competence***:

  Competence means the proven ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development.

- ***Qualifications***:

  Qualifications are the formal outcome of an assessment and validation process which is obtained when a competent body determines that an individual has achieved learning outcomes to given standards.

Executive Summary

Main findings

- Estimated that in 2030, 1 million jobs will be created in the hydrogen value chain.
- Occupational profiles with high demand and potential for bottlenecks are within the technical domains.
  - "Demand for engineers and technicians specializing in chemical processes, industrial engineering, health and safety, and high-voltage electricity is particularly high, coupled with an acute shortage of qualified individuals within these professions."
- The skills and knowledge required for occupational profiles in the hydrogen sector can be categorized along three dimensions:
  1. Level of hydrogen knowledge.
  2. Transversal skills and knowledge.
  3. Specialized skills and knowledge:

     "*This category includes specialised expertise in hydrogen production, transport, storage, operation of equipment and facilities, electrolysers, fuel cells, and hydrogen refuelling stations.*"

- Short programmes for specialists are identified as missing from training offers in initial education.
- In terms of content taught, safety and practical education are considered as fundamental in the education delivered to technical profiles

Summarized recommendations

1. **Develop modular training:**

   Providing a modular training corpus in a flexible, adaptable, and customisable form for different target audiences can help overcome the lack of resources identified by teachers and trainers seeking to develop specialised training. By breaking down complex topics into smaller modules, the training becomes more manageable and easier to comprehend. Key areas of training and delivery methods are identified and discussed as well as a long-term strategy to propose the integration of such a corpus into existing programmes and the development of specialist training.

2. **Define training standards:**
   Setting common European or international training standards to qualify as able to safely work with hydrogen across various work environment will enhance the recognition of qualifications in the sector as well as enable workers mobility.

3. Improve access to continuing professional development.
4. Establish an online community.
5. Encourage the uptake of European mobility for hydrogen education.
6. Promote the attractiveness of the sector.

Skills needs

Profiles that require the highest level of hydrogen knowledge and competencies according to the ESCO classification:

1. Physical and earth science professionals.
2. Project Managers.
3. Engineering professionals (excluding electrotechnology).
4. Chief executives, senior officials, and legislators.
5. Architects, planners, surveyors, and designers.
6. Electrotechnology engineers.
7. Legal professionals.

Key thematic skills and knowledge identified by the industry as the most relevant can be classified into two areas:

Cross-cutting competencies that include:

I. Health, Safety and Hazards related to H2.

II. Legal aspects, regulation and permitting of H2 projects and.

III. Hydrogen system components and integration with renewable energy.

IV. Maintenance of hydrogen equipment and production facilities.

Technology and activity specific competencies and knowledge that include:

I. Hydrogen Production, storage and transport.

II. Fuel cells, electrolysers technology.

III. Hydrogen in mobility application and refuelling stations.

IV. Operation and maintenance of hydrogen equipment and facilities.

Strategic actions and recommendations overview – D2.2

FIGURE 25 - STRATEGIC ACTIONS AND FACILITATORS

Strategic Actions	Examples of Facilitators
1. Develop modular trainings	
1.1 Build a modular training corpus 1.1.1 Assess existing resources prior to developing educational content • Invite awarded EU and possibly national projects to share information on the educational materials developed with the FCH Observatory. • Develop a high-level mapping of modules available on FCH based on the data from the Observatory and as a resource for future (EU) projects 1.1.2 Address the needs identified by industry stakeholders 1.1.3 Choose the optimal training delivery method(s) • Encourage local framework initiatives to ensure access to infrastructures to train hydrogen learners • Develop and build on existing e-infrastructures and content • Organise local partnerships between training providers and industry for education and training	Training providers, Companies, EU projects
1.2 Adapt existing training programmes • Encourage education ministries and training providers to use the modular training corpus developed at European level in their educational offer • Facilitate funding to translate training materials developed by European projects	Training providers, Education ministries, Public authorities
1.3 Develop new specialist training programmes • Coordinate the development of specialised training on a territory • Promote collaboration between training providers to develop specialist training	Training providers, Education ministries, Public authorities
2. Define training standards for hydrogen	
2.1 Establish training standards for safe hydrogen handling	Companies and workers in the hydrogen sector, Professional organisations
2.2 Establish a governing body responsible for enforcing and regularly updating the training standards related to hydrogen	Professional organisations, Companies
3. Improve access to continuous professional development	
3.1 Prepare skilling plans in anticipation of hydrogen development	Companies, Public authorities
3.2 Support continuing professional development with policies and funding	Public authorities, Companies
3.3 Open initial education modules to workers in continuous education	Training providers, Public authorities
4. Establish an online hydrogen community	
4.1 Deliver online training content building on existing e-infrastructures	EU projects, Training providers
4.2 Map out physical labs and infrastructures	Local authorities, Training Providers, EU projects

Figure 27 Strategic actions and recommendations overview - part 1

5. Encourage the uptake of mobility for education to hydrogen	
5.1 Enable learners' mobility	Training providers, EU programmes
5.2 Enable trainers' mobility	Training providers, EU programmes
5.3 Secure funding for mobility	Local, national and European public authorities, Hydrogen companies & Associations
6. Promote the attractiveness of the hydrogen sector	
6.1 Prepare and share information on hydrogen careers in secondary schools	Teachers, Guidance counsellors, Professionals from the sector, National associations on hydrogen, EU projects
6.2 Provide targeted information on transition paths for workers from declining sectors	Local authorities, Employment agencies
6.3 Organise discovery activities in lower levels of education	Teachers, Professionals from the sector, National associations on hydrogen, EU projects
6.4 Disseminate best practices on hydrogen training	EU projects, National associations on hydrogen, Training providers, Companies

Figure 28 Strategic actions and recommendations overview - part 2

Politecnico di Torino – Green Skills for Hydrogen deliverable 3.1 "Hydrogen Skills Core VET Curriculum"

"The primary objective of task 3.1 is the design of a curriculum based upon EU-wide understandable profiles and competences. To achieve this purpose, task 3.1 aims to design a Hydrogen VET Curriculum focused on the competences and occupational profiles identified in the Skills Strategy developed in Work Package 2. The curriculum is intended to be modular and comprehensive for a wide audience, following the recommendations of the Skills Strategy to choose a design that would simplify the replication of training program and/or modules across different national educational systems." [74]

[74] D. Ferrero and M. Santarelli, "Hydrogen Skills Core VET Curriculum," Feb. 2024. Accessed: Mar. 22, 2024. [Online]. Available: https://greenskillsforhydrogen.eu/wp-content/uploads/2024/03/D3.1-Green-Skills-for-Hydrogen-Hydrogen-Skills-Core-VET-Curriculum.pdf

Core Curriculum

The Core Curriculum has been separated into 10 modules to address the competences needs identified. The list of modules and learning units, with the associated learning outcomes, is listed below. The complete Curriculum is shown in figure 31 till figure 35.

1. Hydrogen basics.
2. Hydrogen applications.
3. Hydrogen technologies.
4. Electrochemical systems.
5. Hydrogen mobility.
6. Hydrogen use: combustion, components and detection.
7. Hydrogen safety.
8. Hydrogen economics.
9. Environmental and social impact of hydrogen.
10. Hydrogen initiatives and regulation.

Hydrogen Skills Core Curriculum

1. Hydrogen basics

i. **Hydrogen properties**

a. **Base level**

Content: physical-chemical properties, properties relevant for hydrogen storage/transport, phase diagram of hydrogen, information of energy density (volumetric, gravimetric) compared with other fuels and other energy storage solutions.

b. **Advanced level**

Content: in addition to the base level contents, it includes more details on properties relevant for safety calculations (i.e. flammability/explosivity levels). Focus on hazard and safety aspects relevant for hydrogen production, distribution, storage and refueling.

ii. **Overview of the current hydrogen sector**

Content: hydrogen production worldwide, current applications in the different industrial sectors, traditional methods employed for the production of hydrogen, data briefs on the environmental impact (CO_{2eq} emissions) of each traditional production technology.

iii. **Green Hydrogen for decarbonization and energy transition**

Content: green hydrogen definition, explanation of "hydrogen colours", role of green hydrogen in the decarbonization of the different sectors (energy, transportation, industry), data briefs on the environmental impact of non-fossil hydrogen compared to fossil.

2. Hydrogen applications

i. **Industrial uses of hydrogen**

Content: general overview of the industrial uses of hydrogen, description of the main processes in which hydrogen is used (e.g. oil & gas, olefines, ammonia, microchips, glass manufacturing, steel manufacturing, ammonia) with focus on indicators for the processes (number of plants, size, process efficiency, etc.). Suggested: presentation of relevant examples/case studies of industrial plants.

ii. **Hydrogen in the transportation sector**

Content: overview on the use of hydrogen in the transportation sector for the different segments (passenger cars, trucks, trains, cargo ship, aviation). Description on what technologies are required on board (e.g. fuel cell, battery and compressed hydrogen for FCHV, etc.) and type of the refueling infrastructure needed. Suggested: presentation one or more relevant example (e.g. from EU projects).

iii. **Power-to-Hydrogen for energy storage and sector coupling**

Content: introduction to the Power-to-Gas/Hydrogen concept and its role for sector coupling/energy storage and decarbonization. Pros and cons of Power-to-Hydrogen. Elements of large-scale / long-term chemical storage (Power-to-Power). Suggested: presentation of one or more relevant examples (e.g. from EU projects).

3. Hydrogen technologies

i. **Hydrogen production by electrolysis**

a. **Base level**

Content: basic concept of electrolysis, introduction to the different electrolysis technologies, data briefs on the current status and trends of the technologies (e.g. TRL, efficiency, scalability, cost €/kW - €/kgH_2).

b. **Materials**

Content: materials used for cells and stacks (catalysts, membranes, electrodes). State-of-the-art production processes and innovative techniques for the production of cells and stacks.

c. **Systems and components**

Content: description of electrolysis plants configurations for the different technologies. Main Balance of Plant components (i.e., water pre-treatment, power converters, etc.) focusing on

Figure 29 Core Curriculum - part 1

commercial technologies. Overview on main producers at EU level. Examples of installed systems.

ii. Fuel cell systems

a. Base level

Content: basic concept of fuel cells, introduction to the different fuel cell technologies, data briefs on the current status and trends of the technologies (e.g. TRL, efficiency, scalability, cost €/kW - €/kWh).

b. Materials

Content: materials used for cells and stacks (catalysts, membranes, electrodes). State-of-the-art production processes and innovative techniques for the production of cells and stacks.

c. Systems and components

Content: description of fuel cell plants configurations for the different technologies. Main Balance of Plant components (i.e., air compressors, pre-reformer, ejectors) focusing on commercial technologies. Overview on main producers at EU level. Examples of installed systems.

iii. Hydrogen transport and storage

a. Base level

Content: introduction to different typologies of commercial-level hydrogen storage (compressed, liquid) and transport (pipeline, truck, marine vessels etc.) methods. Short overview of innovative storage (underground storage, LOHC, etc.). Focus on the pros/cons/critical points of the technologies.

b. Materials

Content: Materials for compressed/liquified hydrogen storage vessels and pipelines. Relevant projects. Overview of materials for innovative hydrogen storage (metal hydrides, MOF, LOHC, ammonia).

c. Systems and components

Content: Components of hydrogen storage and transport systems: compressors and pipelines.

iv. Fuel Cells and Electrolysis systems: installation, operation & maintenance

Content: Procedures for installation of electrolyser & fuel cell technology systems. Design and installation factors include the siting of electrolyser & fuel cell installations, hydrogen containment and piping, ventilation requirements, safety and separation distances, positioning of hydrogen sensors. Elements of operation, control and maintenance. Procedures and best practices.

v. Training sessions

a. Training on cell fabrication/stack assembly

Content: laboratory on electrolysers/fuel cell: cell fabrication/stack assembly procedure. Suggested: video experience on cell production or stack assembly. If available: visit to cell production/stack assembly line or laboratory with available examples of cell production equipment or stack components.

b. Training on electrolyser/fuel cell system installation and maintenance

Content: training laboratory on hydrogen installation based on a case study on a installed hydrogen plant. Suggested format: video and/or site visit.

c. Training on hydrogen storage

Content: laboratory focused on sizing an hydrogen storage system connected to a RES-fed electrolyser and designed to provide hydrogen to HRS and/or grid injection point. Suggested: design exercise based on real Power-to-Hydrogen project.

4. Electrochemical systems

i. Electrochemistry basics for electrolysers and fuel cells

Content: basics elements of electrochemistry. Electrochemical reactions equilibrium and overpotentials. Cells polarization. Cells and stacks concept.

ii. Introduction to electrochemical measurements

Content: measurement techniques for electrolysers and fuel cells (current-voltage measurements, Impedance Spectroscopy, etc.), type of equipment used.

iii. Training session: electrochemical measurement

Figure 30 Core Curriculum - part 2

Content: laboratory on electrochemical systems measurement. Experience of polarization/EIS measurement on fuel cell/electrolysis cell. Suggested: video experience or remote laboratory experience.

iv. Modeling of electrolysis and fuel cells systems (cell/stack level)

Content: overview of modeling techniques used at cell/stack level (equivalent-circuit models, physical models, 0D-to-3D) and modeling tools. Focus on physical models: electrochemical, fluidic and thermal models.

v. Modeling of electrolysis and fuel cells systems (system level)

Content: overview of modeling techniques used at system level and modeling tools. Focus on system efficiency estimation. Example of models developed for control purposes.

vi. Training session: system modeling

Content: laboratory on the development of a system model. Suggested: development of an equivalent circuit model of a PEM fuel cell system for the simulation of the dynamics of a PEMFC system installed on a FCHEV.

5. Hydrogen mobility

i. Introduction to Fuel Cell Hybrid Electric Vehicles (FCHEV)

Content: electrical vehicles and hydrogen FC vehicles: general schematics and details of the components: battery pack, BMS, electrical motor, fuel cell and auxiliary systems (air compressor, ejector), onboard hydrogen storage tanks. Details on available commercial solutions and producers.

ii. Hydrogen refueling stations (HRS)

Content: configurations and components (H_2 storage tanks at different pressure, compressors, dispenser) of hydrogen refueling stations and technical aspects of the refilling hydrogen vehicles (details of onboard components and procedure). Centralized/decentralized hydrogen distribution concepts. Safety aspects of hydrogen refueling. Case study of relevant projects.

iii. FCHV and HRS: installation, operation and maintenance, protocols and best practices.

Content: Regulations applied to hydrogen refueling stations. Elements of maintenance procedures for HRS and FCHEV. Examples of HRS projects and lessons learned on maintenance aspects. Protocols and best practices for hydrogen refilling.

iv. Training session: HRS operation and maintenance

Content: Practical training/laboratory on hydrogen refueling systems operation and maintenance. Suggested: video experience. Site visit recommended.

6. Hydrogen use: combustion, components and detection

i. Hydrogen combustion

Content: Introduction to combustion, main elements and terminology. Complete and incomplete combustion, types of combustion (rapid, spontaneous and explosive). Hydrogen flammability and combustion. Hydrogen combustion management: preventing, detecting and suppressing (undesired/uncontrolled) combustion. Hydrogen-based combustion systems: internal hydrogen combustion engines and hydrogen boilers.

ii. High pressure elements: vessels, fittings and components

Content: vessels for high-pressure hydrogen storage: types and sizing; valves, fittings, threads, tubing and piping systems. Elements of installation and maintenance/inspection of components.

iii. Materials for hydrogen storage and transport: advanced level

Content: base level + compatibility of hydrogen with metal and polymer materials. Mechanical degradation of metallic materials by hydrogen embrittlement: analysis of tests and characterization. Procedures for mitigation of metals degradation by hydrogen.

iv. Hydrogen sensors

Content: hydrogen sensors type, specifications, commercial models. Communication systems and protocols. Elements of installation, maintenance and calibration of sensors. Hydrogen flame detection and thermal detectors & imaging systems.

v. Training session: hydrogen detection systems

Content: laboratory/on-site demonstration of hydrogen detection systems.

Figure 31 Core Curriculum - part 3

7. Hydrogen Safety		
i.	**Hydrogen hazards for people and equipment**	
		Content: Health hazards of hydrogen leaks/releases. Harmful effects of hydrogen combustion on humans (temperature, direct contact, radiant heat flux, overpressure). Damage to structures, equipment and environment caused by hydrogen fires, impact of overpressure on structures and equipment. Labelling of hydrogen systems. Personal protective equipment.
ii.	**Hydrogen Safety, Risks & Standards**	
		Content: Risk assessment elements, health and safety procedures. Legislation and standards for hydrogen and hydrogen carriers safety. Case study on risk assessment.
iii.	**Compressed and liquid hydrogen: safety strategies, hazards and safety issues**	
		Content: Hazard of compressed and liquid hydrogen release. Consequence of release. Jet fires. Safety strategies implemented (e.g. TPRD). Case studies of hydrogen: lessons learned.
iv.	**Training session: hydrogen safety**	
		Content: Laboratory training on hydrogen safety. Laboratory/E-laboratory on hydrogen safety.
8. Hydrogen Economics		
i.	**Hydrogen market**	
		Content: Overview on the hydrogen market (production and end-uses), international and EU. Focus on hydrogen demand by sectors, projection of the market for the future in the different sectors. Market opportunities for green hydrogen.
ii.	**Hydrogen economy: cost of hydrogen, status and perspectives**	
		Content: Cost of hydrogen from the different sources, SoA numbers and future projections and cost structure. Hydrogen transportation costs. Factors affecting hydrogen cost. Scenarios of hydrogen cost (e.g. IEA scenarios).
iii.	**Techno-economic analysis of hydrogen systems**	
		Content: methodology for the techno-economic assessment of projects (LCOH, NPV and PBT). Application to hydrogen projects. Case studies.
iv.	**Hydrogen projects implementation**	
		Content: Projects and case studies for the green hydrogen introduction in different sectors. Green hydrogen hubs. The big challenge: match hydrogen production and hydrogen offtake: concept of the Hydrogen Valleys. Socio-economic aspects of hydrogen projects implementation and ownership (state-, community- and privately owned projects).
v.	**Training session: economic evaluation of a hydrogen project**	
		Content: economic evaluation of a selected hydrogen project. Suggested: team exercise based on a real case study. Evaluation of different technological options in terms of economic performance and selection of the most performing one.
9. Environmental and social impact of hydrogen		
i.	**Environmental impact of hydrogen systems**	
		Content: introduction to environmental analysis. Basic elements of LCA analysis. Overview of environmental analysis applied to hydrogen generation. Case studies.
ii.	**Elements of social acceptability of hydrogen projects**	
		Content: elements of social acceptability of green hydrogen and its infrastructure. Project and initiative to increase social acceptability. Case studies.
iii.	**Training session: environmental impact of hydrogen projects**	
		Content: exercise on the evaluation of the environmental impact of a selected hydrogen project. Discussion of social acceptability implications.
10. Hydrogen initiatives and regulation		
i.	**Hydrogen initiatives at international/EU/national level**	
		Content: overview of hydrogen support initiatives worldwide. Focus on EU instruments for supporting green hydrogen. Examples of applications.
ii.	**Hydrogen regulation and permitting**	
		Content: Overview of the hydrogen energy law and regulations across several countries. Regulations related to hydrogen technologies in different scenarios/applications during the

Figure 32 Core Curriculum - part 4

entire hydrogen life cycle. Key elements of hydrogen installations permitting process. Case studies for relevant application examples (e.g., renewable-connected electrolysers, refueling stations, fuel cells for backup power application, etc).

iii. Hydrogen projects in EU

Content: Overview of hydrogen deployment projects in EU. Examples and case studies (e.g. hydrogen valleys).

Figure 33 Core Curriculum - part 5

GroenvermogenNL

GroenvermogentNL focuses on accelerating a well-functioning market for industrial use of green hydrogen. GroenvermogenNL is a temporary organization that emerged from the programming of three Top Sectors (HTSM, Chemistry and Energy). The aim is to accelerate the market for green hydrogen (and green chemistry). GroenvermogenNL therefore focuses primarily on connecting and strengthening existing initiatives in the field of R&D, pilots, demonstrations and human capital.

Exploration of post-initial training and development offerings aimed at the application of green hydrogen

KPMG has been asked by the National Research Organization for Educational Research (NRO), part of the Netherlands Organization for Scientific Research (NWO), hereinafter 'the client', to carry out the exploration for the post-initial training offering as part of the fourth workflow of the HCA of GroenvermogenNL (i.e., 'National hydrogen education and training package'). KPMG did this in close coordination with the supervisory committee and the contractor for the exploration for the initial training offer, namely Technopolis B.V. and Hutspot. For this exploration a combination of quantitative desk research combined with qualitative research was conducted.[75]

In total 82 organizations were studied for desk research from which 28 organizations were selected for in-depth interviews that were deemed representative for the public- & private training providers and companies within The Netherlands. This inventory has shown that 30 of the 82 organizations (37%) have post-initial learning and development offerings in the field of (green) hydrogen. 18 organizations (22%) do not offer a post-initial learning and development offer or that it is not clear from the quantitative inventory whether there is a formal offer. The remaining group of 34 organizations (41%) do not formally have a post-initial learning and development offer, but are active in the region in various ways to drive the green hydrogen transition and organize learning and development activities.

Main conclusions:

[75] NRO Case number: 405-00-860-271, "Verkenning post-initieel opleidingsen ontwikkelaanbod gericht op de toepassing van groene waterstof," Oct. 2023. Accessed: Mar. 25, 2024. [Online]. Available: https://groenvermogennl.org/wp-content/uploads/2024/01/20231018_Eindrapportage-KPMG-finaal_Verkenning-post-initieel-leer-en-ontwikkelaanbod_NWO_GroenvermogenNL.pdf

- Post-initial learning and development offerings regarding (green) hydrogen is said to be limited with the existing offers being mostly in starting- or pilot phases. Companies seem to be a bit reluctant to invest in new corporate learning training in this topic.
- Big diversity in in how trainings are being offered. Majority of the offers have more of an orientating character with a focus on what green hydrogen is, how it works, and how the whole value chain will look like.
- For public and/or private organizations there seems to be a higher level of ambition compared to the actual availability of training programs. Companies seem to be a bit more reluctant in their ambitions and look at green hydrogen with a little bit of scepticism.
- Th majority of available trainings seems to be focused on the whole value chain to make it more accessible for a broader range of people. Very little training providers seem to have a deep focused training e.g. only upstream, only midstream, or only downstream. There do seem to be some parties who focus on the applications of green hydrogen in the built environment sector and the mobility sector.
- Most of the interviewees is of the opinion that the post-initial learning & development offers will rapidly develop and should be flexible to the demands of the job market. As a result, the interviewees don't see multiyear degrees solely focused on green hydrogen as the preferred step. Learning communities in cooperation between companies and knowledge centers seem to be more fitting.

Additional data

Qualitative research: interviews with knowledgeable stakeholders in the Northern Netherlands Hydrogen environment.

Interview on hydrogen education at Noorderpoort (VET) [76]

Mentions GroenvermogenNL

  - Have set up a learning community for hydrogen.
  - Researching on national level what is needed to realize hydrogen economy.
    - Roadmaps are developed about what already is happening in the educational sector and what is planned for the future regarding H_2.
- Withing Noorderpoort, 4 elective courses have been developed.
  - One with a more general content on hydrogen as a whole.
  - 3 more deep dive about hydrogen e.g. H_2 in industry.
- States that currently no study program exists that solely focusses on hydrogen to create hydrogen specialists, doesn't expect this to happen either.
  - Example given: automotive students are trained to work on all the cars but are getting extra information about hydrogen so that they can work on hydrogen cars as well.
- Expects that mainly additional trainings for already existing professionals will be in high demand and extra hydrogen courses for current study programs.

[76] R. Hogt, "Interview over trainings- en lesmateriaal op het MBO," Mar. 06, 2024, Groningen.

- It is getting noticed that the phase of “get acquainted with hydrogen” has already been surpassed and that we are in the next phase of actually building projects.
    - Gives example that companies like RWE are expressing their needs for really trained professionals who are able to assemble and maintain electrolysers.
- Teachers will have a different role in the future when it comes to hydrogen.

Interview Hanzehogeschool Groningen on hydrogen minor [77]

- The minor Hydrogen in the Energy Transition was recently developed as a result of the project ‘Groene Waterstof Booster’.
    - From a school point of view there is actually a need for less minors as more minors make it harder to fill classes with the same number of students. This is a contributing factor to why there are not multiple hydrogen minors that focus on specific aspects of the value chain.
- The program is set up in 3 phases with each worth 10 ECTS and works currently with case studies without exams. Currently there are 6 real-life cases provided by external parties with groups of 5 students for each case. The outlook of the phases is the following:
    - The problem analysis: Analysing what the current problem is of the case owner provided by an external company.
    - The problem solution: What is the quality of the designed solution and the given advice to the external case owner.
    - Personal Development: Did the student showed personal growth and how well is the student able to reflect on his own work and actions.
- For the future it is expected that exams will be integrated as testing someone’s knowledge now sometimes proofs to be difficult as it is rather subjective.
- In terms content focus, the minor starts with the basis of electrical engineering. This knowledge is then used to gain knowledge on business case. Additional knowledge learned is mechanical engineering that works in a supportive way to develop a business case.
- The feedback of participating students so far in the times that the program has ran:
    - + They like the challenge of having a hands-on project from a real client.
    - – Assignments are perceived as too vague -> used to old way of education.
    - – The very technical engineers expected more of a deep dive into the operational aspects of hydrogen. E.g. operating an electrolyser.
- The future development of the minor will focus on having more long-term partners to provide case studies so that a continuation on previous projects can be easier realized. As mentioned before, it is expected that exams will be integrated in the future. The company RWE is also expected to be one of the long-term partners to provide the students with case studies.

