

Exploring the Landscape of Hydrogen Professional Development Courses for Workforce Readiness: A Web-Scraping and Thematic Analysis Study

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Abstract

As global energy demand continues to rise and lower-emission technologies gain traction, the need for a hydrogen-ready workforce across engineering and energy systems has intensified. As hydrogen technologies mature and diversify, ongoing professional development (PD) training is essential for engineers and clean energy professionals to remain current with evolving technologies, standards, and applications. Despite increasing policy attention and technological progress, hydrogen PD training offerings vary widely in provider distribution, level of curricular integration, and alignment with validated learning outcomes. This study presents a systematic landscape analysis of 164 hydrogen-related training courses using web-scraping and thematic analysis methods. Course data were collected from publicly available online sources provided by professional societies, industry organizations, and private training entities. From these initial findings, six thematic course domains and four provider types were identified from the course metadata. Hydrogen Safety, Risk Management, and Emergency Response represented the largest thematic category (25%), followed by Hydrogen Technology, Engineering Systems, and Operations (18%); Cross-Cutting Renewable Energy Systems and Energy Transition (17%); Hydrogen Science, Fundamentals, and Chemistry (16%); Hydrogen Applications and End-Use Integration (14%); and Hydrogen Economy, Policy, Markets, and Business Applications (9%). Provider analysis of the sample included Industry and Professional Organizations (62%) offering the majority of courses, followed by Massive Open Online Courses (MOOCs, 31%), Industry Research Institutes (6%), and independent Training Providers (2%). Provider-by-theme patterns indicated that specialized safety training dominated the course landscape and was primarily delivered by professional organizations. Overall, the findings suggest a need for more competency-aligned and integrated training pathways spanning the hydrogen value chain. The results highlight the roles of professional societies, independent training entities, and universities in strengthening the hydrogen workforce pipeline through professional training. Course providers can drive more effective, industry-aligned PD pathways that keep pace with rapidly evolving energy system development.

Keywords: hydrogen education, clean energy, low-carbon, professional development, workforce readiness, web-scraping, thematic analysis

1. Introduction

Hydrogen is increasingly recognized as a central pillar of global decarbonization strategies, with governments, industry alliances, and international agencies identifying it as essential for achieving net-zero energy systems [1, 2]. As production, storage, transport, and end-use technologies accelerate, workforce readiness has emerged as a critical constraint, with recent analyses highlighting shortages in safety, engineering, operational, and regulatory competencies across the hydrogen value chain [3, 4]. In response, initiatives such as the