[77] B. ter Veer, “Hydrogen minor at Hanzehogeschool Groningen,” Mar. 27, 2024, Groningen.

- The program has currently 30 students with around 50% of them being Dutch.
- Cases can vary from economical to technical. Current cases are:
  - Business case comparison between producing hydrogen and buying it from a local supplier to see which one is more cost effective.
  - The integration of a battolyzer and how to optimize this from an operational perspective to find a balance point.
  - Analysing the effects of a hydrogen neighbourhood on the local grid.
  - A technical case on how to reduce the water vapor that is realized by H_2 trucks that drive around in the city.
- Aside from the cases provided by external parties, the program also offers around 15 guest lectures from professionals in the working field.
- In the future there might be a shift to fewer cases, but more suitable for the minor.

Interview on hydrogen education at EnTranCe and the Master Energy for Society [78]

- The education part of EnTranCe is currently working together with the university of Amsterdam in a joint venture, through a big JTF project, to set up a joint master's degree which focusses on hydrogen.
- Hydrogen courses are being developed for (project) coordinators that are active in the sustainability sector including an online course about fuel cells.
- An inventorisation of Massive Open Online Course (MOOC) has been done. The following MOOCs were found:

[78] H. Moesker, "Interview about hydrogen education at EnTranCe," Apr. 02, 2024, Groningen.

Name	What	Level/ target group	By whom	Language	Physical / online?	Costs	Remarks	Link
Sustainable hydrogen and electrical energy storage	Production, transport, delivery, storage Not only hydrogen but also batteries	Master	TU Delft (F. Mulder)	English	Physical	Sheets freely availabl e	Is part of SET programme, not a MOOC OpenCourseWare: sheets are available online	Website
Hydrogen as an energy vector	Production (electrolysis), storage, fuel cells	Not mentione d, probably at least bachelor	EMMA	English	Online	Free	7 weeks, self-paced	Website
TeacHy	MSc in Fuel Cell and Hydrogen Technologies (a full master, not a specialisation in Mechanical or Electrical Engineering etc. such as everyone else)	master	Horizon 2020	English	Physical	Not free	E-mail 2023.01.25 from project coordinator: 'Currently running it in the second year at University of Birmingham. It will start running at Prague University of Chemical Technology from academic year 2023/24. As the project has finished, other parties will have to pay for the content.' So, is not MOOC	Website
Deeltijdcursus waterstof	5 dagen	Bachelor	HAN	Dutch	Physical	1950€	Technisch perspectief, op	Website

							HBO niveau aangeboden	
Hydrogen energy	Includes exam and Galileo Master Certificate (GMC)	Not mentioned	Renewable Energy Institute	English	Online	540£	Live virtual class room or online on-demand	Website
Course – Global Hydrogen	Educates you in 7 activities about the challenges and opportunities of the shift towards hydrogen	None, only a general interest in energy transition	New Energy Academy	English	Online, with option for offline	Free	Technology Economy Socio-cultural Impact of environment Law & Regulations Leadership Hydrogen Valley Tour	Website
Hydrogen Academy	Some general presentations	General	Linde	English	Online	Free		Website

- A workshop about hydrogen is being developed for the Master programs Renewable Energy (EMRE) and Sustainable Energy System Management (SESyM).
- Within the Master program Energy for Society (E4S), hydrogen projects are currently mainly focused on the legal and regulation aspects of hydrogen.
- Bachelor's degrees and master's degrees in general should do more with hydrogen in their education programs.
- The Master program E4S will in the future be more case study based rather than theoretical classes when it comes to hydrogen education.

Interview on hydrogen education at ROC Tilburg (VET) and about RIF project (South-Netherlands) [79]

ROC Tilburg

- Have an elective course H_2 for the study program mechanical installations

[79] M. Drabbe, G. van Eijk, and O. van Iersel, "Energy transition education at ROC Tilburg and RIF project," May 06, 2024, Tilburg.

- The agenda for hydrogen education on a broader/regional level should still be formulated across the province of Noord-Brabant (NB).
    - Current hydrogen courses are mostly organized from own interests by enthusiastic teachers.
- Regional Investment Fonds (RIF) project has been set up to organize education for the energy transition for the whole region of NB.
    - Mobility sector education has its own RIF project.
- The local market is still not asking much for hydrogen personnel.
    - Grid congestion currently has a higher priority in the region of NB.
    - Added to that, that there is currently not enough steering from national policies for the Southern regions of The Netherlands when it comes to the energy transition and hydrogen.
- As of now, no accredited hydrogen education present in the NB region.

RIF project – Daar brandt nog Licht

'Daar brandt nog Licht' is a network of education, business and government partners who work together to provide faster, smarter and more flexible training for the energy transition in North Brabant. The project has started on 24/01/2024 and will last until 31/07/2027. This is a collaboration between high schools, VET institutions, and Universities of Applied Science. In total 30 different parties participated. The project received a subsidy of 1.1 millitheeuros from the Regional Investment Fonds.[80]

The main goal of the project is: "*Making North Brabant future-proof through innovative and enterprising education, aimed at the professions of tomorrow.*[81]

To achieve this goal, the following two ambitions are formulated:

1. Create a comprehensive, tailor-made training offer in each labour market region for initial training and for existing employees (lifelong learning/development).
2. Together with municipalities, UWV, Leerwerkloketten and other relevant parties in the region, develop an educational offer for people in the WW and WWB with a view to social and labour participation. The schools ensure a dovetail connection with vocational training. The schools are also prepared to take the lead in setting up and organizing these regional arrangements that are tailored to the needs of the region.

[80] R. H. Dijkgraaf, "BRIEF VAN DE MINISTER VAN ONDERWIJS, CULTUUR EN WETENSCHAP," Apr. 26, 2023, Tweede Kamer der Staten-Generaal, Den Haag. Accessed: Jul. 31, 2024. [Online]. Available: https://www.eerstekamer.nl/behandeling/20230426/brief_regering_toekenningen/document3/f=/vm2vezfl99zu.pdf

[81] Fontys Hogeschool, "Daar Brandt nog Licht."

The project consists of 5 different tracks:

1. **Cooperation**: The focus lies here in bringing together institutions from different levels to achieve a common goal.
2. **Roadmap energy transition**: Focus on the development of a digital roadmap for the education institutions in the region to fit the energy transition.
3. **Educational Development**: Focus on the actual development of fitting courses and materials to educate/train people for the energy transition.
   → Connected with track 2.
4. **Stimulating LLO + lecturer professionalization**: Focus on supporting "Leven Lang Ontwikkelen"(Life Long Developing) based on the philosophy that learning is never finished. Other focus is mapping the needs of the markets and lectures to further professionalize lectures for courses within the energy transition.
5. **Research and knowledge exchange within the MIEC**: Focus on sharing the knowledge gained through the project within the MBO (VET) Innovation & Expertise Community to ensure the community benefits from the project.

Interview on hydrogen education for European Masters SESyM and EMRE at EnTranCe – Corina Vogt [82]

European Master Sustainable Energy System Management

- Company visits. Recent example: Green Planet
- Hydrogen lectures are currently under development.
  - Both for the core semester as well as for the specialization semester.
- In the specialization, EI&R and SBCC will be integrated in 10 EC course with multiple lectures about hydrogen and a workshop. Will also consist with a bit of lab work.
- Module for Business Ecosystem Design (BED) is also going to focus on hydrogen more.
- There is awareness that the legal aspects are underexposed, but no plan yet to expand this further.

European Master in Renewable Energy

- Hydrogen is strongly reflected in the specialization of Sustainable Fuels.
- Lab work with the operational functioning of electrolysers and fuel cells.
- Looking into students possibly build their own electrolyser and/or fuel cell.
  - Depending on whether it is allowed due to safety.
    - Note: If you want to work with hydrogen, you should always think about safety for students.
- A 5 EC Power-to-Hydrogen module already exists.

[82] C. Vogt, "Hydrogen education for European Masters SESyM and EMRE," Jun. 06, 2024, Groningen.

Further notes:

- Plan to integrate at least 10 EC of hydrogen in each Master.
- One of the things that is important with hydrogen is how do you position it: What can it do and what should it do, in a safe way.

  Questions received from the market: To what extent can H2 take over the role of earth's ash and to what extent can you use hydrogen for storage.

Interview on hydrogen education at Drenthe College – Willem Hazenberg[83]

- Drenthe College focusses with its hydrogen activities on industry. A multi-disciplinary teacher team (practoraat) has been set up consisting of 4 elective courses:
  - All-round operational technician.
  - Basic knowledge about H_2 to safely work in industry.
  - Automotive VET program at TT Assen.
  - Aspects of hydrogen from production till refueling station.
- Things that are already under development for the future at Drenthe College:
  - Industry Course: Why? > “klimaat akkoord”, this is being followed by the industry. Education focusses on Material, business cases, everything that is needed.
  - Working with Marokko for an English taught course. Dutch teachers will go there to train/educate people. Participants will then receive a Dutch/European certificate as participants will have formally completed the elective course. Therefore having demonstrable knowledge for working on hydrogen installations. Additional safety training is then required.
  - Drenthe College wants to set up a Resato gas station at 200 bar in Emmen to tinker with and gain experience.
- Topics that are still in the discussion phase and not yet under development:
  - LLL”(LevenLangLeren)” (Life Long Learning) – training courses for hydrogen. Basic training for hydrogen with opportunities for specialization.
  - Partially e-learning: Ozone package. Includes more than 300 courses, 9 or 10 hydrogen courses. All technical-like courses.
- Things that Drenthe College expect that would be needed for hydrogen education in the future based on signals from the market:
  - Greater depth is needed because the current offering is too basic.
    - Example: training participants should be able to learn to work with 800 bar pressure systems.
    - Greater depth is needed in maintenance, inspection and safe working.
    - What is ATEX, how do you deal with this? HAZOP studies etc.
    - How should inspections be done with H2 systems/components?
  - MBO (VET) students are more likely to want something closer to home and also pay less attention to sustainability.

[83] W. Hazenberg, “Interview on hydrogen education at Drenthe College,” Jun. 11, 2024, Groningen.

The Energy Training Centre

5 day training course for adults (online)[85]

Objectives

- Understand the green Hydrogen and its principle
- Apply green Hydrogen in different industries and its requirements
- Analyse the shifts and required actions
- Plan for moving toward this change
- Position the company in a way to take advantage of this shift
- Determine if moving toward Hydrogen can benefit their company

Attendees

- Individuals who are leading or actively engaging in a program in a company that is dealing with Hydrogen and clean energy
- Those who aspire to learn about this new subject for finding a unique job opportunity
- Entrepreneurs who want to establish a new business in this area and want to use this fantastic opportunity of hydrogen economy to create the next big business
- Anybody else who likes to learn more and wants to use this opportunity to find their aspiration to help to create a better world through this hydrogen shift

Outlines:

- DAY ONE: WHAT IS GREEN HYDROGEN?
  - Hydrogen and its principle | types of Hydrogen |Hydrogen production | benefits |effect on the environment | Advantage and limitation |
- DAY TWO: GREEN HYDROGEN ECONOMY AND ITS REQUIREMENTS
  - mass-scale production | Advantages and limitations | Required infrastructure How to make this shift | Requirements and Barriers
- DAY THREE: HOW CAN WE BE READY FOR THIS SHIFT?
  - Understanding the shift | requirements | What can we do and when? |shift affect the market | Should we start now?

[85] The Energy Training Centre (o. J.): *Green Hydrogen Projects Training Course*. Verfügbar unter: https://energytraining.ae/course/green-hydrogen-projects (Zugriff am 25.11.2025).

- DAY FOUR: INNOVATIVE AND SUSTAINABLE SOLUTIONS
    - New opportunities and limitations | make this industry more sustainable | Areas of innovation to create the shift | Innovative solutions for Hydrogen production | real implementation of sustainable solutions in the hydrogen industry
- DAY FIVE: CASE STUDIES AND IMPLEMENTATION
    - Hydrogen implementation by Companies | Recent shifts toward hydrogen in different countries | Big private investments in this area | How a billionaire tries to empower the hydrogen economy? | Where from here?

Queensland: Hydrogen Industry Workforce Development Roadmap (2022-2032)[86]

This Roadmap identifies a range of short-, medium- and long-term actions to deliver on this vision, focused on:

- Building a pipeline of skilled, adaptable workers for the hydrogen industry
- Sharing knowledge to support hydrogen skills, training and safety
- Maximising the benefits of hydrogen for communities through a local approach to skills, training and workforce development
- Using data insights to plan for industry workforce needs over time.

[86] Queensland Government, Department of Employment, Small Business and Training (2022): *Hydrogen Industry Workforce Development Roadmap 2022–2032*. Brisbane: Queensland Government. Verfügbar unter: https://www.publications.qld.gov.au/ckan-publications-attachments-prod/resources/5fffcbcc-7605-46ed-86b4-2c2a91e7acad/hydrogen-industry-workforce-development-roadmap.pdf (Zugriff am 25.11.2025).

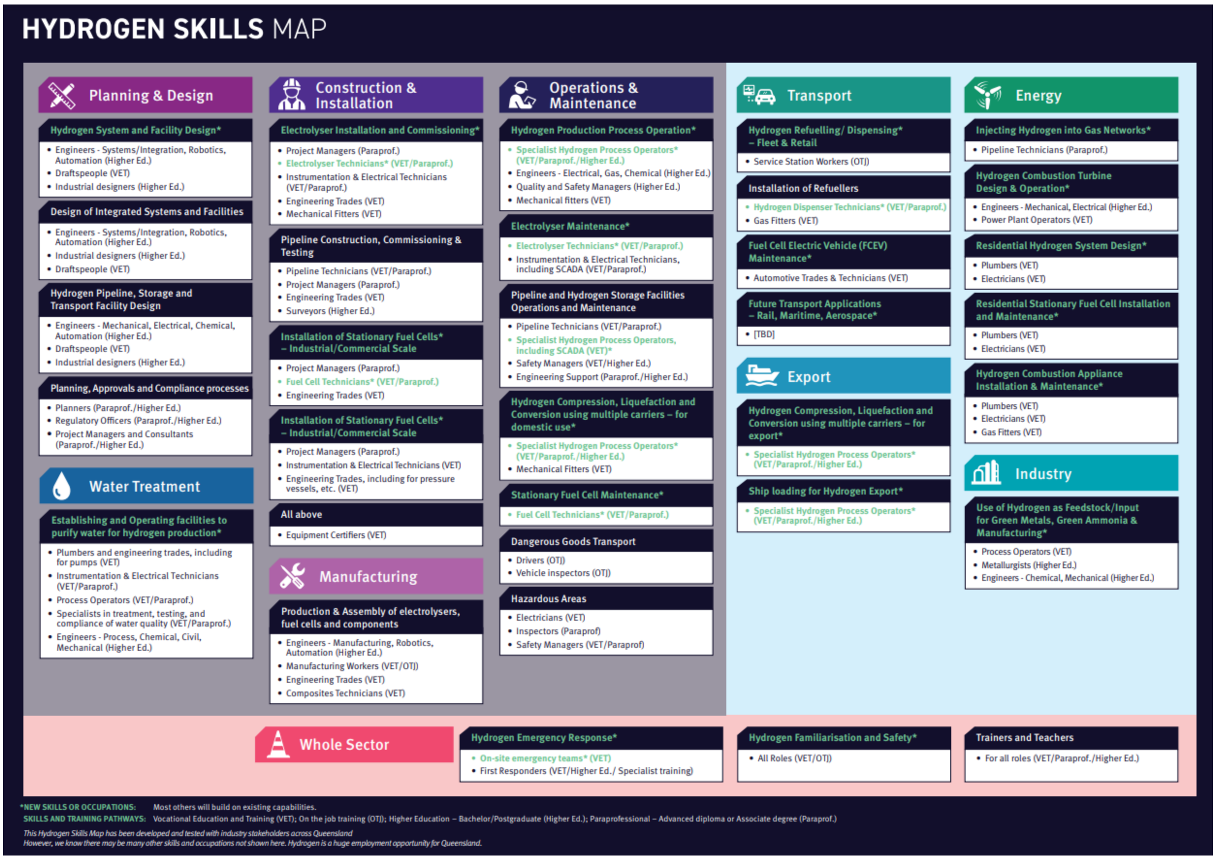

Figure 34 Hydrogen Skills Map

They offer an investors toolkit

Fuelling a hydrogen future: STEM Skills for Secondary Learning courses have been developed to target Years 7 – 10 and Years 11 – 12 and are curriculum-aligned for easy integration into the classroom environment.

Students will explore:

- Chemical and physical properties of hydrogen
- History of hydrogen fuel
- Hydrogen applications
- Hydrogen storage and transport
- Hydrogen safety
- Future of the hydrogen industry.

European Hydrogen Observatory[87]

- Hydrogen Basics - Dive into the fundamental concepts and acquire a clear perspective on the role of hydrogen in the energy transition.

Figure 35Clean Hydrogen Partnership JU – Hydrogen Basics

- Education Materials - Access a wide range of public educational materials covering topics from across the hydrogen value chain.
  - Basic electrochemistry
  - General
  - H2 End-uses
  - H2 Production
  - H2 Storage and Distribution
  - Life Cycle and Social Assessment, eco-design, recycling
  - Regulations, Codes, Standards & Safety
  - Techno-economic evaluation
- Training Programmes - Find hydrogen-related courses or programmes in European countries that match your interests and profile.
  - Basic electrochemistry
  - H2 End-uses: buildings
  - H2 End-uses: energy, power generation
  - H2 End-uses: industry
  - H2 End-uses: transport
  - H2 Production
  - H2 Storage, Transport and Distribution
  - Life-Cycle Assessment, eco-design, recycling
  - Regulations, Codes and Standards
  - Safety
  - Techno-economic evaluation

[87] Clean Hydrogen Partnership / European Hydrogen Observatory (o. J.): *Learn about Hydrogen*. Verfügbar unter: https://observatory.clean-hydrogen.europa.eu/learn-about-hydrogen (Zugriff am 25.11.2025).

TÜV Austria Training

- General Hydrogen
    - Hydrogen in the future energy system
    - Properties and sources of danger when handling hydrogen
    - Principles of occupational safety when handling hydrogen
    - Overview of hydrogen technologies
        - Supply
        - Storage and transport
        - Use in power plants and fuel cell systems
    - Insights into gas plants
        - Application examples in energy generation and mobility
    - Expert session
        - Explosion protection
        - Material compatibility
        - Green Hydrogen" guarantees of origin
- Introduction to hydrogen technologies
    - The stuff dreams are made of - or a little more?
    - Properties of hydrogen and comparison with other fuels
    - Sources of danger when handling hydrogen
    - The basics of explosion protection
    - Occupational safety when handling hydrogen
    - Overview of hydrogen technologies
    - Testing
- Basic principles for the safe handling of hydrogen
    - Damage to hydrogen systems
    - Hydrogen compatibility and damage mechanisms
    - Hydrogen components (pipes, valves, connections, hoses, etc.)
    - Hydrogen refuelling stations
    - Basics of leak testing
    - Testing

TÜV SÜD Akademie Österreich (o. J.): *Wasserstoff – Seminare und Ausbildung*. Verfügbar unter: https://www.tuvsud.com/de-at/store/akademie-at/seminare-und-ausbildung/wasserstoff (Zugriff am 25.11.2025).

- Safe working on hydrogen systems for manufacturers
  - Development of a suitable safety concept
    - Basic procedure
    - Identify sources of danger
    - Determine protective measures
  - Examples of accidents at gas plants
  - Regulations for hydrogen technology: Production
    - Overview
    - Regulations for stationary systems
    - Regulations for mobile systems (focus: drive)
  - Distribution of roles between manufacturer / planner and operator
  - Testing
- Safe operation of systems with hydrogen for operators
  - Planning safe hydrogen systems
  - Regulations for hydrogen technology: Operation
    - General industrial safety regulations
    - Risk assessment
    - Operating conditions
    - Regulations for stationary systems
    - Regulations for mobile systems (focus: drive)
    - Notes on gas system testing (GAP)
    - Notes on the gas system installation test (GSP)
  - Liability responsibilities
  - Testing
- Material compatibility in conjunction with hydrogen
  - Introduction Hydrogen compatibility
  - Damage mechanisms and examples
    - Hydrogen embrittlement
    - High temperature hydrogen attack
    - Hydrogen & microorganisms
    - Hydrogen sickness of aluminium & copper
  - Hydrogen compatibility: Metals
    - Materials testing for hydrogen compatibility
    - Fracture mechanics and hydrogen
    - Design and processing in hydrogen applications
    - Documentation in hydrogen applications
  - Hydrogen compatibility: Polymers

    - Hydrogen purity / hydrogen-natural gas mixtures
    - Influence of material defects
  - Basics of fuel cell technologies
    - Introduction to hydrogen
    - Structure of a fuel cell and applications
    - Fuel cell technology
    - Subsystems of a fuel cell
    - Regulations and responsibilities
  - Basics of electrolysis technologies
    - Introduction to the basics of hydrogen
    - Basics of electrolysis
    - Electrolysis principles
    - Application of electrolysis plants
    - Important regulations and responsibilities

Additional findings

Factsheets at a basic level concerning different areas of the hydrogen value chain, such as Production, application,…)[89]

- Word hydrogen courses[90]
- Educational material for schools in the US[91]
- Hydrogen Tools Portal – Safety Resources[92]
- Hydrogen Academy qualification modules[93]

[89]Hydrogen Europe (n.d.): *Tech Descriptions* (Factsheets zur Wasserstoff-Wertschöpfungskette). Brüssel: Hydrogen Europe. Available: https://hydrogeneurope.eu/in-a-nutshell/tech-descriptions/ (Accessed on 25.11.2025).
[90]World Hydrogen Leaders (o. J.): *Courses / Training Courses*. London: World Hydrogen Leaders (S&P Global Energy). Verfügbar unter: https://www.worldhydrogenleaders.com/courses (Accessed on 25.11.2025).
[91]The NEED Project – National Energy Education Development Project (n.d.): *Educators* (K-12 teaching materials and curricula, including hydrogen modules). Available at: https://www.need.org/educators/ (Accessed on 25 November 2025).
[92]Hydrogen Tools (H2tools) (n. d.): *Hydrogen Tools Portal – Safety Resources*. Available at: https://h2tools.org/ (Accessed on 25.11.2025).
[93]Hydrogen Academy (n. d.): *Qualification Modules*. Available at: https://www.hydrogen-academy.net/qualification-modules (Accessed on 25.11.2025).

Related hydrogen projects/courses

Green Skills for Hydrogen project

Hydrogen is a key pillar of the EU's strategy to achieve its 2050 decarbonisation goals. The rapid development of the European Hydrogen Value Chain over the coming years is expected to generate approximately 1 million highly skilled jobs by 2030, and up to 5.4 million by 2050. Supporting this growth, the European Hydrogen Observatory (EHO) has identified 253 training programmes across 19 countries as of June 2024, with master's programs (51%) and professional training courses (33%) forming the core segments. These programmes predominantly use English (51%) and address the varied skill demands of the hydrogen sector.

The European Hydrogen Skills Alliance (Green Skills for Hydrogen) is a four-year project bringing together partners from 15 European countries and funded under the EU's Erasmus+ programme[94]. The primary objective is to design and implement a highly innovative, effective, and sustainable Hydrogen Skills Strategy for Europe that will ensure the skills needs of the rapidly expanding and evolving Hydrogen Value Chain can be met in the short, medium, and long term. This blueprint will address the skills need of workers in Declining Sectors and Transition Regions to provide them with upskilling and reskilling opportunities within the Hydrogen sector.

Green Skills for Hydrogen will establish a long-term partnership between Industry and Education; design an innovative and sustainable Hydrogen Skills Strategy; develop, test and roll-out VET curricula and training programmes in line with latest market needs and consistently linked with EU instruments and tools; continuously develop skills and careers that empower technical professionalism in both green and digital competences; and disseminate and rollout the VET training to maximise European impact.[95]

Description of the reskilling and upskilling activities

The upskilling and reskilling training programmes in the hydrogen field are rooted in the global transition towards sustainable energy solutions. With the increasing recognition of hydrogen's potential as a clean and versatile energy carrier, there is a growing demand for skilled professionals in this field. Reskilling and upskilling training programmes are educational initiatives designed to enhance or acquire new skills and knowledge of the workforce and young people to meet the challenging targets of the Declining Sectors and Transition Regions in order to bridge the skills gap and ensure that a workforce is proficient in designing, implementing, and maintaining hydrogen technologies. This helps workforce/professionals stay competitive, adapt to changing job requirements, and advance within their careers.

94 Green Skills for Hydrogen. https://greenskillsforhydrogen.eu/

95 Green Skills for Hydrogen: Deliverable D3.1 – Hydrogen Skills Core VET Curriculum. March 2024. https://greenskillsforhydrogen.eu/wp-content/uploads/2024/03/D3.1-Green-Skills-for-Hydrogen-Hydrogen-Skills-Core-VET-Curriculum.pdf

Upskilling and reskilling activities can be realised though educational training programmes, which can take various forms, such as masterclasses, summer schools, seminars, workshops, etc., that immerse participants in a specific language or technical environment to accelerate learning. Therefore, reskilling and upskilling training programmes are crucial in the rapidly evolving labour market, such as the hydrogen sector, empowering the workforce to thrive in their careers and contribute effectively to their industries.

Urgent trainings in Greece

Context and Objectives

The urgent trainings that were conducted in Greece were designed for occupational profiles affected by the Energy Transition in the Region of Western Macedonia. These trainings aimed at providing upskilling and reskilling opportunities to undergraduate and postgraduate students, engineers, and technicians, enabling them to pursue careers in the hydrogen value chain. According to the European Hydrogen Observatory, Greece hosts only a small number of hydrogen-related training programs compared to Western European countries. The country accounts for fewer than 5% of training programmes mapped across Europe. However, its focus on innovative and urgent training efforts, such as summer schools and short-term reskilling initiatives, aligns with broader European trends, which have seen a 40% increase in such programs between 2022 and 2023.

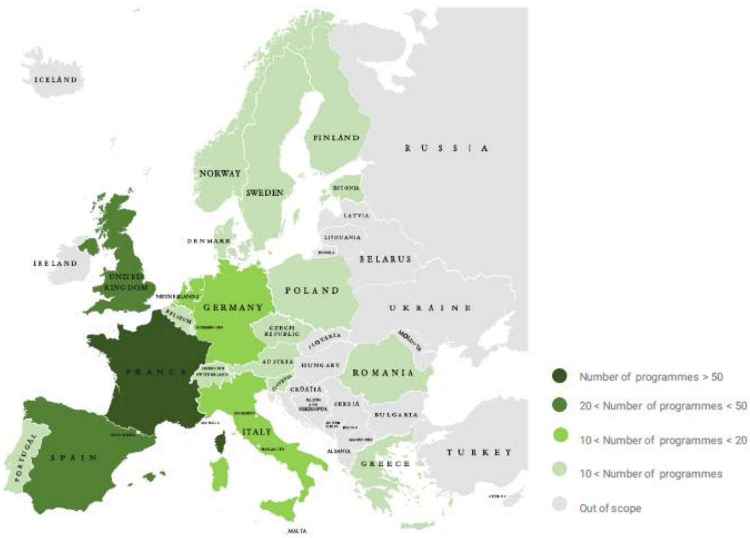

Figure 36: Geographical distribution of training programmes in Europe by ranges (European Hydrogen Observatory, Report 03: The hydrogen education and research landscape, October 2024)

In this framework, four (4) urgent training programs took place in Western Macedonia, Greece, organized by the Cluster of Bioeconomy and Environment of Western Macedonia (CluBE) and Advent Technologies, in cooperation with the University of Western Macedonia. These programs included the "Masterclass: One-Day Hydrogen," designed to provide foundational knowledge on the hydrogen value chain; the "Hydrogen Summer ScH2ool," aimed at students interested in hydrogen technologies; the "Engineering Our Future: Developing Hydrogen Skills," tailored for engineers impacted by the energy transition; and the 2nd Hydrogen Summer ScH2ool. These trainings attracted a diverse audience and provided valuable opportunities for professional development, knowledge exchange, and engagement with leading experts in the field.

Target groups

Considering the project's objectives, the target groups of the urgent trainings consisted of undergraduate and postgraduate students as well as engineers and technicians that are affected by the energy transition. In Greece, these groups align with the European Hydrogen Observatory's identified high-priority profiles, such as engineering professionals, project managers, and VET trainees. Specific focus is placed on reskilling technical professionals and students to align with the skill demands of hydrogen production, storage, and distribution technologies.

More specifically, the **Masterclass: "One-Day Hydrogen"** was suitable for professionals within and outside of the energy sector, seeking more knowledge on the hydrogen value chain. The participants included stakeholders, policymakers, engineers, innovation, research, and energy producers.

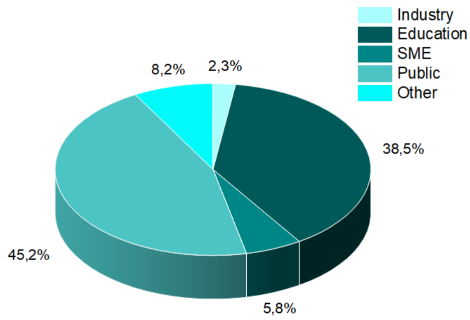

Figure 37: Participants of the Masterclass: "One-Day Hydrogen" training

The Masterclass: "One – Day Hydrogen" paved the way for more specialised urgent trainings. In this context, the **"Hydrogen Summer ScH2ool"** was organised shortly afterwards, which was designed for undergraduate and postgraduate students interested in hydrogen technologies.

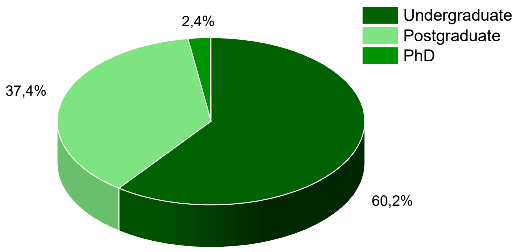

Figure 38: Participants of the “Hydrogen Summer ScH2ool” training

Following the success of the first session, the **“2nd Hydrogen Summer ScH2ool”** was conducted at the University of Western Macedonia and attracted 63 participants, including undergraduate and postgraduate students, professionals, engineers, and technical staff from both Greece and abroad.

Finally, the **“Engineering our Future: Developing Hydrogen Skills”** training was implemented for the engineers of the Technical Chamber of Greece/Department of Western Macedonia (such as chemical, mechanical, civil, and electrical engineers). The total number of participants in these trainings was more than 100, which was the declared KPI in the proposal.

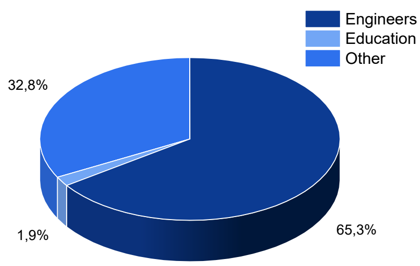

Figure 39: Participants of the "Engineering our Future: Developing Hydrogen Skills" training

Topics

As we embrace a zero-emission energy system, there is now a growing consensus that hydrogen will play a vital role in the race to decarbonisation. Hydrogen can be used to store and transport (renewable) energy efficiently. It is poised to meet a vast range of energy needs and accelerate efforts to achieve a climate-neutral economy by 2050. Training programs in Greece reflect this vision by addressing topics like hydrogen end-use applications, production processes, and safety, consistent with European priorities. According to the European Hydrogen Observatory, Greece’s programs align with key training subjects, such as hydrogen production (69% of European programs) and safety (44%), emphasizing its role in preparing for a hydrogen-based energy transition. Furthermore, the demand for skills and expertise in the hydrogen industry is set to grow exponentially. In this context, the trainings that were organised in Greece were in line with these targets. More specifically, the **Masterclass: “One-Day Hydrogen”** training covered the entire hydrogen value chain, the role of hydrogen in the energy transition in the region of Western Macedonia and the creation of a Pan-European Hydrogen Industry Hub of Western Macedonia, aligning with the ultimate aim to achieve a carbon-neutral economy by 2050. The participants had the chance to explore the characteristics of hydrogen as a leading carbon-free candidate, hydrogen production, transport, storage, and end-use application. They were also able to learn more about the technological, economic, regulatory, and safety context of hydrogen, as a critical player in the global energy transition.

The second training program that was organised in Greece was the **“Hydrogen Summer School”**, providing undergraduate and postgraduate students from Greek institutions with the opportunity to expand their knowledge and develop their skills, while learning from experts in the rapidly developing hydrogen sector. The programme covered hydrogen technologies (production, transport, storage and handling), electrolysers and fuel cells, hydrogen safety issues, H_2-to-X technologies, Hydrogen Refuelling Stations, as well as funding opportunities for hydrogen. During the training, a workshop on creating a hydrogen start-up company took place, as well as a round table regarding the creation of a Hydrogen Valley in Western Macedonia. In addition, two study visits were held, at the Laboratory of Alternative Fuels and Environmental Catalysis (LAFEC) at the University of Western Macedonia in Kozani and at the Centre of Research and Technologies (CERTH)/Chemical Process & Energy Resources Institute (CPERI) in Thessaloniki.

The **“2nd Hydrogen Summer ScH2ool”** was organized in Greece, providing undergraduate and postgraduate students, as well as professionals, engineers, and technical staff from Greece and abroad, with the opportunity to expand their knowledge and develop their skills while learning from leading experts in the hydrogen sector. The programme covered hydrogen technologies, including production, storage, transportation, and end-use applications, as well as safety issues and economic aspects related to hydrogen. During the training, Advent Technologies conducted a pilot session on High Temperature Proton Exchange Membrane (PEM) technology, accompanied by a live demonstration of their products. Additionally, an interactive workshop featured the Hydrogen Game, a hands-on learning activity developed as part of the Green Skills for Hydrogen project. As part of the programme, a study visit was organised at DESFA’s industrial facilities in Nea Mesimvria, Thessaloniki.

Another training programme that took place in Western Macedonia, entitled**: “Engineering our Future: Developing Hydrogen Skills”** was organised in cooperation with the Technical Chamber of Greece/ Department of Western Macedonia and was specifically designed for the engineers who are affected by the transition and are members of the Technical Chamber. This programme was designed to address Just Transition and accelerate decarbonisation in the Region of Western Macedonia. The topics of the training included the current status and challenges of hydrogen technologies (production, storage, transport), uses, properties, and safety issues regarding hydrogen utilisation for heat and power. Furthermore, Advent Technologies’ fuel cell systems were presented during the training, with a focus on how the innovative HT-PEM fuel cell technology effectively replaces polluting diesel generators, providing clean power to diverse sectors such as marine, automotive, and aviation.

Speakers

The speakers of the trainings in Greece included a diverse group of approximately fifty experts from academia, industry, and research institutions. Professors represented leading Greek universities, such as the University of

Western Macedonia, Aristotle University of Thessaloniki, and the National Technical University of Athens, alongside European institutions like the Karlsruhe Institute of Technology (KIT) and University of Genoa. Industry representatives included professionals from Advent Technologies, Hellenic Hydrogen, Motor Oil, DESFA, TÜV Hellas/TÜV Nord, and Jacobs Engineering Group. Contributions from research institutions such as CERTH/CPERI and FORTH/IG, as well as European organizations like Hydrogen Europe, further enriched the sessions.

Figure 40: Masterclass: "One-Day Hydrogen"

Figure 41: "Hydrogen Summer ScH2ool" training

Figure 42: "2nd Hydrogen Summer ScH2ool" training

Figure 43: "Engineering our Future: Developing Hydrogen Skills" training

Hydrogen Science and Technology": The Only MSc Program in Greece on Hydrogen Technology provided by the University of Western Macedonia

Figure 44: "Hydrogen Science and Technology" MSc Program provided by the University of Western Macedonia

The Departments of Mechanical Engineering and Chemical Engineering of the University of Western Macedonia, Kozani – Greece, jointly provide the novel Master of Science (MSc) Program in "Hydrogen Science and Technology". This is the only MSc program in the country which focuses specifically on the science and technology of hydrogen and aims at the education of expert scientists and executives who will support the development of the hydrogen economy in the region of Western Macedonia and Greece[96].

[96] University of Western Macedonia (UoWM): Hydrogen Science and Technology. https://hydrogen.uowm.gr/

The **goals** of the MSc program are as follows:

• **to educate expert engineers and scientists** who will support the development of science and technology for the production, storage, transport, and safe utilization of hydrogen fuel in the industry, in buildings and in transportation,

• **to disseminate knowledge and execute research** in the scientific fields targeting the development, the optimization and the operation of hydrogen operation units, systems and plants (production of grey, blue and green hydrogen, Power-to-Gas strategies, fuel cells, cogeneration and trigeneration systems, hydrogen vehicles etc.),

• **to prepare expert engineers**, entrepreneurs and company executives who will initiate and develop a new energy model and a novel energy market using hydrogen as an energy carrier in the new decarbonization era, and finally

• **to provide a scientific and administrative potential** which will support sustainability and will protect the natural environment and the cultural human values through the development of a viable hydrogen economy.

Topics for the Hy2Market training guidelines

Work Package 3 of Green Skills for Hydrogen aims to design and develop an innovative Hydrogen VET Curriculum, integrate work-based learning components, identify qualification paths for learners, and design a program to actively promote the mobility of apprentices in the EU. The following topics were derived from the D3.1: “Hydrogen Skills Core VET Curriculum”. The primary objective of Task 3.1 is to design a Hydrogen VET Curriculum focused on the competences and occupational profiles identified in the Skills Strategy to address the priority occupational profiles that affected from the energy transition.

1. Introduction to the Hydrogen Economy

i. Hydrogen basics

ii. Understanding of the hydrogen market and value-chain

iii. Specialisation on each aspect of the green hydrogen value-chain

iv. Green hydrogen for decarbonisation and energy transition

v. Integration of different renewable and hydrogen technologies into complete systems

vi. Hydrogen economy

2. Green Hydrogen Production

i. Electrolyser system installation, operation and maintenance

ii. Expertise on electrolysers design, electrocatalysis, manufacturing and process, safety, risks and hazards related to H_2

3. Hydrogen Transport

i. Hydrogen injection and distribution

ii. Liquefaction specialists, compressors design

4. Industrial Use of Hydrogen

i. Advanced technical qualification in mechanics, combustion, and generators

ii. Material compatibility, detection and simulation of leakage, combustion, and ignition

5. Mobility use of Hydrogen

i. Hydrogen Refuelling Stations

ii. Fuel Cell Electric Vehicles (FCEVs)

iii. FCEVs and HRS: maintenance, protocols and best practices and regulation

iv. HRS operation and maintenance

6. Internal Knowledge exchange

i. Legal aspects, regulation and permitting of H_2 projects

ii. Hydrogen initiatives at international/EU/national levels

iii. Hydrogen EU projects

Target audience for the Hy2Market training guidelines

The Green Skills for Hydrogen project has collaborated closely with hydrogen stakeholders across the EU to comprehensively understand, document, and outline the existing and future demand for hydrogen-related occupational profiles[97]. The aim is to identify the occupational profiles in high demand, assess the characteristics and intensity of this demand, and analyse the required level of “hydrogen knowledge” of these profiles. The level of hydrogen knowledge required of each occupational profile differs based on the role and responsibilities of the position. To address both the skills demands and the gaps in training and education offers, the Skills Strategy for the hydrogen sector outlined strategic recommendations and actions which need to be implemented. The groups are categorised into the following groups based on the D2.2: “European Hydrogen Skills Strategy”, which was developed on the Green Skills for Hydrogen project. In this framework, profiles that require the highest level of hydrogen knowledge and competencies according to the ESCO classification are: 1) Physical and earth science professionals 2) Project Managers 3) Engineering professionals (excluding electrotechnology) 4) Chief executives, senior officials and legislators 5) Architects, planners, surveyors and designers 6) Electrotechnology engineers 7) Legal professionals. In addition, qualified engineers and technicians specialised in hydrogen, and support functions such as sales, management and public servants are in high demand.

Based on the existing knowledge and the mapping of the hydrogen related occupational profiles within Green Skills for Hydrogen, the target audience for disseminating the Hy2Market findings and training guidelines that will be implemented, could include the following occupational profiles:

[97] Green Skills for Hydrogen: Deliverable T2.1 – Final Deliverable T2.1. April 2023. https://greenskillsforhydrogen.eu/wp-content/uploads/2023/04/Final-deliverable-T2.1.pdf

Industrial and Business

- Management
- Operators
- Business Developers
- Procurement
- SMEs, H2 start-up companies
- HR staff
- Technicians (electrochemical, electrical, mechanical, automation, production, chemist, laboratory technicians, maintenance, material science technicians, process and precision technicians, installation coordinator, fire test technicians, service technicians, plant operators, machine operators, assemblers, metal workers)
- Finance & Economics (H2 finance experts, Investment manager, Finance specialists, Economists)

Engineers

- Electrical & Chemical (chemical engineers, electrochemical engineers, electrical engineers, automation engineers, electrical design engineers- electrolysers, electrical and power electronics engineers, renewables engineers, fuel cells engineers, refuelling station engineers, simulation engineers, electrical and mechanical equipment engineers (balance of plant))
- Civil (civil engineers, infrastructure engineers, construction engineers)
- Industrial (Industrial engineers, product design engineers, reservoir engineers, precision engineers, material science engineers, development and integration engineers, process engineers, design engineers, production engineers, quality engineers)
- Mechanical (Vehicle architect, Hydraulic engineers, mechanical engineers, maintenance engineers, engine development engineers)
- Environmental (safety planning engineers, occupational hazards engineers, safety construction and operation engineers, environmental engineers)
- R&D engineers
- Fire, explosions & contamination experts (i.e. firefighters)

Education

- Scholars
- Students (PhD or MSc)
- Industrial entries
- VET training providers
- Research institutions
- Industrial science researchers

Other

- Media/journalists
- Policy Makers/Politicians (ministries, municipalities)
- Administrative staff at public services (Administration managers, administration professionals)
- Vehicle drivers
- Public agencies
- H_2 clusters, consulting companies
- General Public
- Commercial (Sales and marketing manager, account managers, purchasers, purchasers and sourcing managers, Business development managers, business and commercial managers, business developers)
- Digitalization (Web designer, software developer, data analysis professionals, analyst)
- Communication (communication experts, communication specialists)
- Policy & legal (Lawyers, H_2 regulation specialists

Dissemination Channels for the Hy2Market training guidelines

A structured way of disseminating the Hy2Market findings towards relevant target groups is needed. It is important to actively disseminate the training guidelines to target groups through different dissemination channels, which could include:

- Masterclasses, summer schools, VET trainings
- Conferences, Workshops, train-the-trainer sessions
- Online content (presentations, videos, etc), E-learning Platforms
- Publications, public reports and public project deliverables
- Printed Materials (flyers, brochures, posters, and fact sheets)
- Webinars and Online Events
- Press Releases and Newsletters

Appendix C – Survey Results

Demographics for the Survey

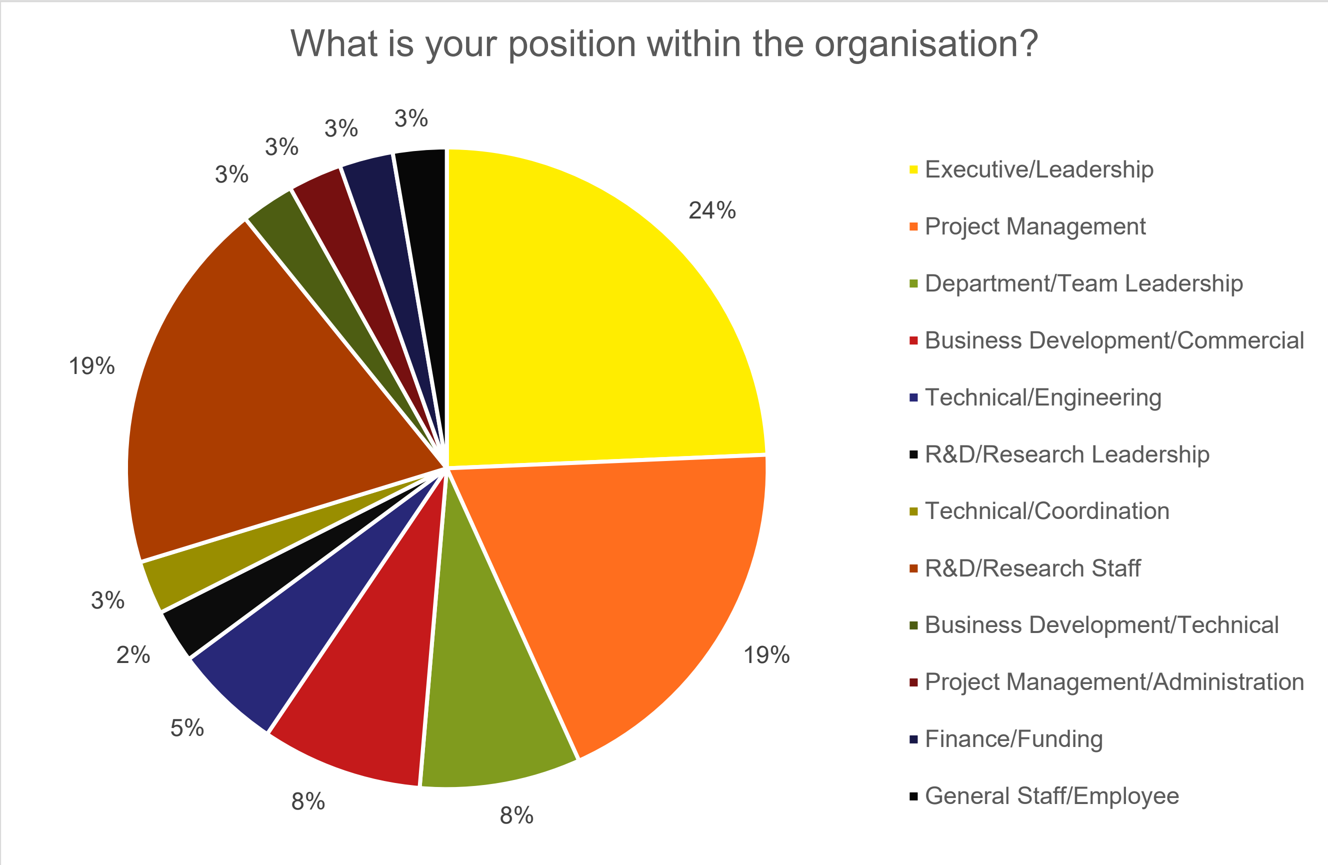

Figure 45 What is your position within the organization?

What is your organisation's core business?

- Energy Transition/Policy & Market Integration
- Renewable Energy Company
- Hydrogen Infrastructure/Manufacturing
- Engineering & Consulting Services
- Gas & Hydrogen Transport
- Renewable Energy Solutions Provider
- Engineering/Production Services

- Regional Energy Agency
- Research/Process Engineering & CCU
- Renewable Power Plant Development/Operation
- Hydrogen Technology/Compression & Separation
- Regional Environment/Energy Agency
- Environmental Consulting/Urban Development
- Hydrogen Sector Support
- Project Management/Engineering
- Hydrogen Production
- Water Treatment Technology/Innovation
- Hydrogen Production
- R&D/Bioeconomy/Project Coordination
- Software Development
- Process Engineering/Simulation
- Steel Production/Industry
- Research
- Scientific Research
- Research & Innovation
- Project Management/Consultancy/Sales
- Hydrogen Project Coordination
- Transport/Road Mobility
- Hydrogen Distribution
- Regional Economic Development
- Research Facility
- Hydrogen Sector Support
- Engineering/Assembly/Automation
- Sector Association/Promotion
- Process Optimization/Software & Computer Vision
- Engineering/Technical Consultancy
- Enterprise Support/Competitiveness

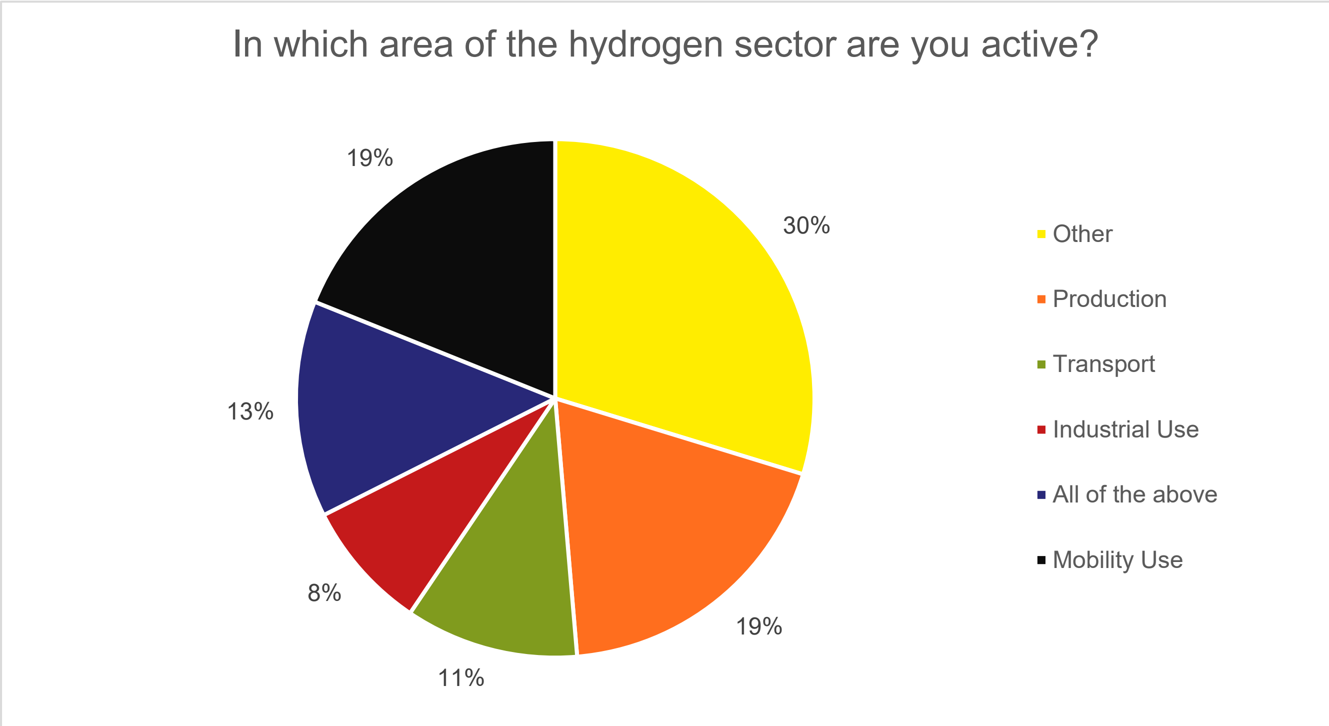

Figure 46 In which area of the hydrogen sector are you active?

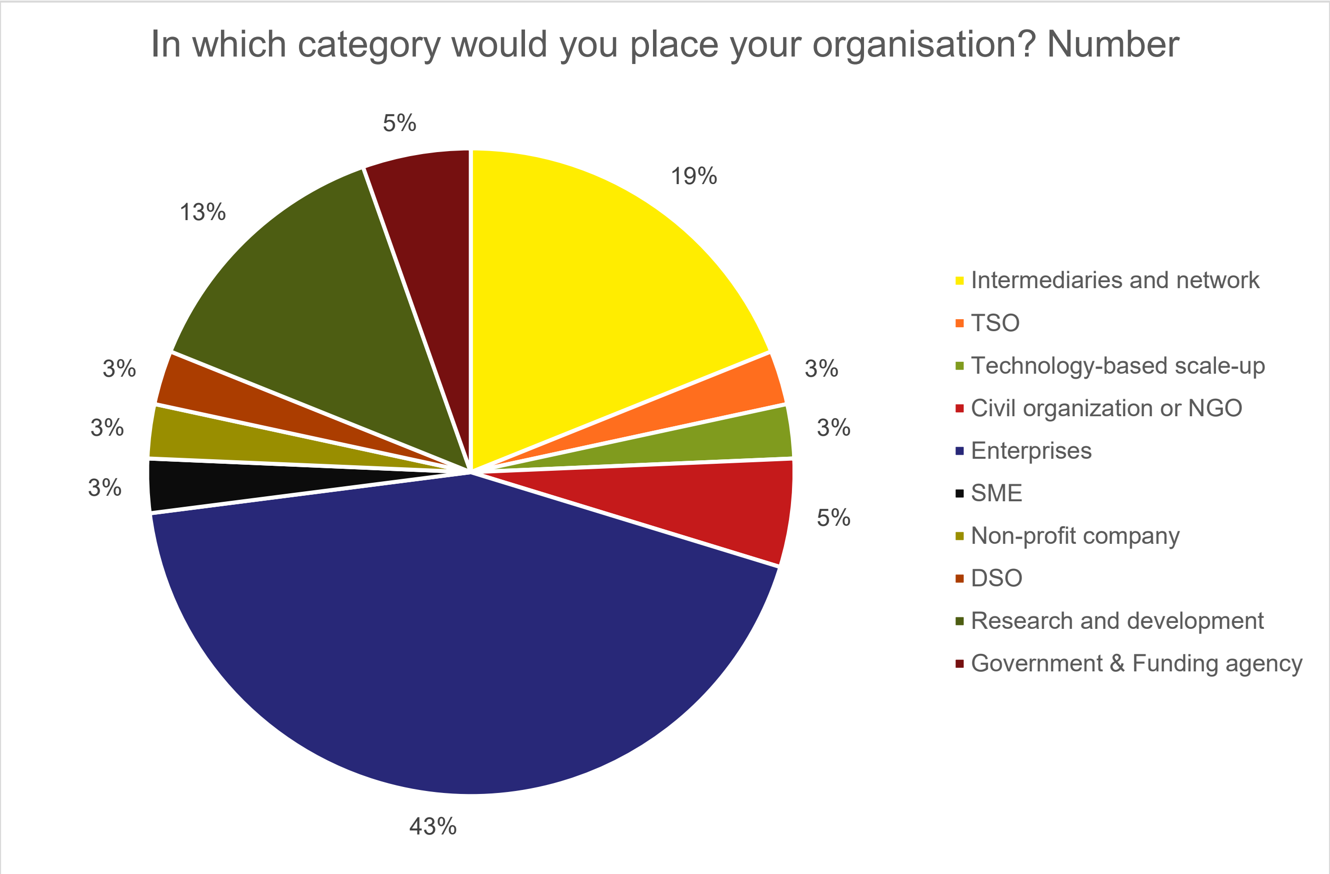

Figure 47 In which category would you place your organization?

6. Do individuals in **Operation and Maintenance** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

Yes	10
No	11
Not applicable	16

Figure 48 Operation and Maintenance – Hydrogen-related activities

7. Which knowledge should people in **Operation and Maintenance** roles have?

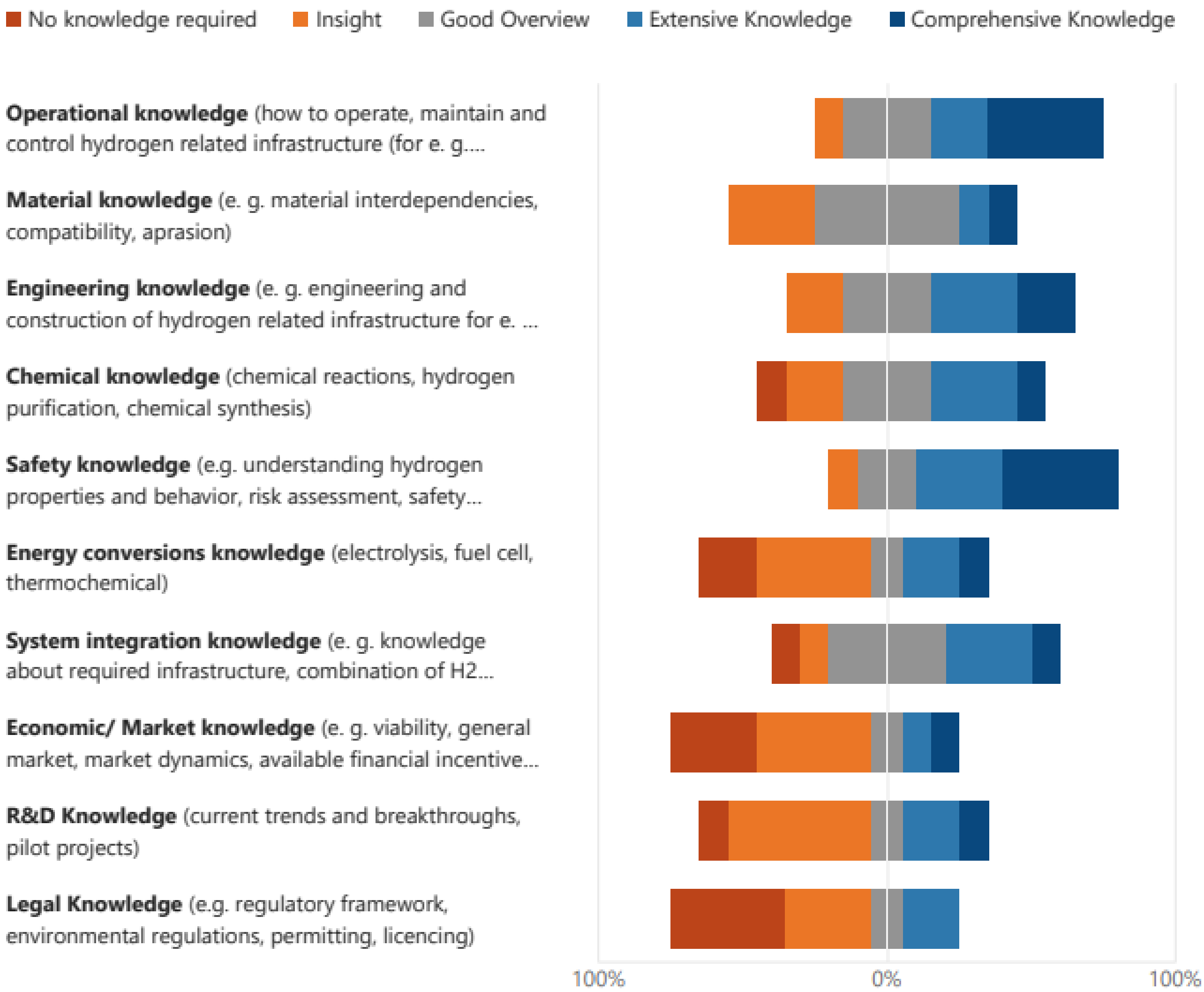

Figure 49 Operation and Maintencane – Knowledge

8. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **Operation and Maintenance**?

Figure 50 Operation and Maintenance – Other knowledge

9. Where should people in **Operation and Maintenance** roles get their knowledge from?

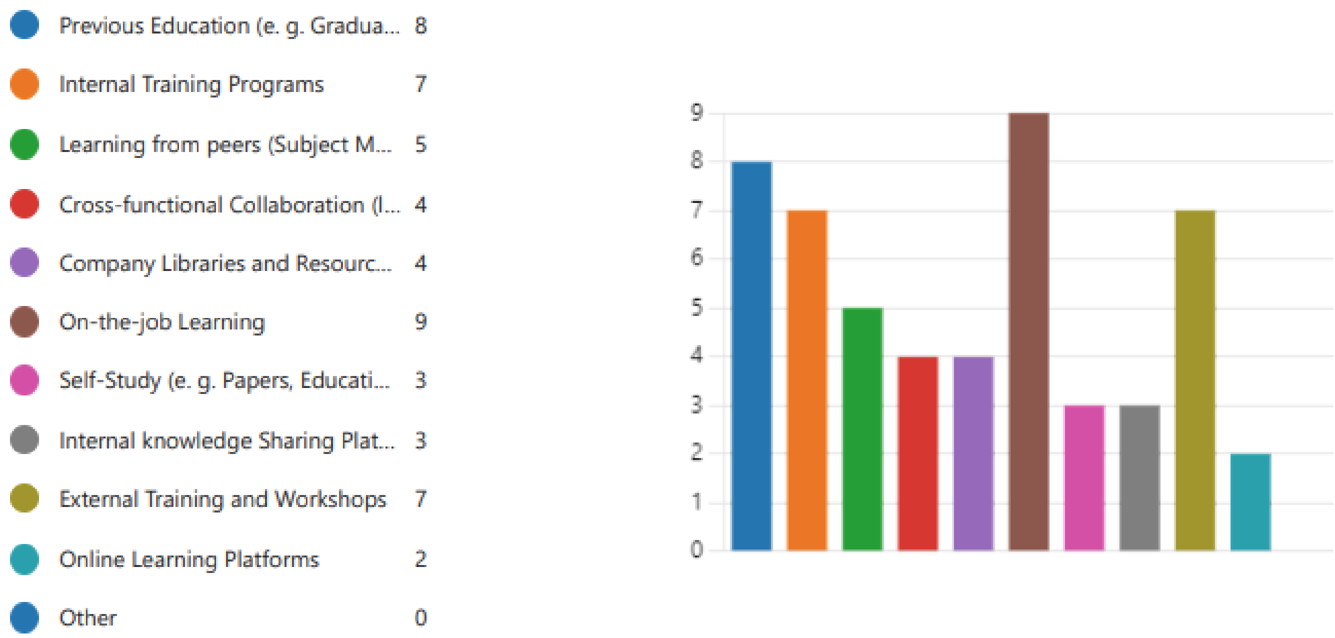

Figure 51 Operation and Maintenance – Source of knowledge

10. Do individuals in **Mechanical Engineering** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

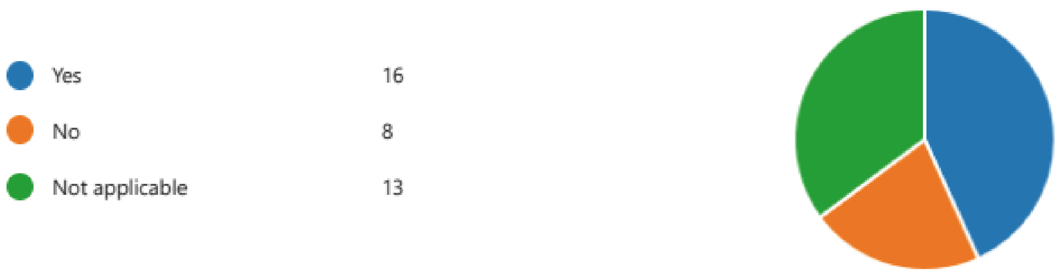

Figure 52 Mechanical Engineering – Hydrogen-related activites

11. Which knowledge should people in **Mechanical Engineering** roles have?

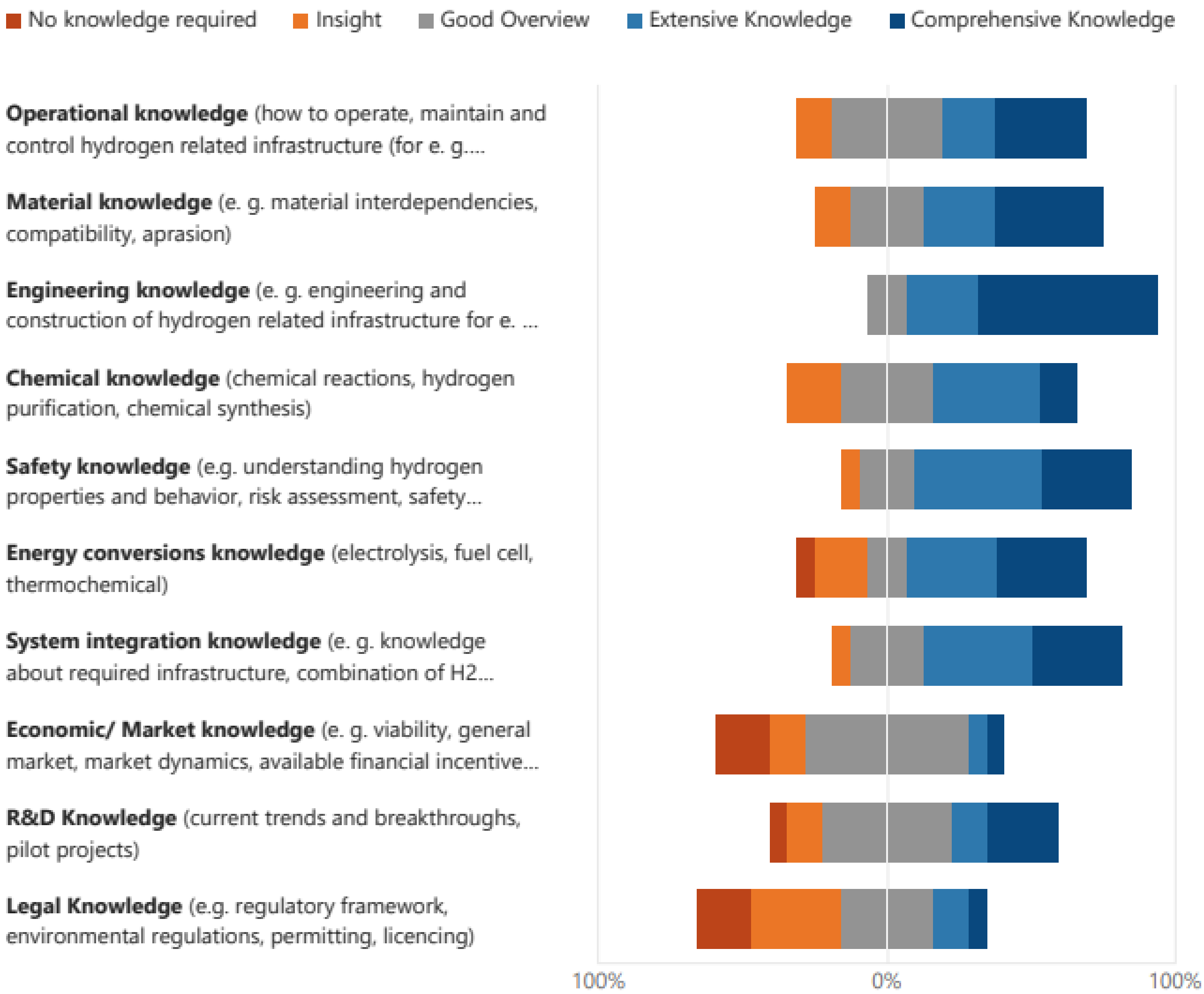

Figure 53 Mechanical Engineering - Knowledge

12. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **Mechanical Engineering**?

3
Responses

Latest Responses

Figure 54 Mechanical Engineering – Other knowledge

13. Where should people in **Mechanical Engineering** roles get their knowledge from?

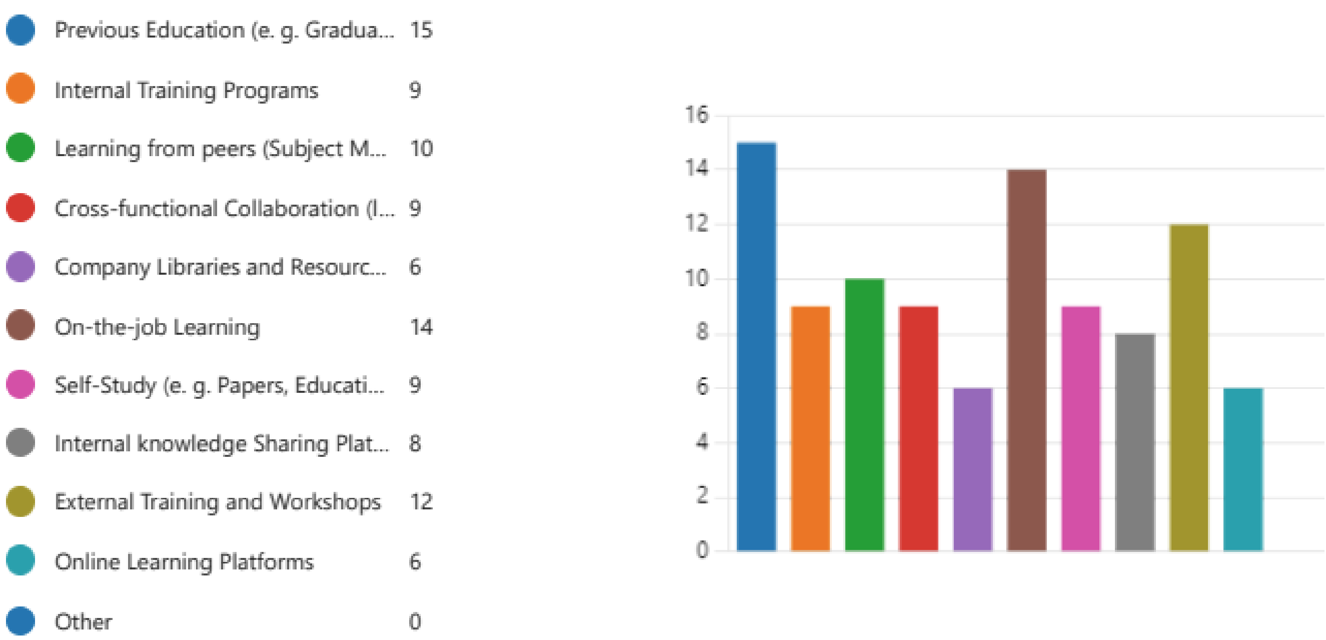

Figure 55Mechanical Engineering – Source of knowledge

14. Do individuals in **Chemical Engineering** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

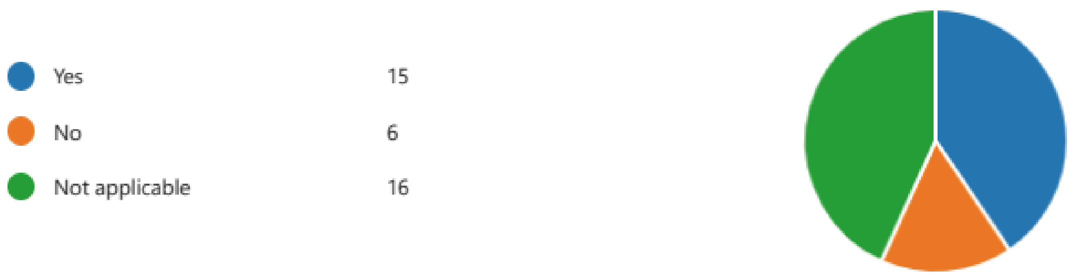

Figure 56 Chemical Engineering – Hydrogen-related activites

15. Which knowledge should people in **Chemical Engineering** roles have?

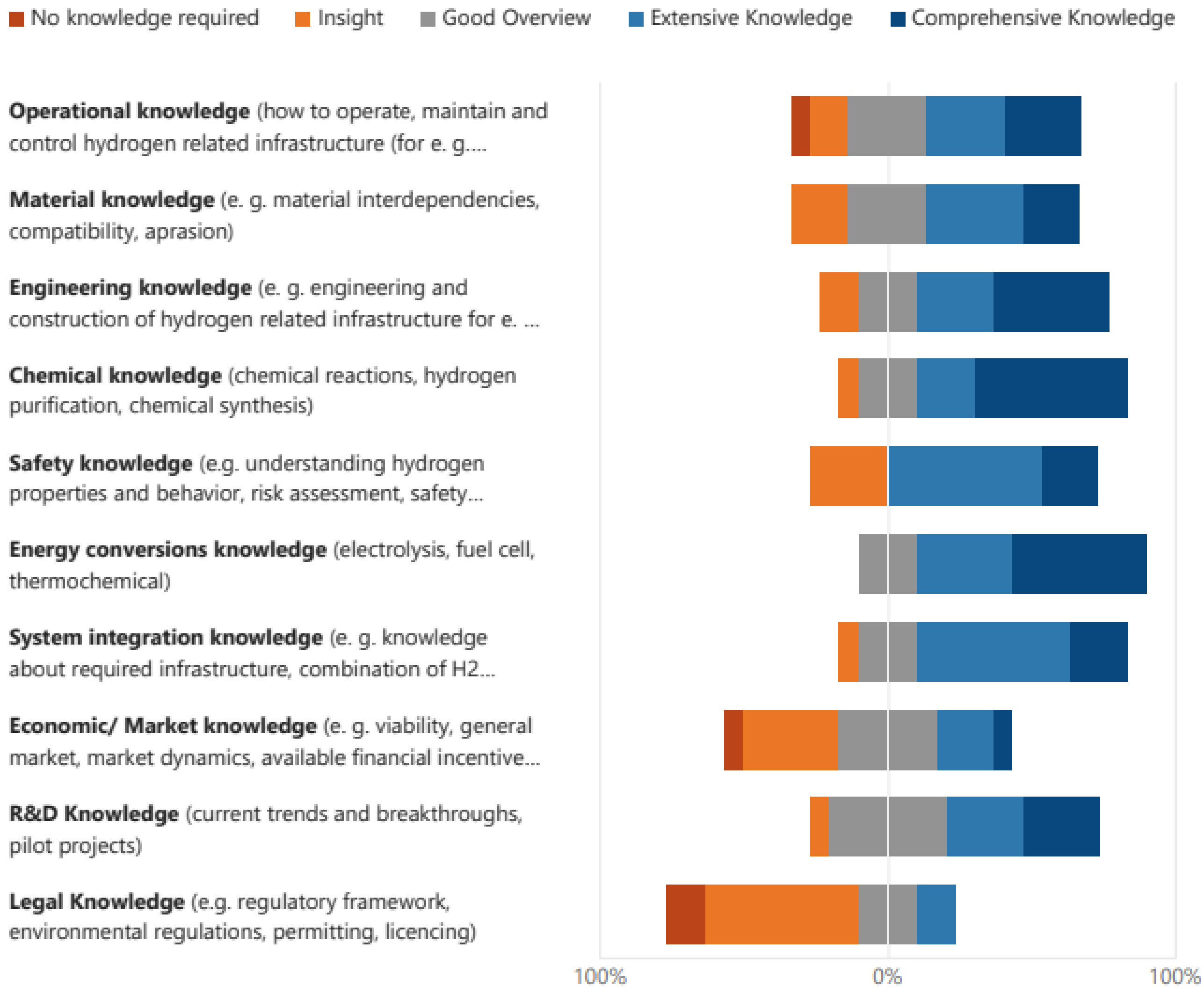

Figure 57 Chemical Engineering - Knowledge

16. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **Chemical Engineering**?

Figure 58 Chemical Engineering - Other knowledge

17. Where should people in **Chemical Engineering** roles get their knowledge from?

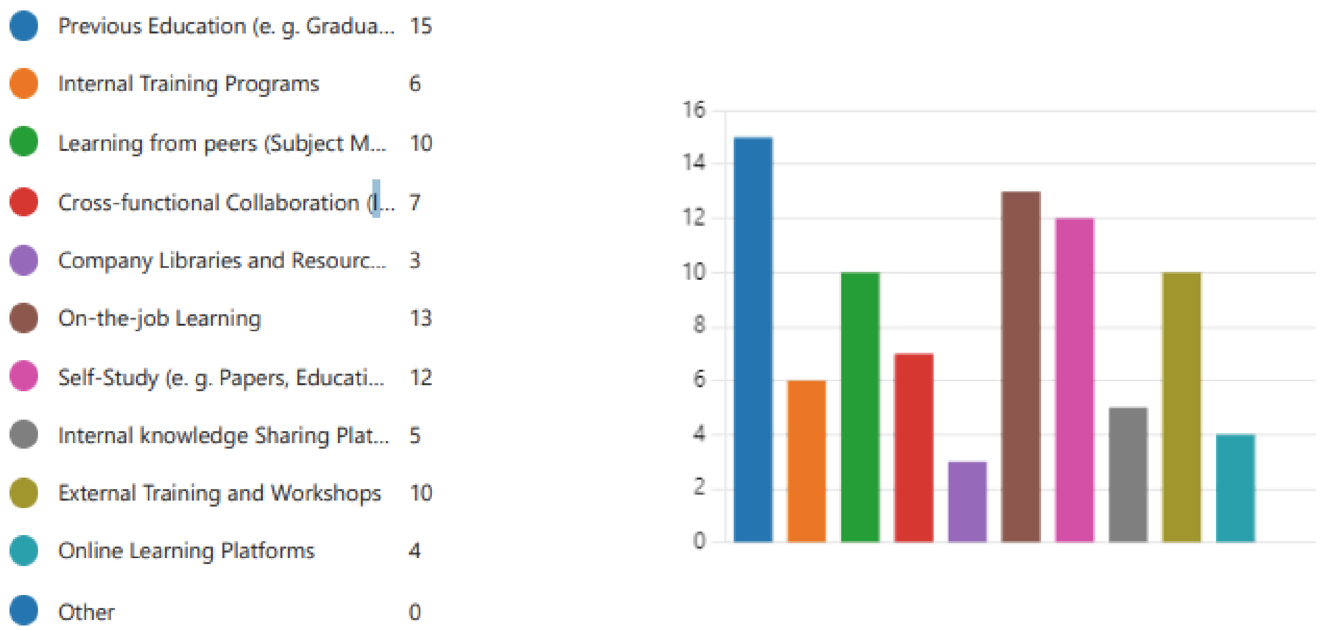

Figure 59 Chemical Engineering - Source of knowledge

18. Do individuals in **Electrical Engineering** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

Figure 60 Electrical Engineering - Hydrogen-related activities

19. Which knowledge should people in **Electrical Engineering** roles have?

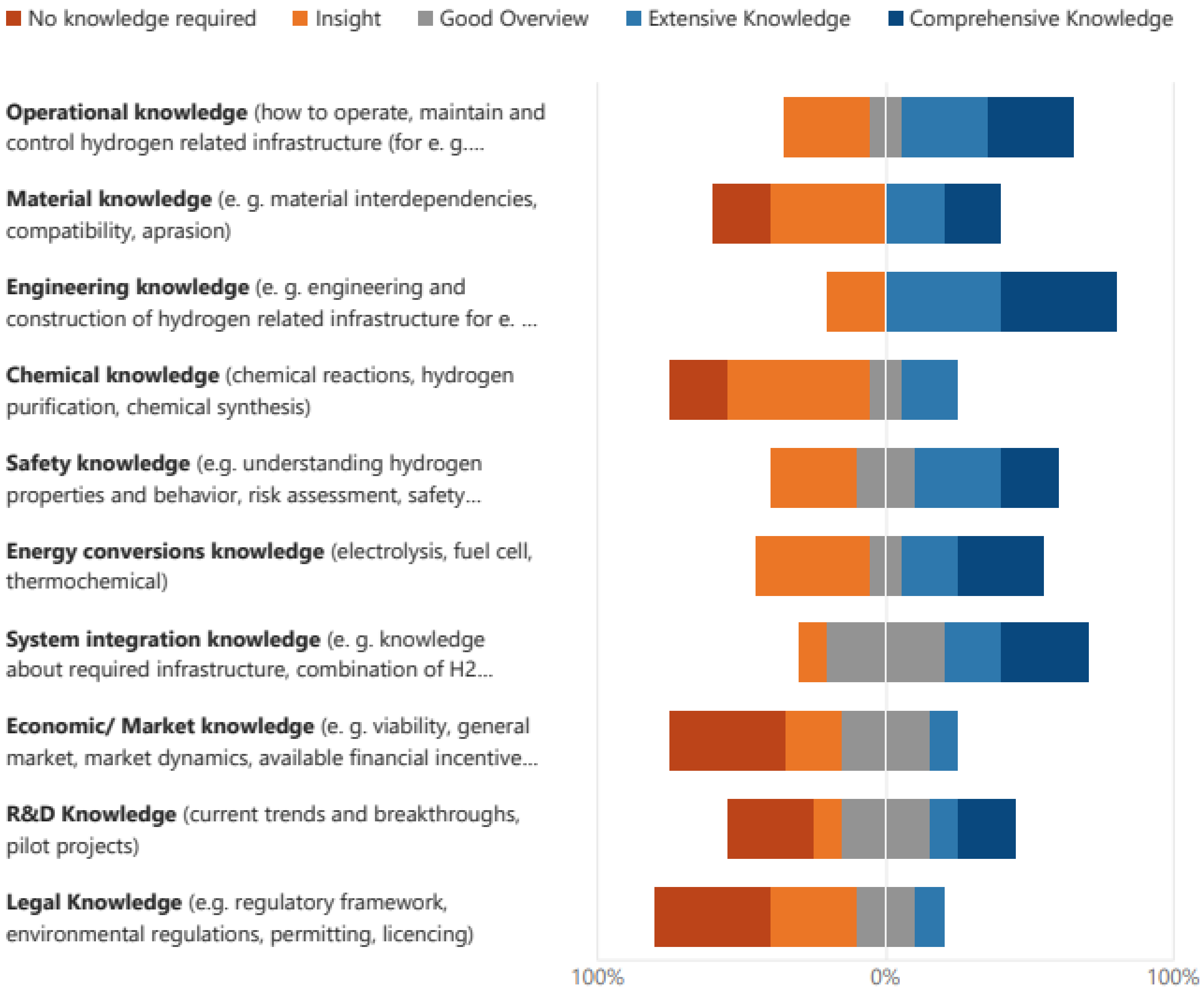

Figure 61 Electrical Engineering - Knowledge

20. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **Electrical Engineering**?

Figure 62 Electrical Engineering - Other knowledge

21. Where should people in **Electrical Engineering** roles get their knowledge from?

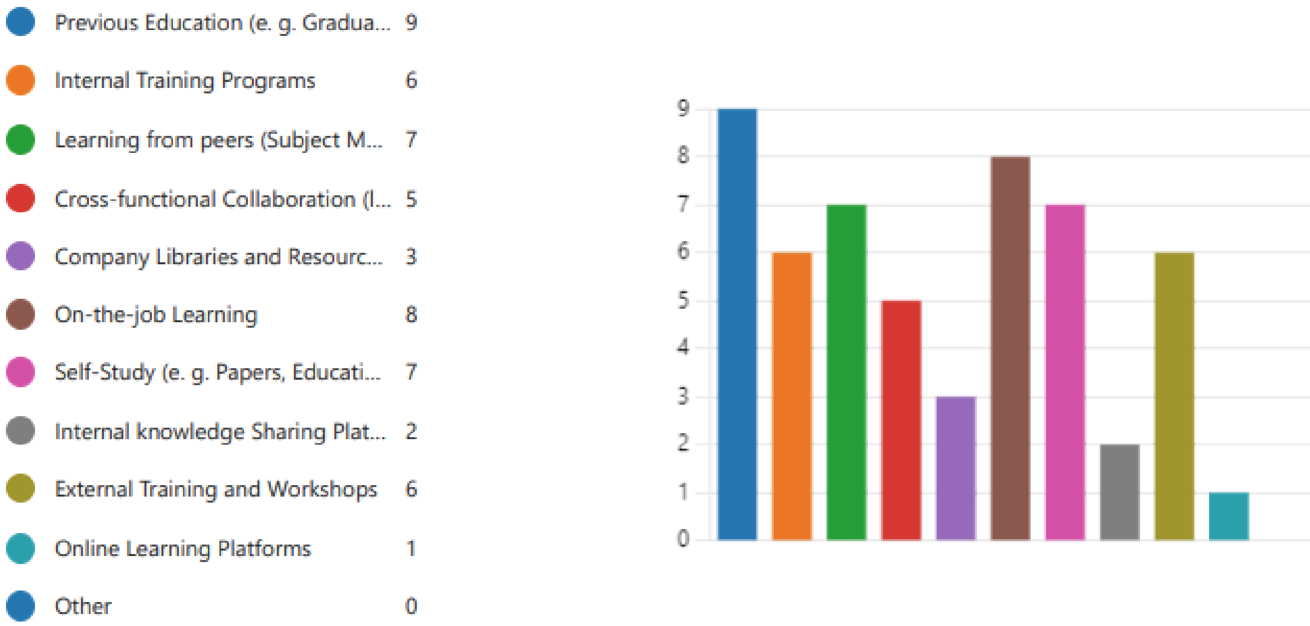

Figure 63 Electrical Engineering - Source of knowledge

22. Do individuals in **Finance and Accounting** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

Figure 64 Finance and Accounting - Hydrogen-related activities

23. Which knowledge should people in **Finance and Accounting** roles have?

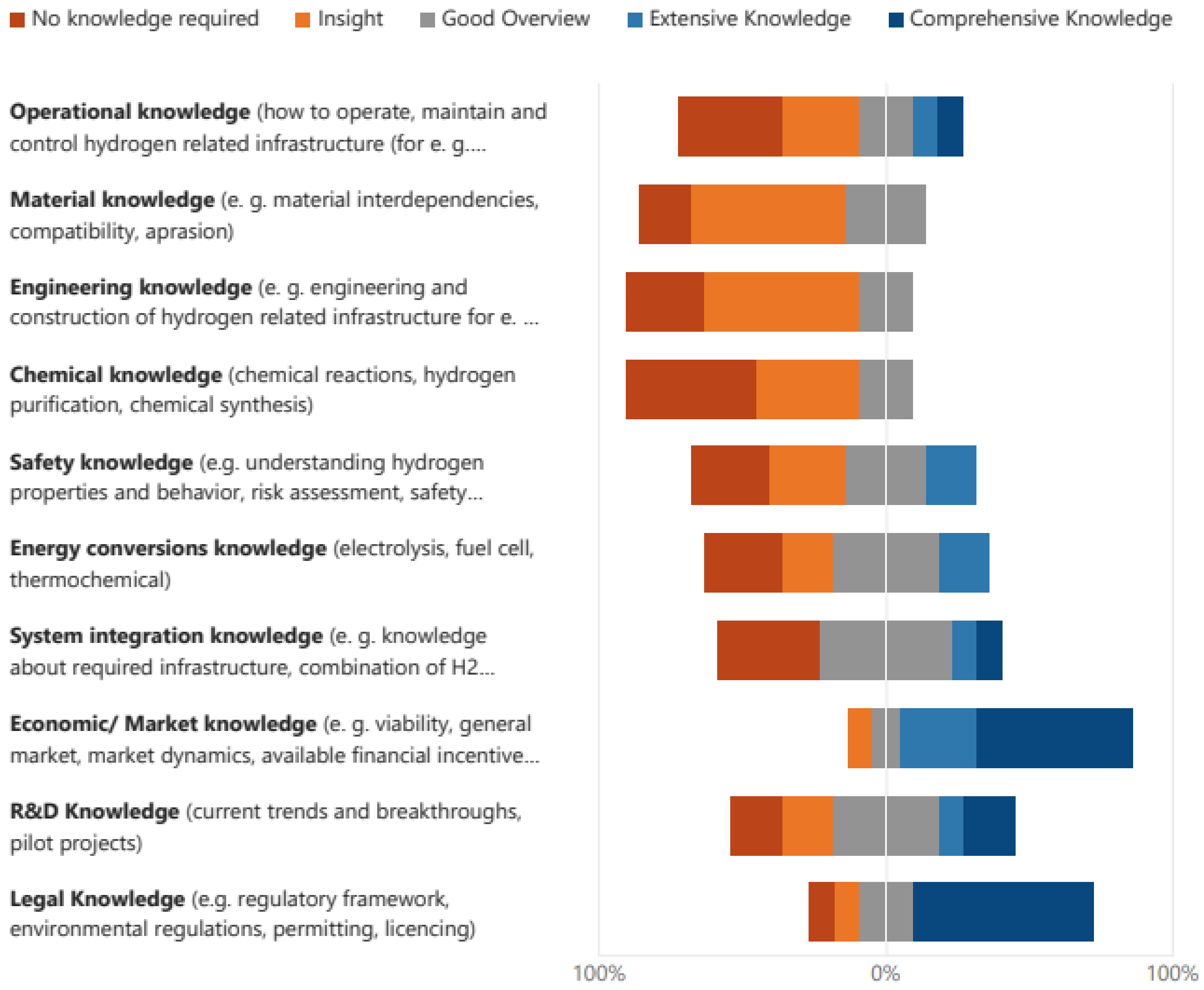

Figure 65 Finance and Accounting - Knowledge

24. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **Finance and Accounting**?

3

Responses

Latest Responses

Figure 66 Finance and Accounting - Other knowledge

25. Where should people in **Finance and Accounting** roles get their knowledge from?

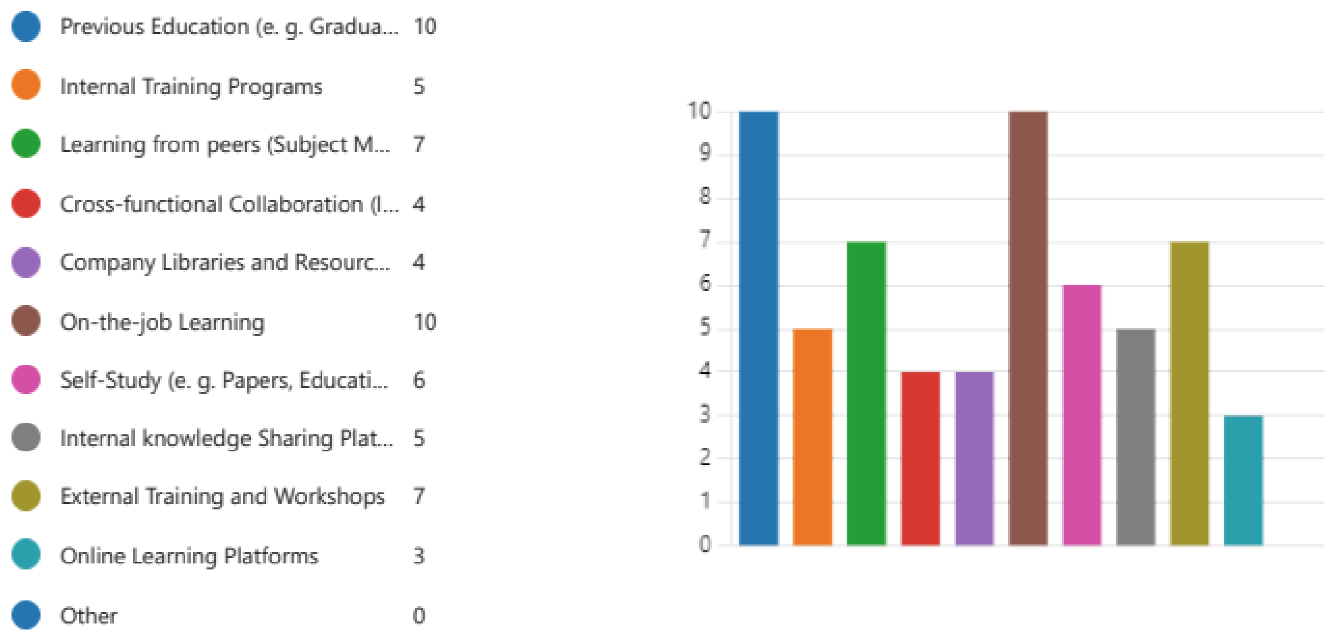

Figure 67 Finance and Accounting - Source of knowledge

26. Do individuals in **Purchasing, Logistics and Supply Chain** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

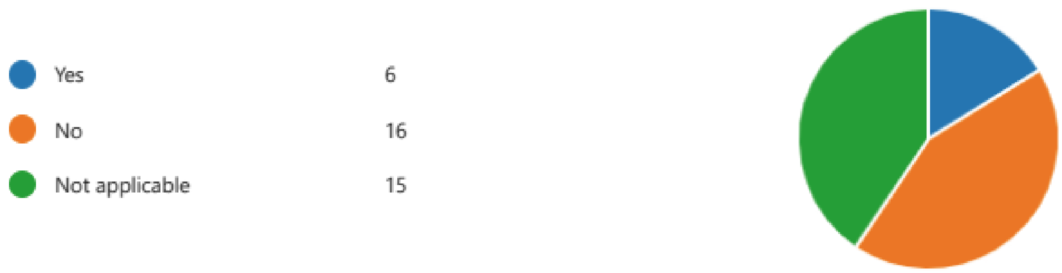

Figure 68 Finance and Accounting - Hydrogen-related activites

27. Which knowledge should people in **Purchasing, Logistics and Supply Chain** roles have?

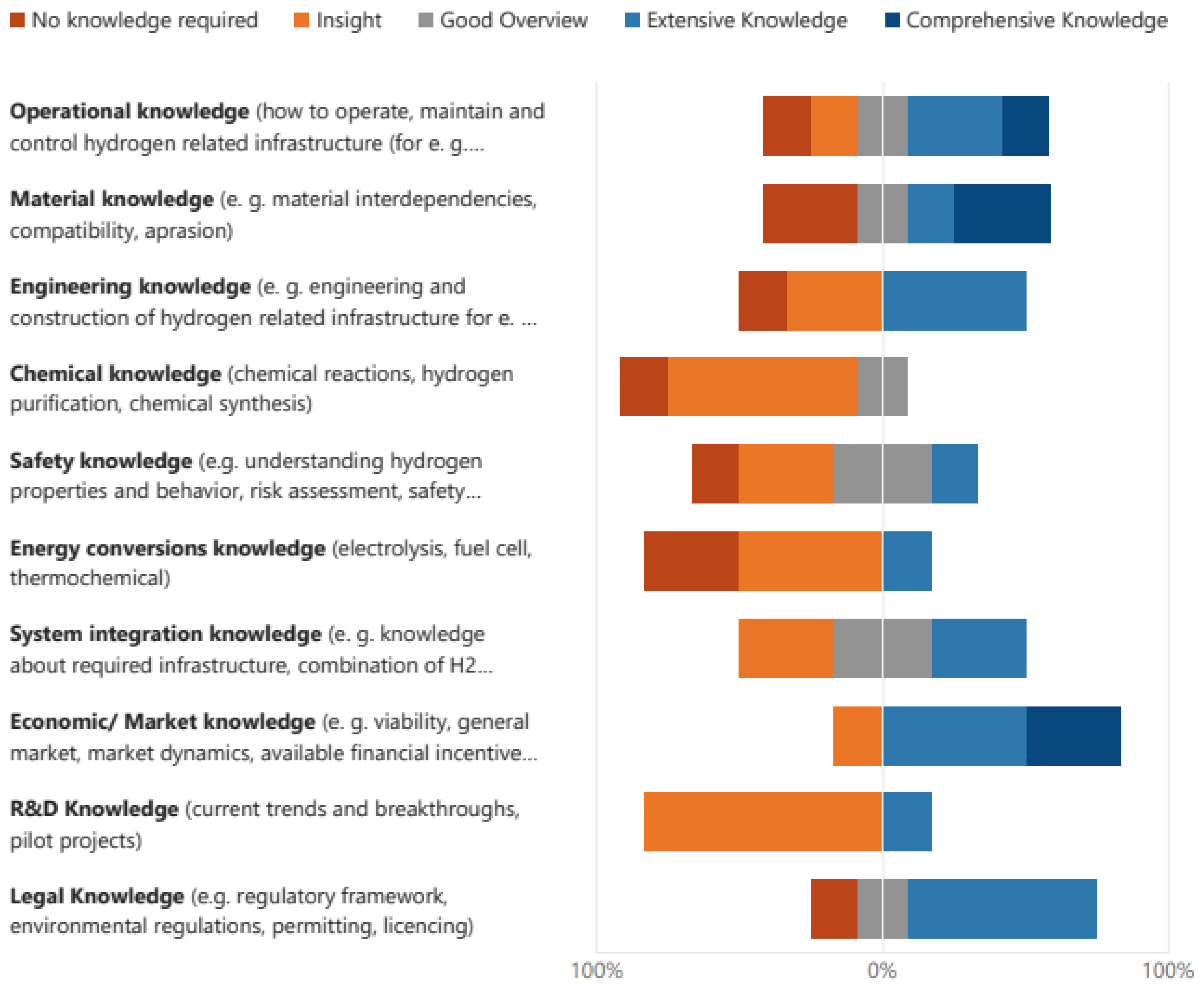

Figure 69 Purchasing, Logistics and Supply Chain - Knowledge

28. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **Purchasing, Logistics and Supply Chain**?

Figure 70 Purchasing, Logistics and Supply Chain - Other knowledge

29. Where should people in **Purchasing, Logistics and Supply Chain** roles get their knowledge from?

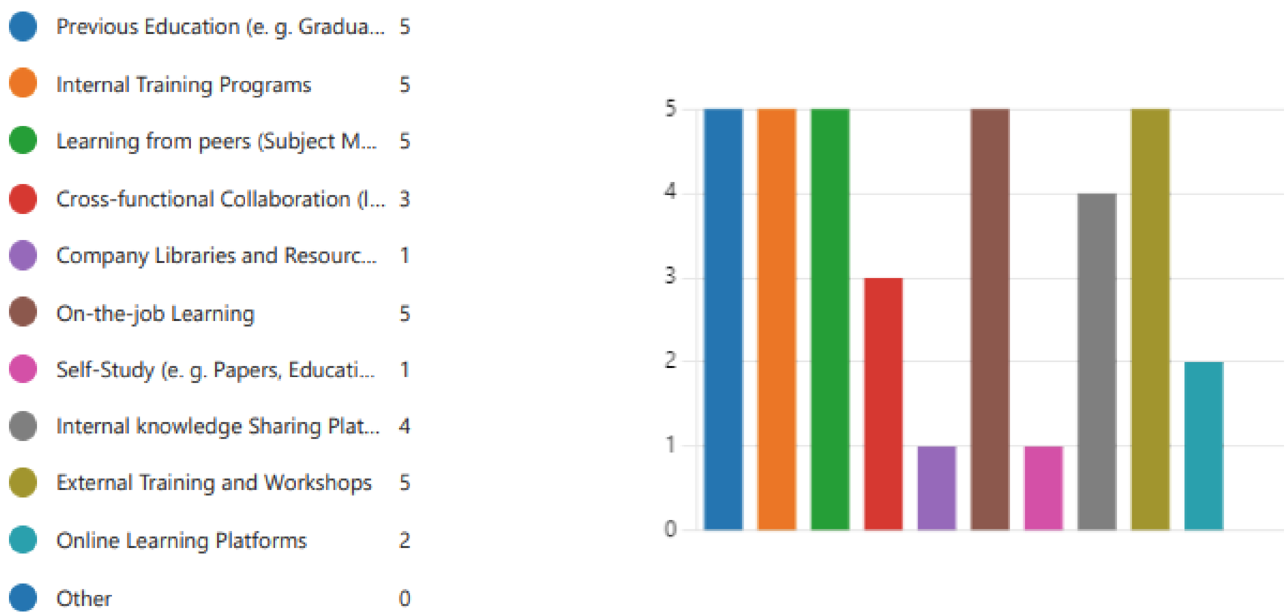

Figure 71 Purchasing, Logistics and Suppy Chain - Source of knowledge

30. Do individuals in **IT** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

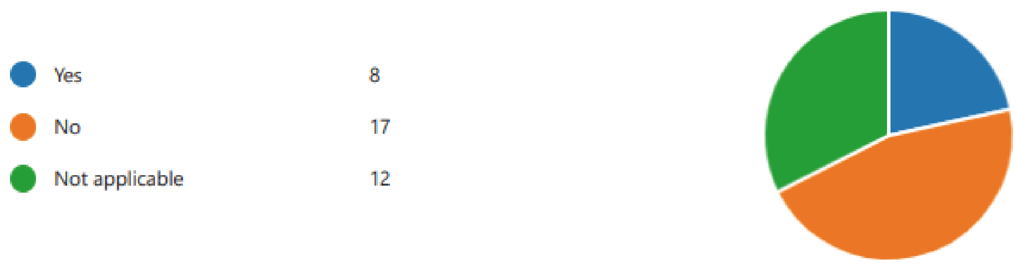

Figure 72 IT – Hydrogen-related activites

31. Which knowledge should people in **IT** roles have?

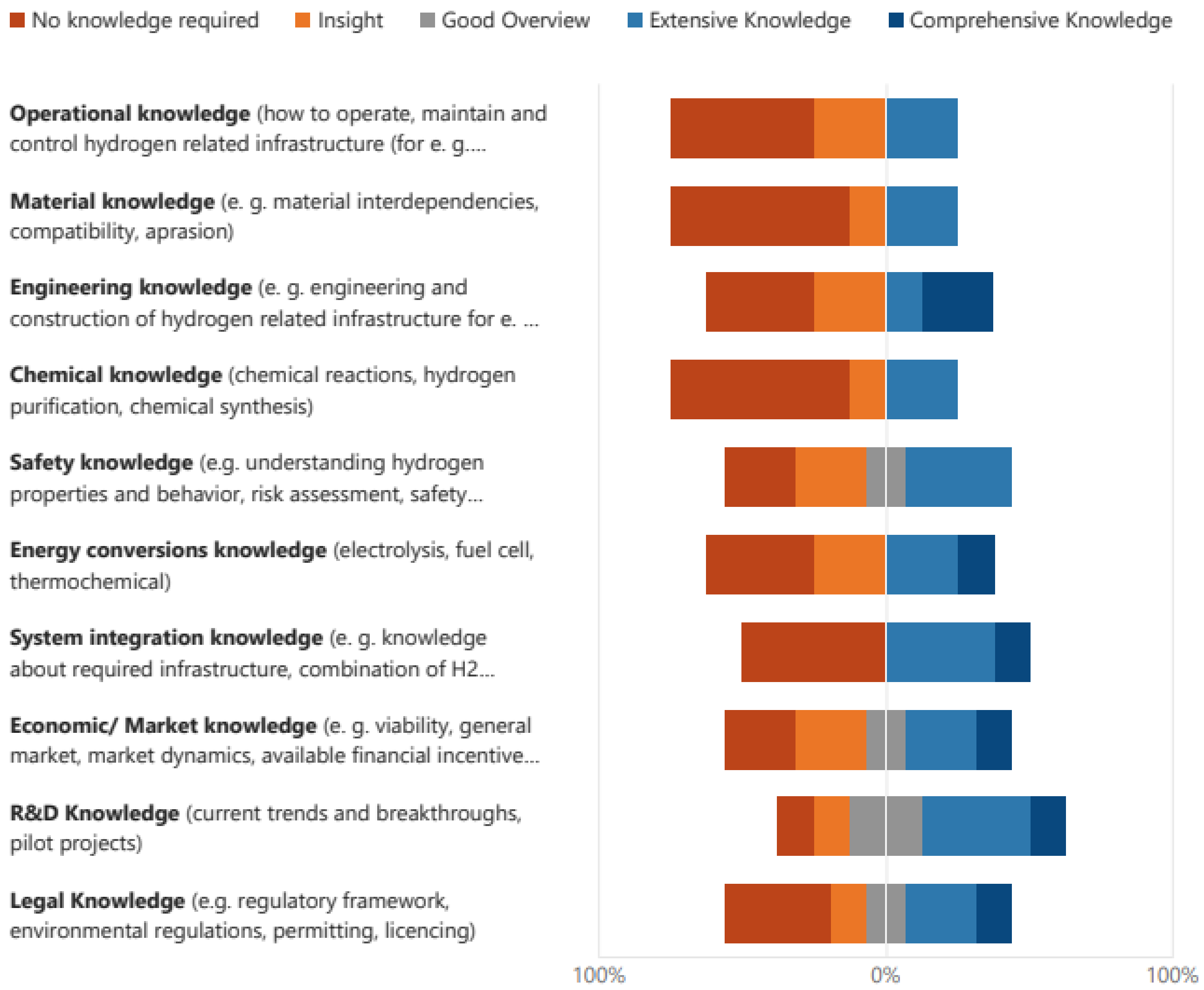

Figure 73 IT - Knowledge

32. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **IT**?

Figure 74 IT - Other knowledge

33. Where should people in **IT** roles get their knowledge from?

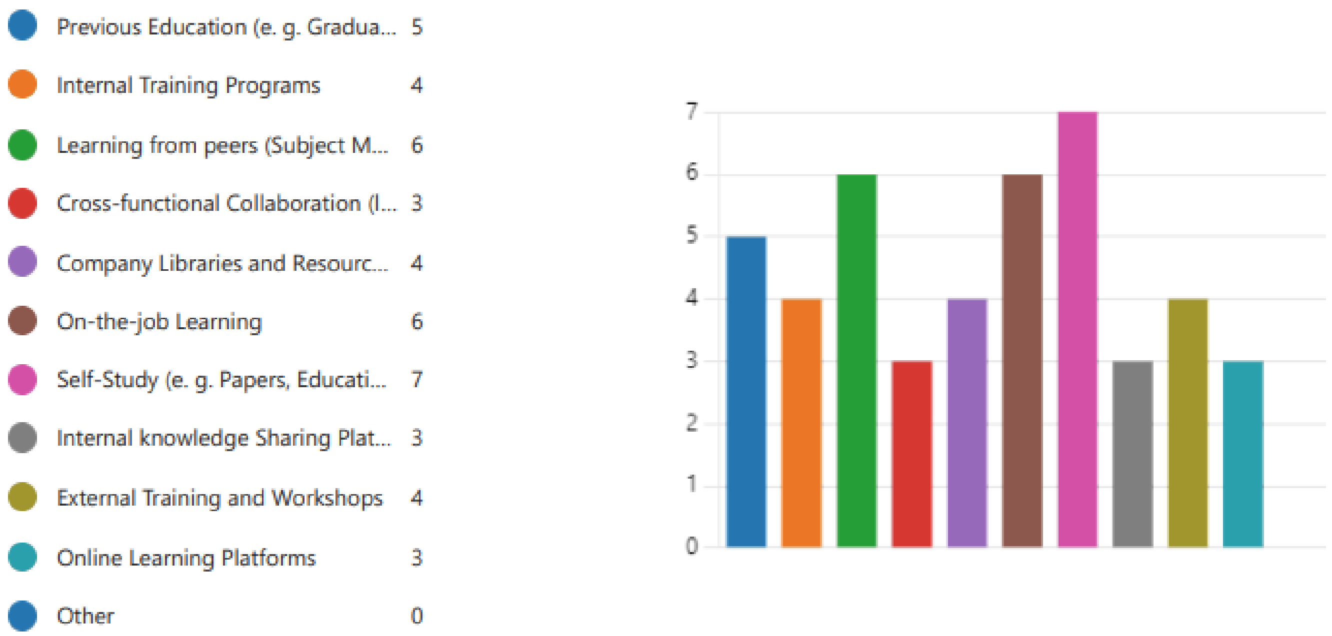

Figure 75 IT - Source of knowledge

34. Do individuals in **R&D (Research and Development) / Innovation** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

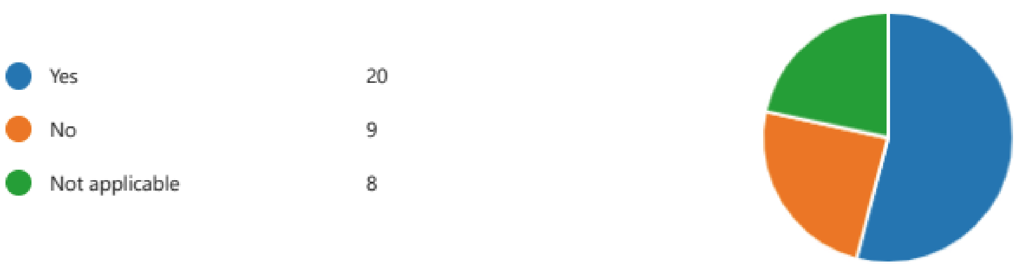

Figure 76 R&D - Hydrogen-related activites

35. Which knowledge should people in **R&D (Research and Development)/ Innovation** roles have?

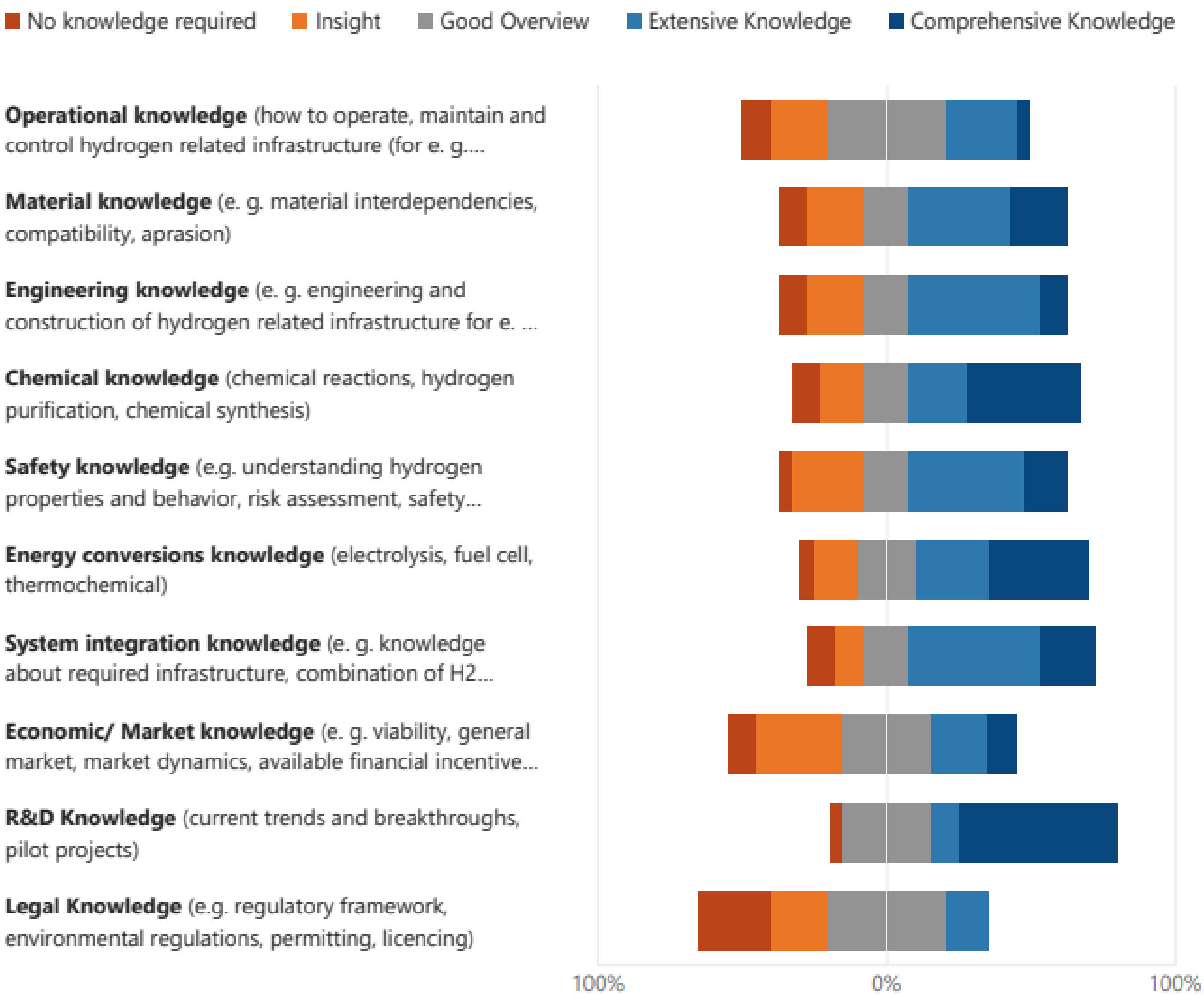

Figure 77 R&D - Knowledge

36. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **R&D (Research and Development)/ Innovation**?

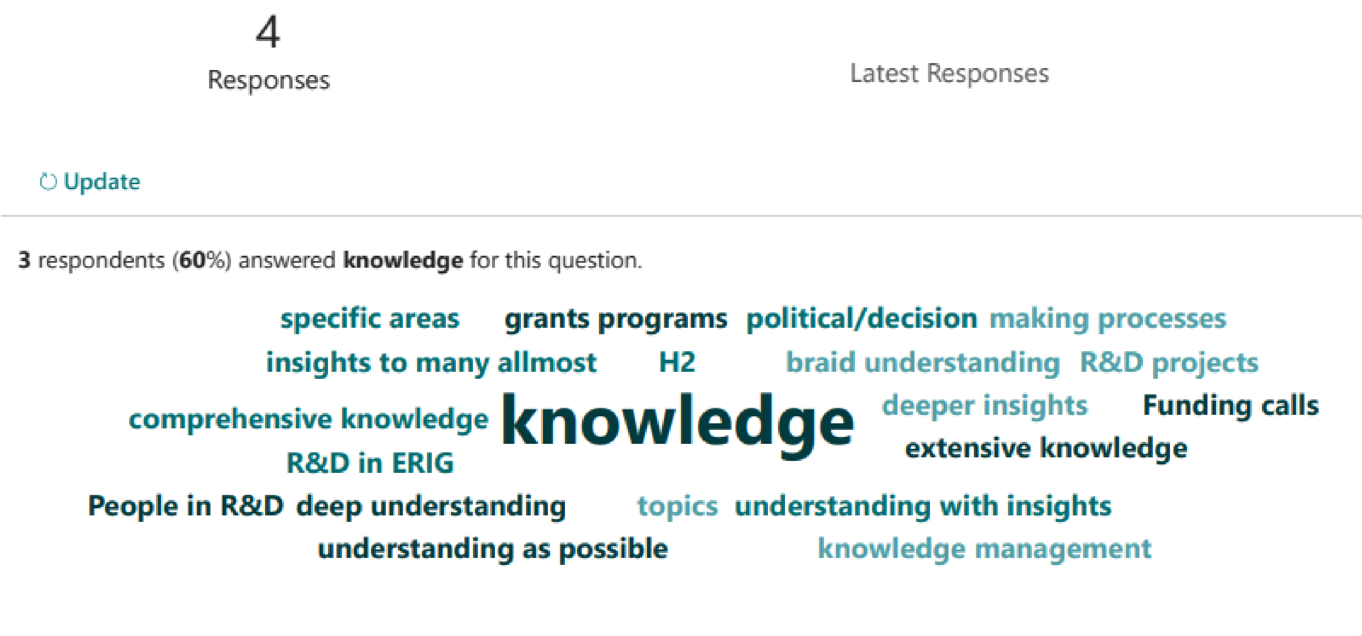

Figure 78 R&D - Other knowledge

37. Where should people in **R&D (Research and Development)/ Innovation** roles get their knowledge from?

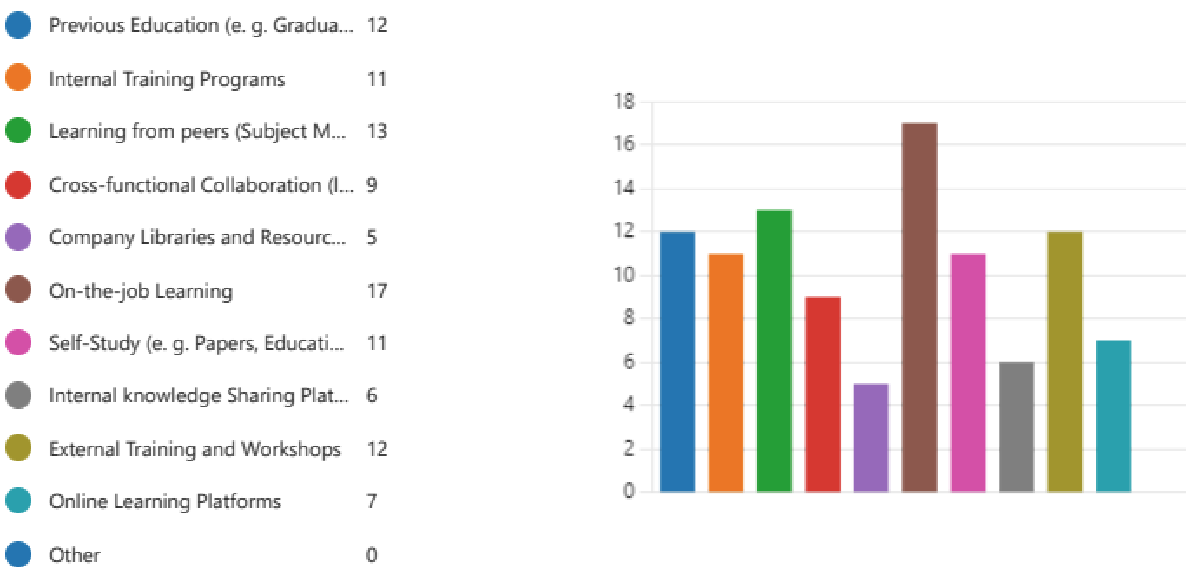

Figure 79 R&D - Source of knowledge

38. Do individuals in **Quality and HSE (Health, Safety and Environment)** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

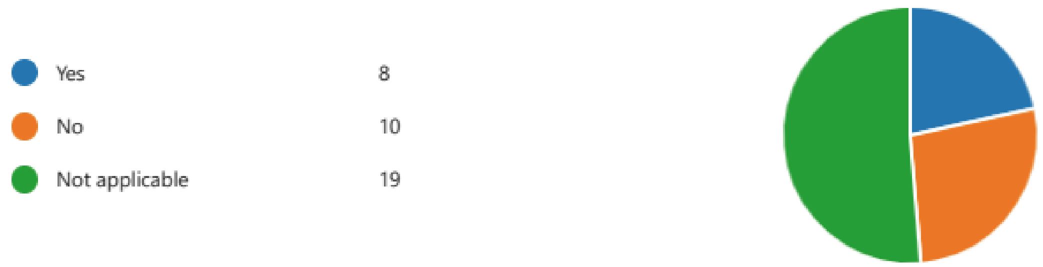

Figure 80 Quality and HSE - Hydrogen-related activities

39. Which knowledge should people in **Quality and HSE (Health, Safety and Environment)** roles have?

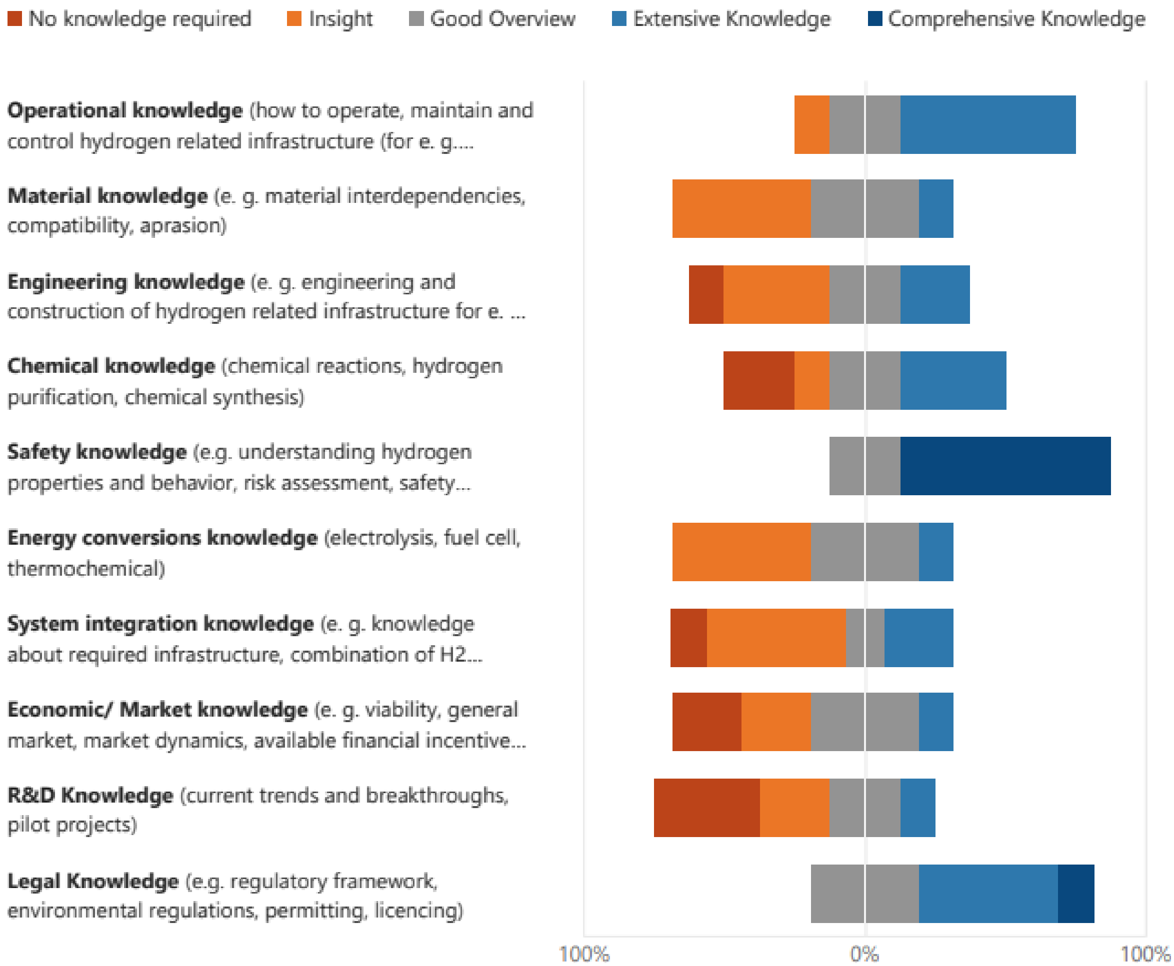

Figure 81 Quality and HSE - Knowledge

40. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **Quality and HSE (Health, Safety and Environment)**?

Figure 82 Quality and HSE - Other knowledge

41. Where should people in **Quality and HSE (Health, Safety and Environment)** roles get their knowledge from?

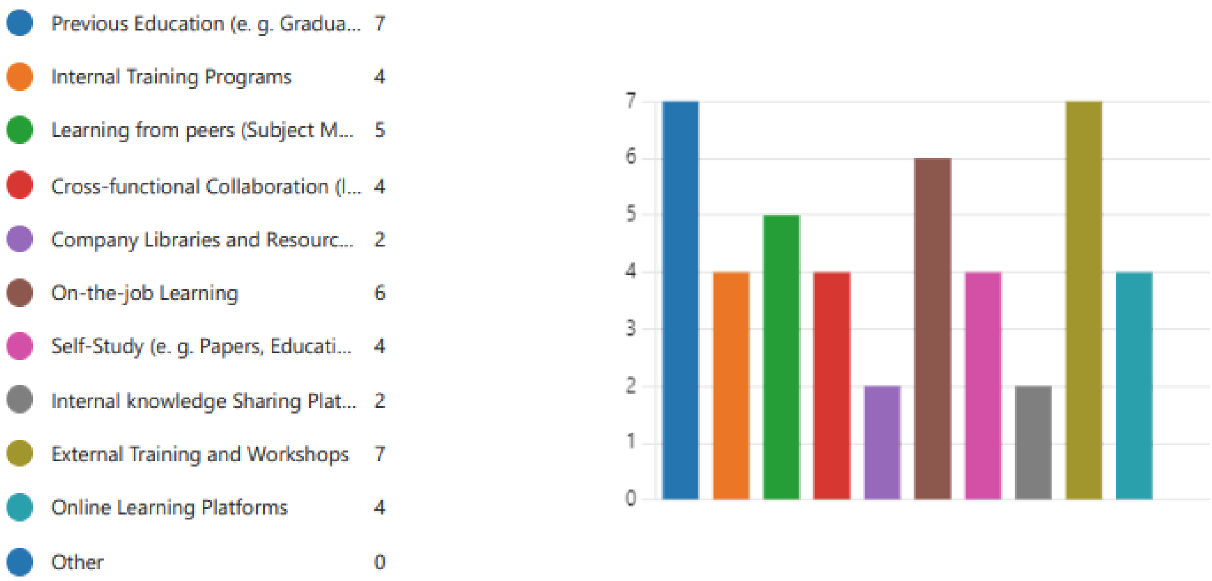

Figure 83 Quality and HSE - Source of knowledge

42. Do individuals in **Mid- and First-Level Management** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

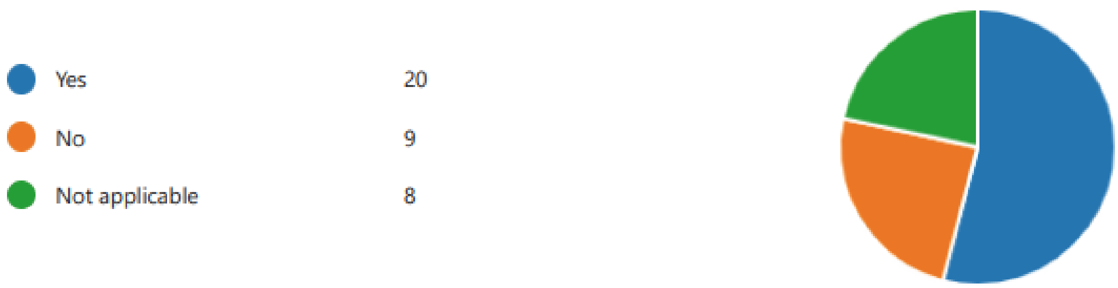

Figure 84 Mid-and First-Level Management - Hydrogen-related activities

43. Which knowledge should people in **Mid-and First-Level Management** roles have?

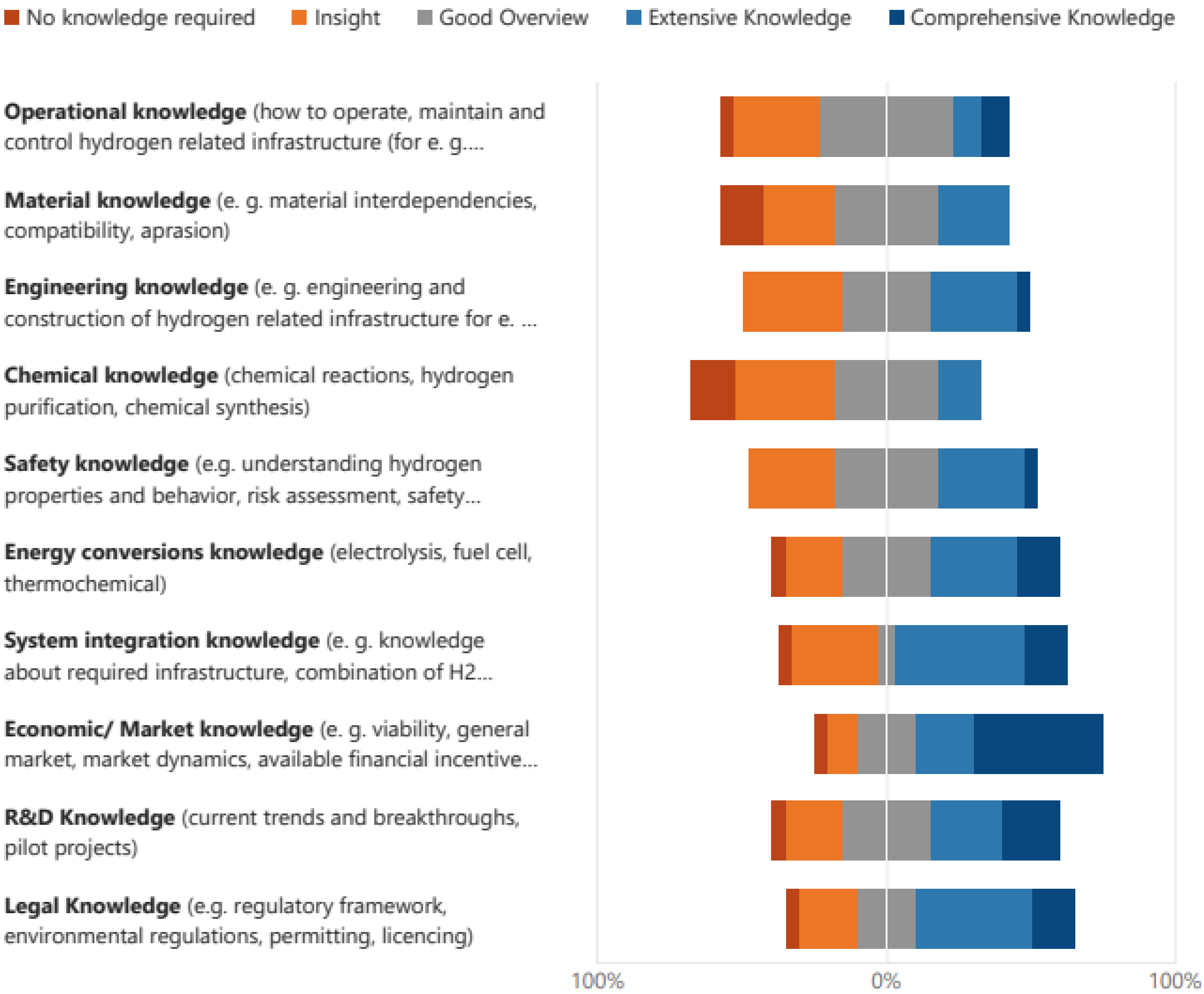

Figure 85 Mid-and First-Level Management - Knowledge

44. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **Mid-and First-Level Management**?

6
Responses

Latest Responses

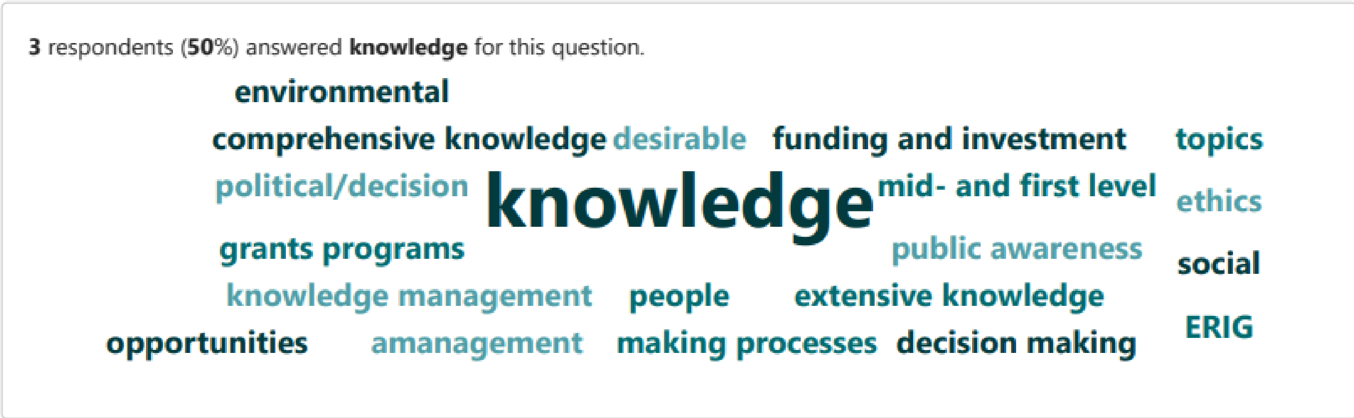

Figure 86 Mid-and First-Level Management - Other knowledge

45. Where should people in **Mid-and First-Level Management** roles get their knowledge from?

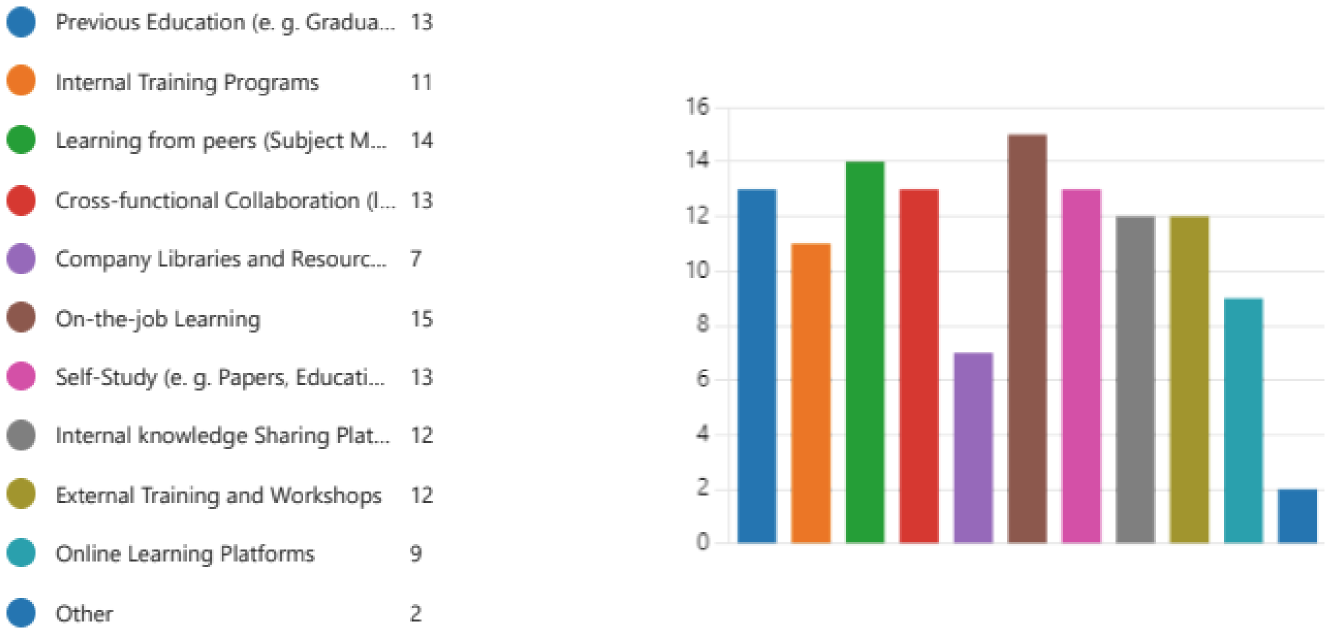

Figure 87 Mid-and First-Level Management - Source of knowledge

46. Do individuals in **Top-Level Management** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

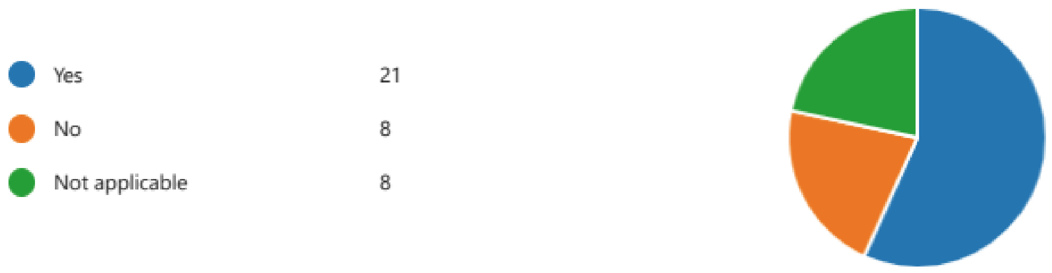

Figure 88 Top-Level Management - Hydrogen-related activities

Figure 89 Top-Level Management - Knowledge

48. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **Top-Level Management**?

5
Responses

Latest Responses

Figure 90 Top-Level Management - Other knowledge

49. Where should people in **Top-Level Management** roles get their knowledge from?

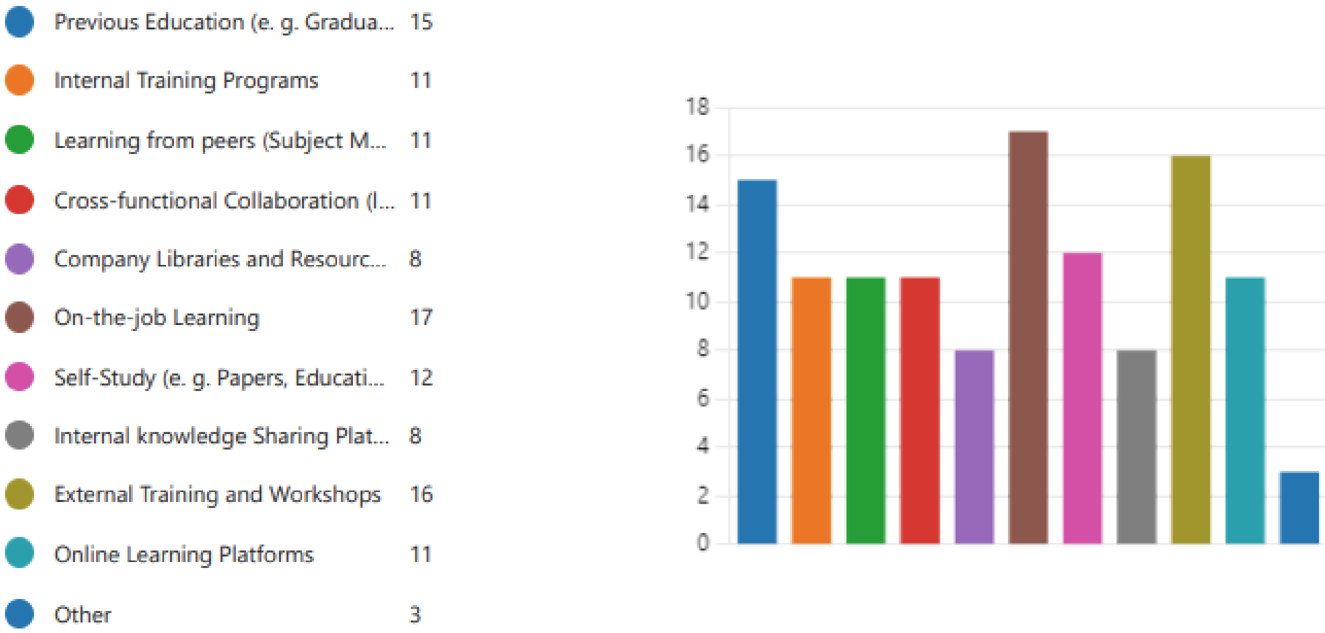

Figure 91Top-Level Management - Source of knowledge

50. Do individuals in **HR (Human Resources)** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

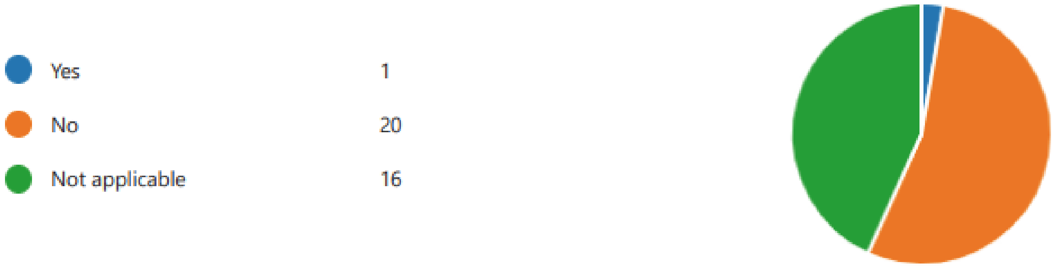

Figure 92 HR - Hydrogen-related activities

51. Which knowledge should people in **HR (Human Resources)** roles have?

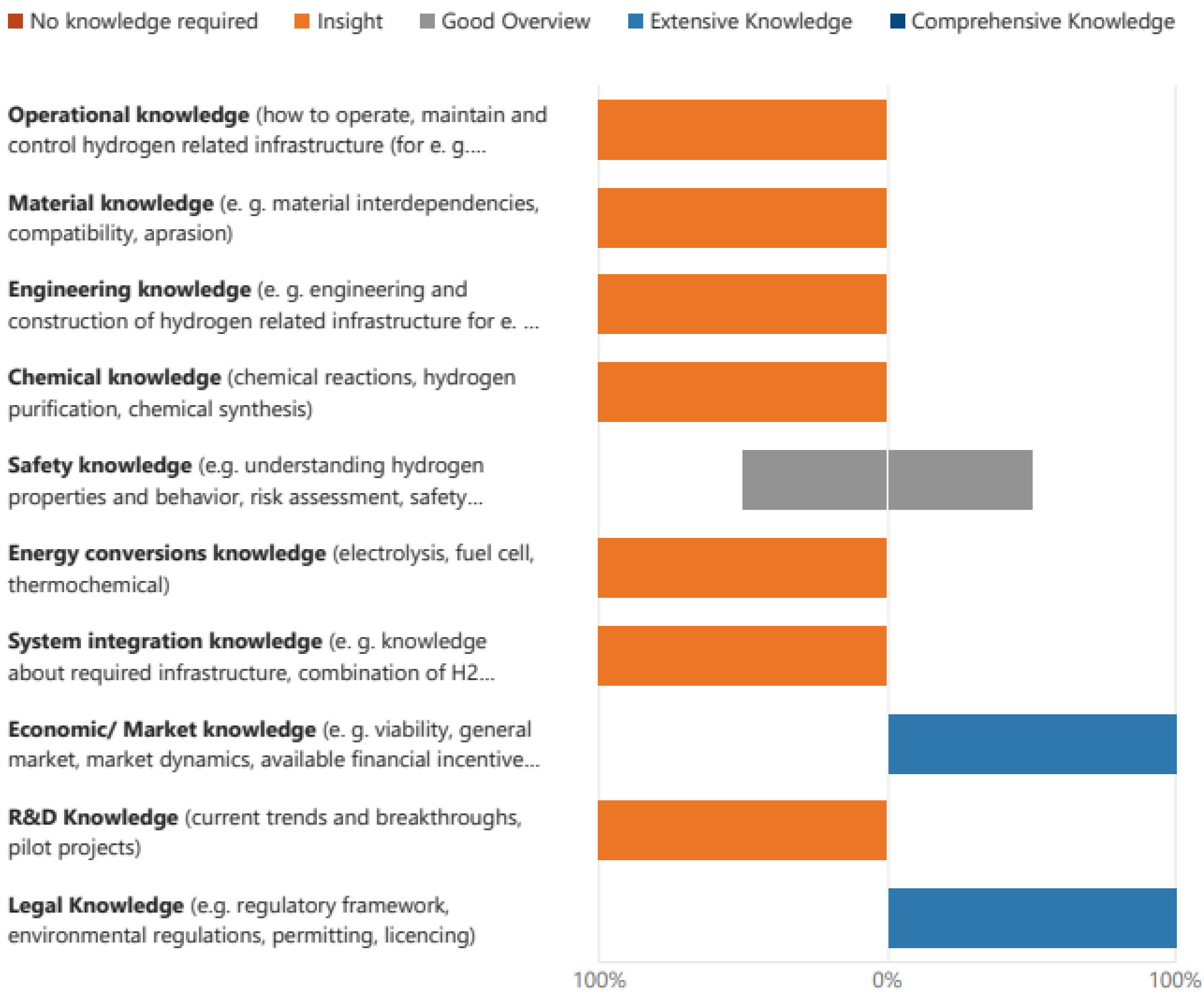

Figure 93 HR - Knowledge

52. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **HR (Human Resources)**?

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Responses

Latest Responses

Figure 94 HR - Other knowledge

53. Where should people in **HR (Human Resources)** roles get their knowledge from?

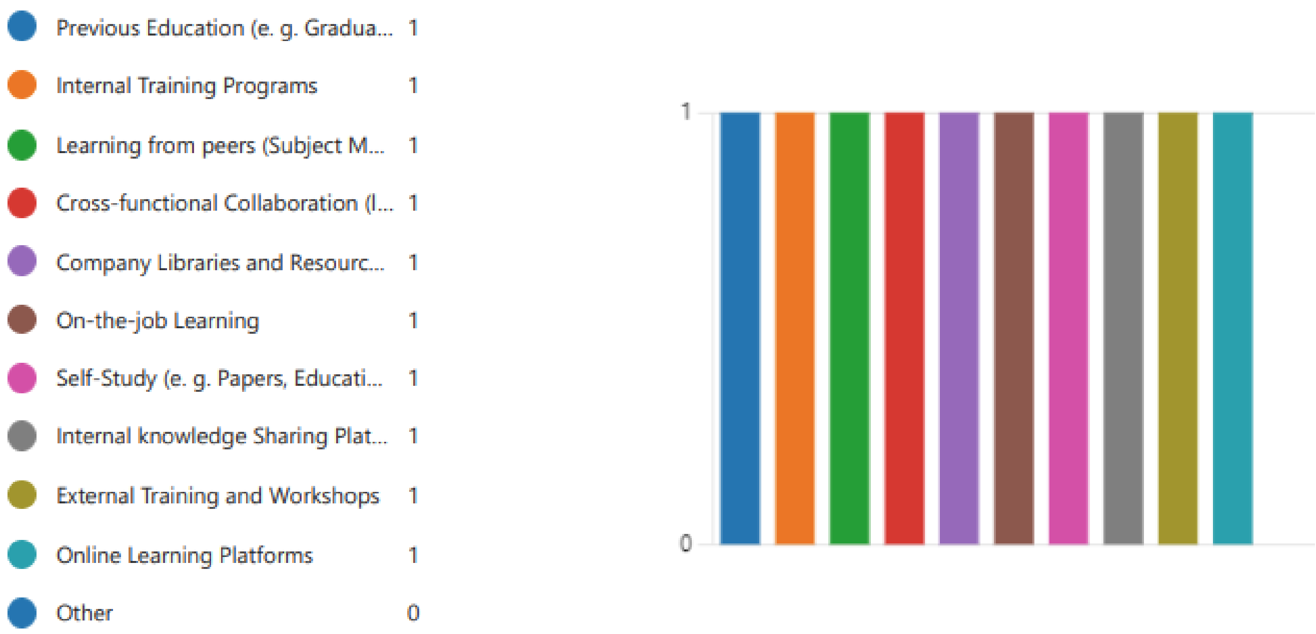


Figure 95 HR - Source of knowledge

54. Do individuals in **Legal Management** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

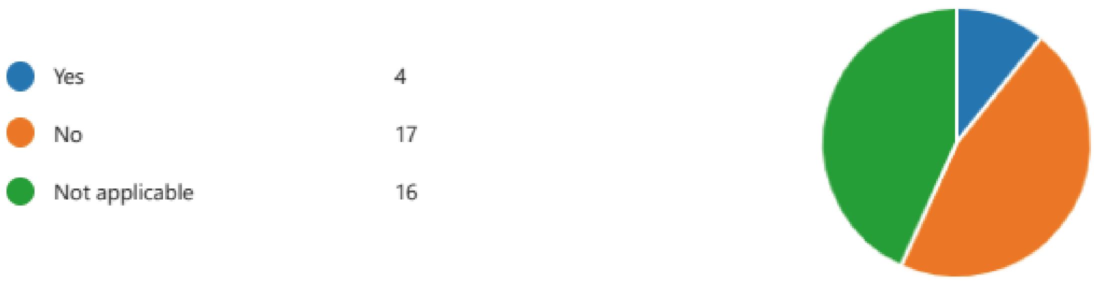


Figure 96 Legal Management - Hydrogen-related activites

55. Which knowledge should people in **Legal Management** roles have?

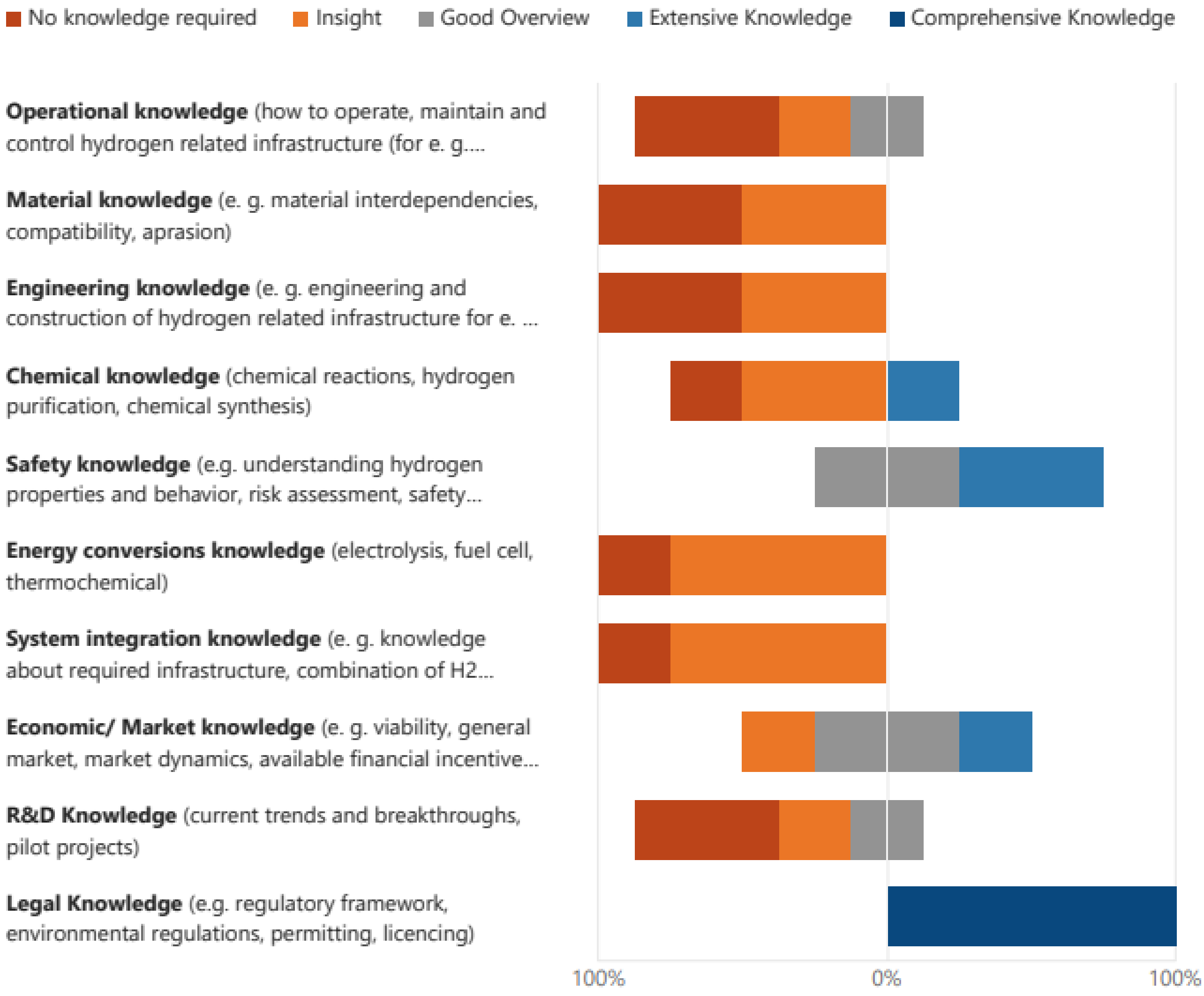


Figure 97 Legal Management - Knowledge

56. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **Legal Management**?

Figure 98 Legal Management - Other knowledge

57. Where should people in **Legal Management** roles get their knowledge from?

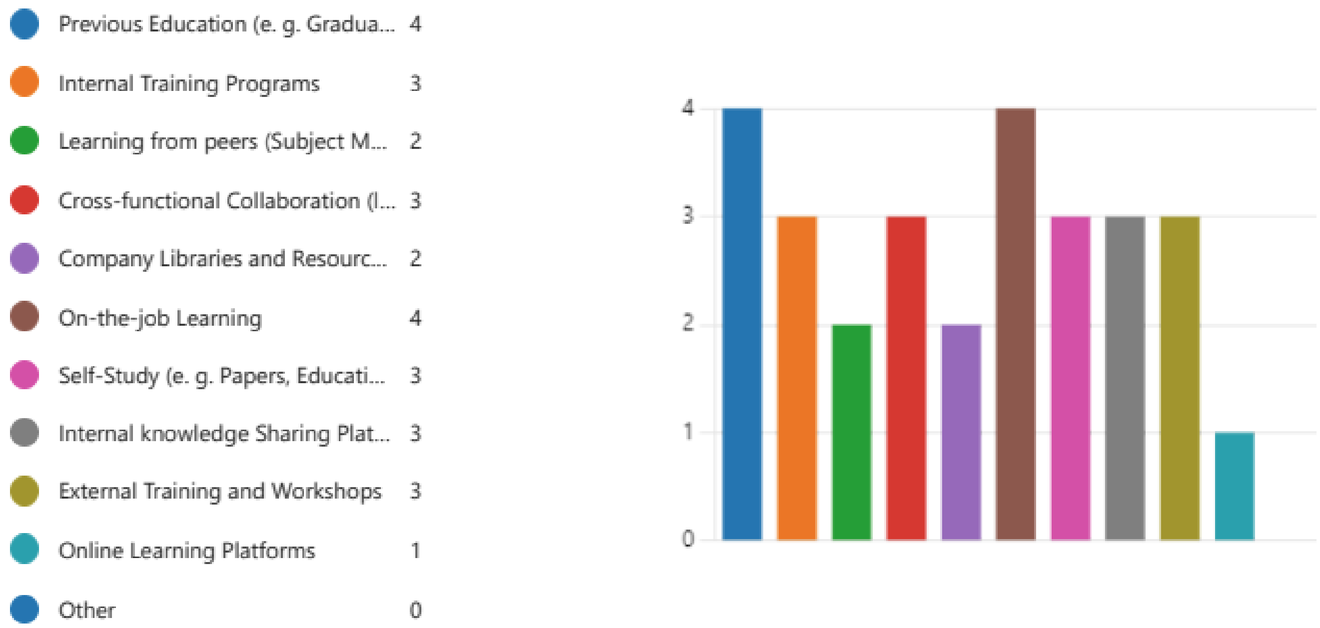


Figure 99 Legal Management - Source of knowledge

58. Do individuals in **Operational Logistics** roles currently (or shortly ~ 2 years) have any involvement with hydrogen-related activities within your organization?

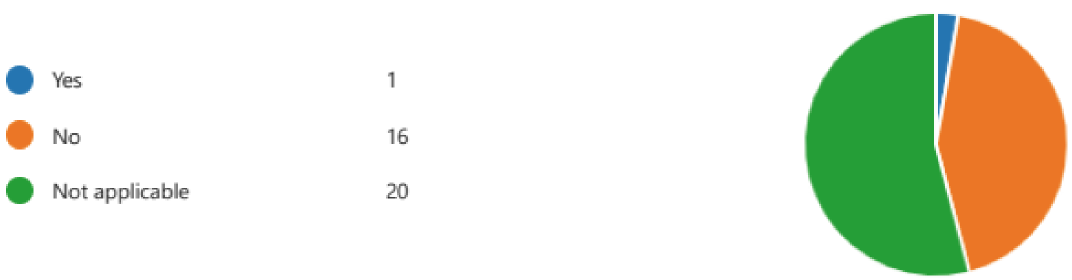


Figure 100 Operational Logistics - Hydrogen-related activites

59. Which knowledge should people in **Operational Logistics** roles have?

Figure 101 Operational Logistics - Knowledge

60. Is there knowledge that wasn't included in the last question, that would however also be required by people in the role of **Operational Logistics**?

Figure 102 Operational Logistics - Other knowledge

61. Where should people in **Operational Logistics** roles get their knowledge from?

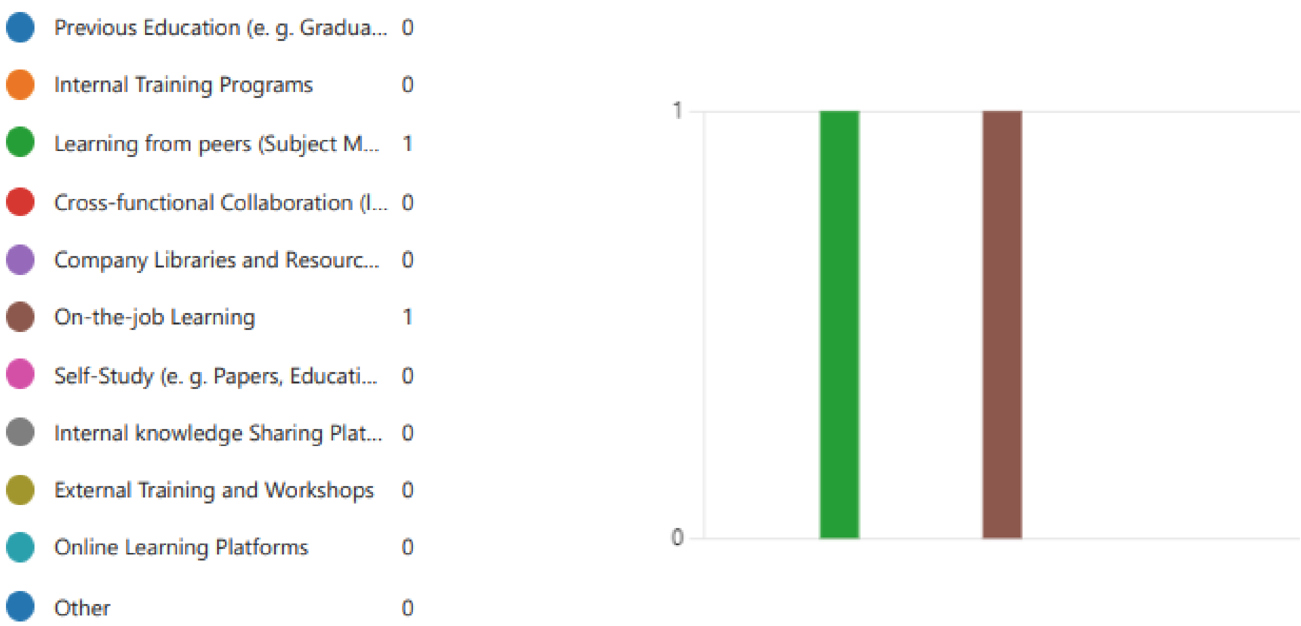


Figure 103 Operational Logistics - Source of knowledge

62. Is there a role that was missing from the questions above?

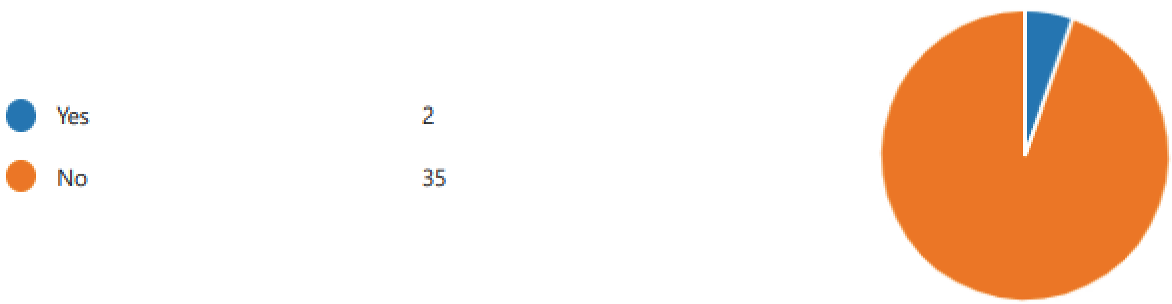


Figure 104 Other roles

63. Which role was not included, and what specific knowledge does this role require?

2
Responses

Latest Responses

Figure 105 Other knowledge

64. Which Work Package are you participating in Hy2Market

Figure 106 Work Package participation

65. What are the challenges you are facing within the completion of the task so far?

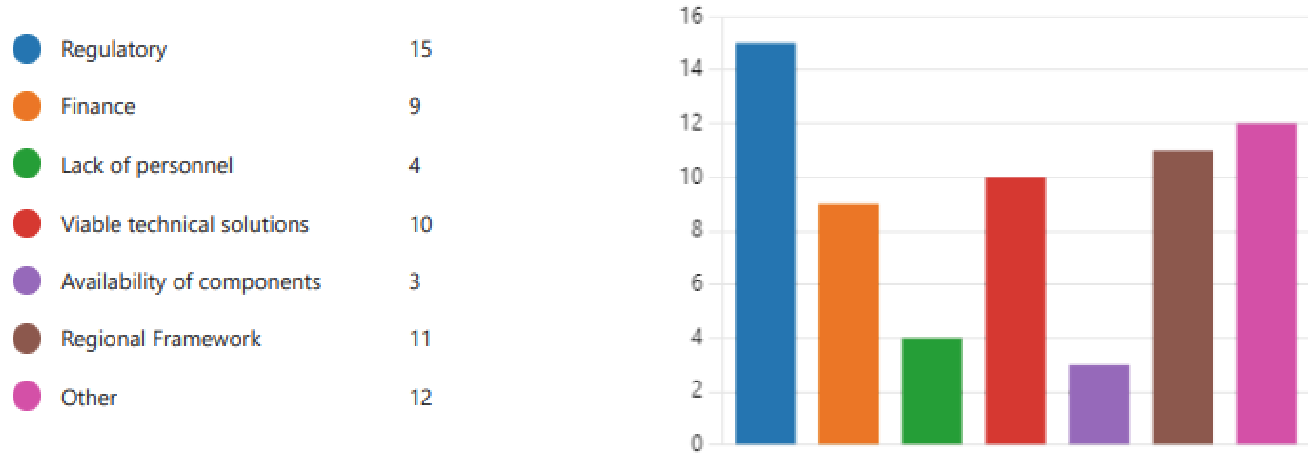


Figure 107 Challenges

66. What challenges do you foresee for the rest of the project?

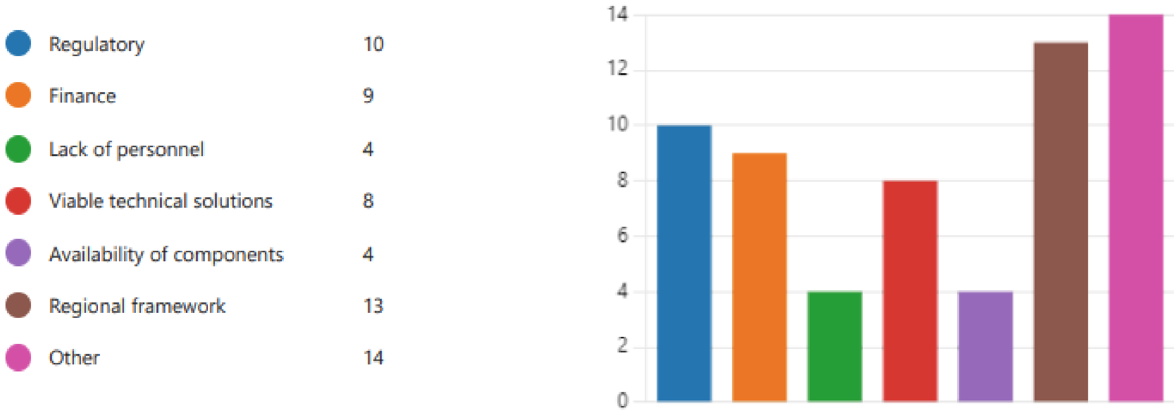
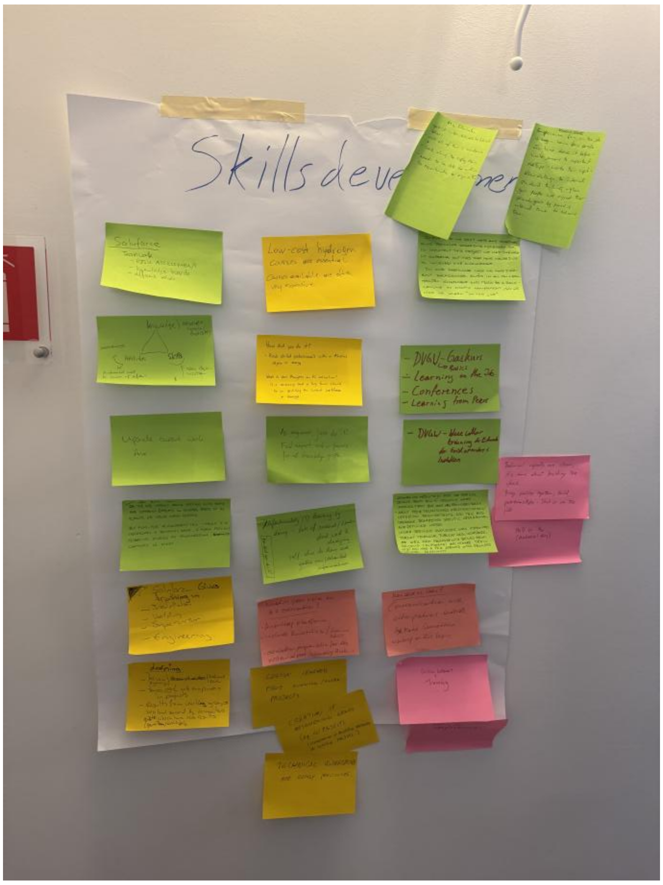
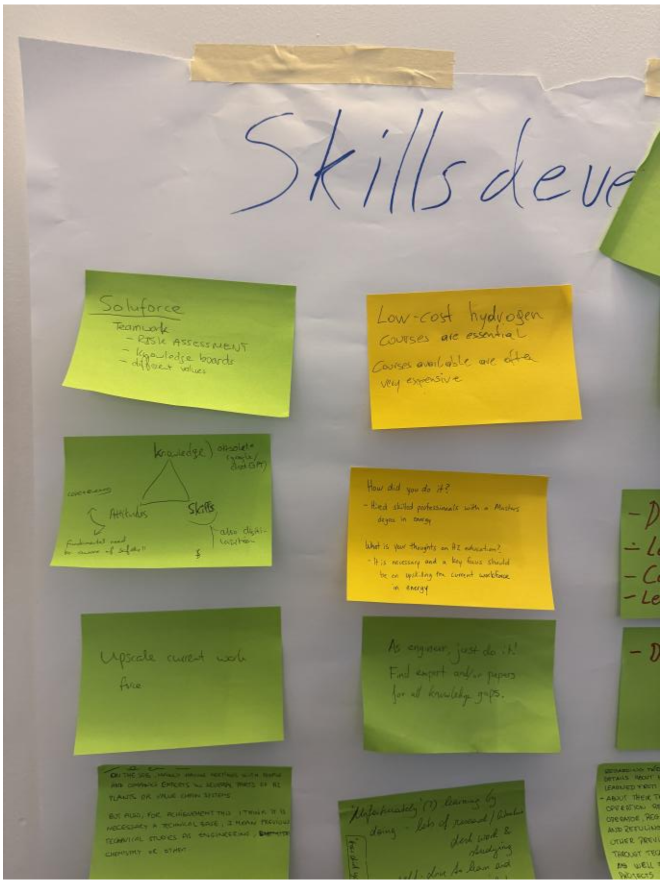
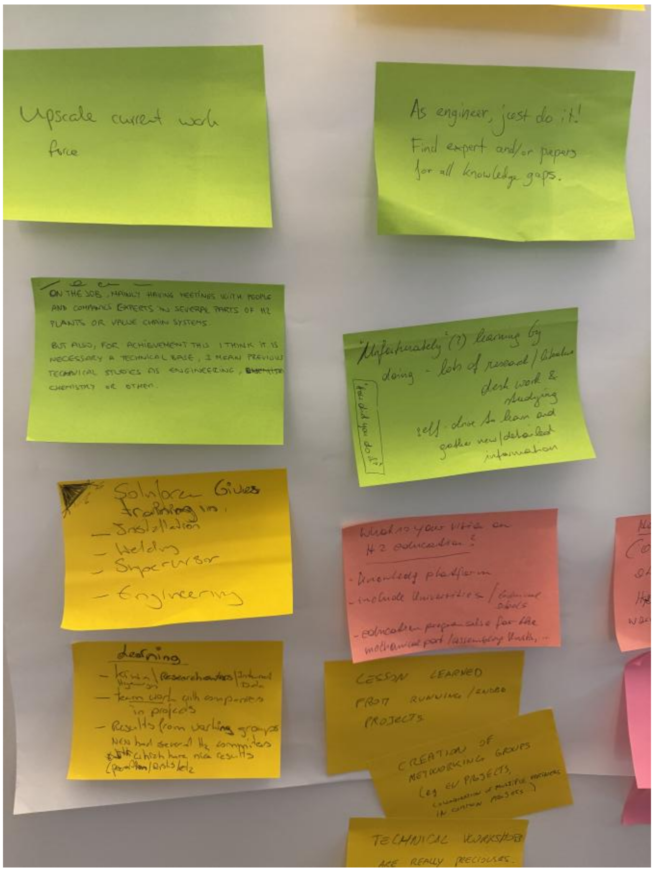


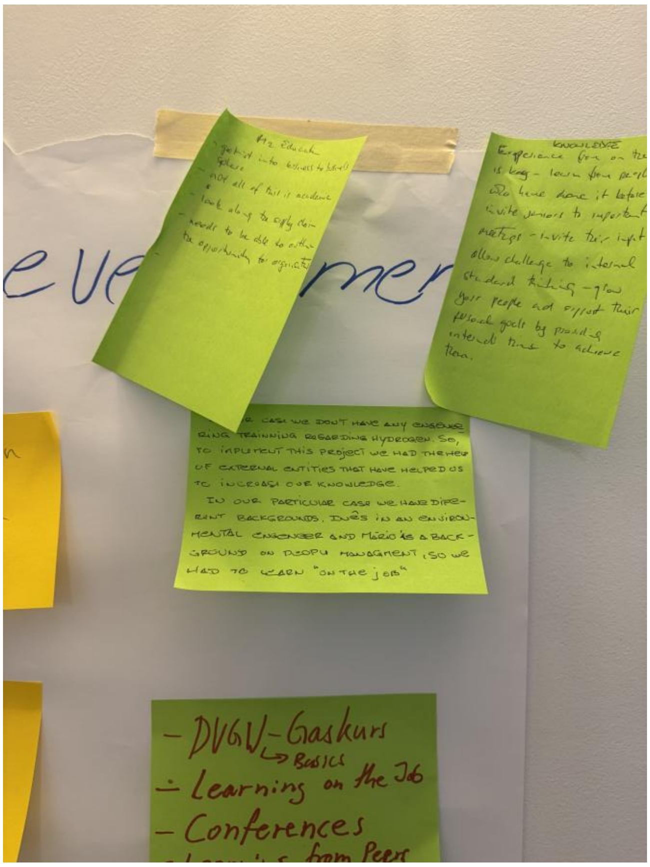
Figure 108 Foreseen challenges

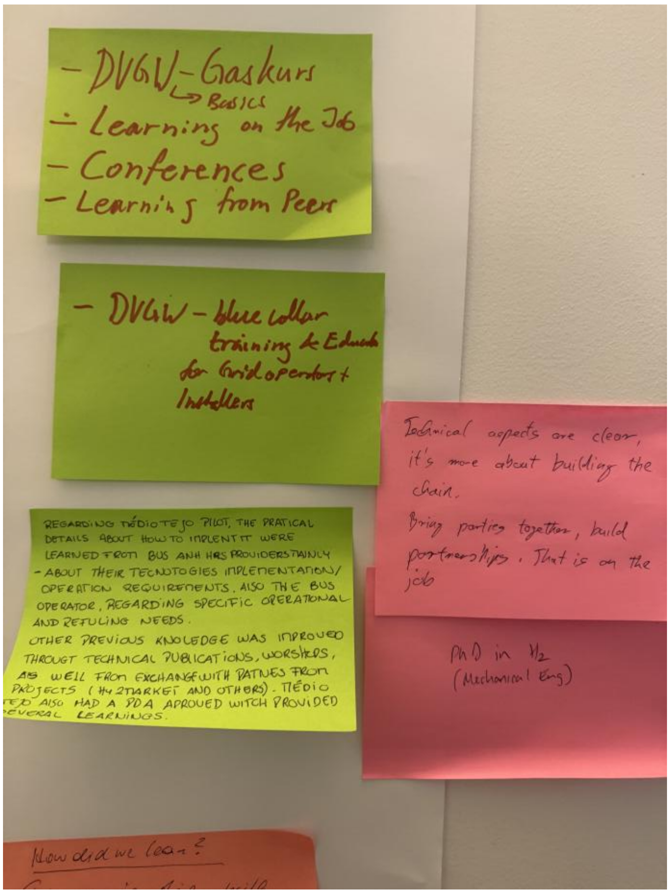
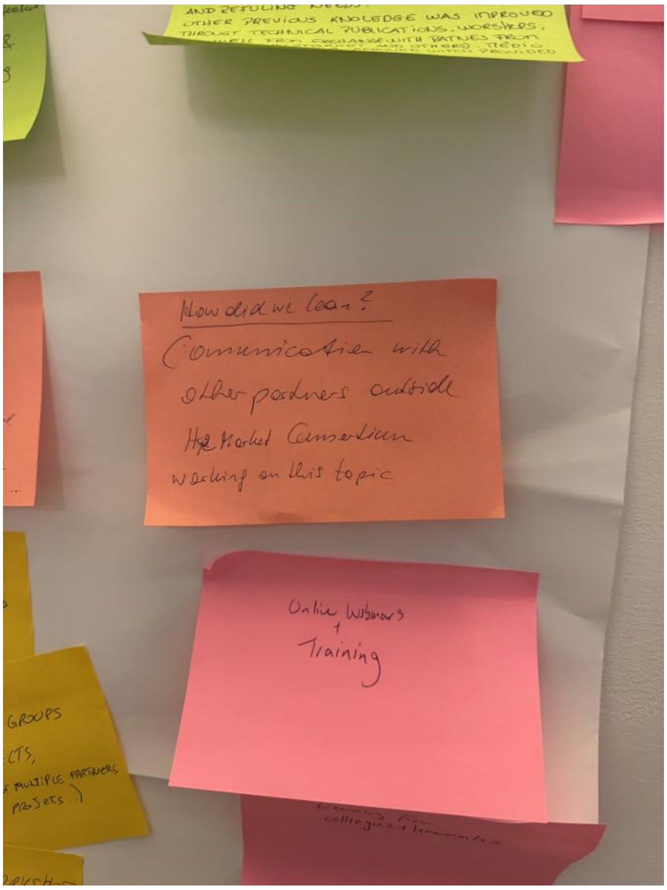
Appendix D – Sticky Notes on Skills Development from the Hy2Market General Assembly






Upscale current work force
As engineer, just do it! Find expert and/or papers for all knowledge gaps.
ON THE JOB, MAINLY HAVING MEETINGS WITH PEOPLE AND COMPANIES EXPERTS IN SEVERAL PARTS OF H2 PLANTS OR VALUE CHAIN SYSTEMS.
BUT ALSO, FOR ACHIEVEMENT THIS I THINK IT IS NECESSARY A TECHNICAL BASE, I MEAN PREVIOUS TECHNICAL STUDIES AS ENGINEERING, CHEMISTRY OR OTHER.
"Unfortunately" (?) learning by doing - lots of research / literature desk work & studying
self-drive to learn and gather new/detailed information
Solidforce Gives training in:
- Installation
- Welding
- Supervisor
- Engineering
What is your vision on H2 education?
- Knowledge platform
Learning
LESSON LEARNED FROM RUNNING / ENDED PROJECTS
CREATION OF NETWORKING GROUPS
TECHNICAL WORKSHOPS ARE REALLY PRECIOUS


KNOWLEDGE
IN OUR CASE WE DON'T HAVE ANY ENGINEERING TRAINNING REGARDING HYDROGEN. SO, TO IMPLEMENT THIS PROJECT WE HAD THE HELP OF EXTERNAL ENTITIES THAT HAVE HELPED US TO INCREASE OUR KNOWLEDGE.
IN OUR PARTICULAR CASE WE HAVE DIFFERENT BACKGROUNDS, INÊS IN AN ENVIRONMENTAL ENGINEER AND MÁRIO AS A BACKGROUND ON PEOPLE MANAGMENT, SO WE HAD TO LEARN "ON THE JOB"
- DVGW - Gaskurs → Basics
- Learning on the Job
- Conferences


- DVGW - Gaskurs
Basics
- Learning on the Job
- Conferences
- Learning from Peers
- DVGW - blue collar training & Education for Grid operators + Installers
Technical aspects are clear, it's more about building the chain.
Bring parties together, build partnerships. That is on the job
PhD in H_2
(Mechanical Eng)
How did we lean?

How did we lean?
Communication with other partners outside Hy2Market Consortium working on this topic
Online Webinars
+
Training

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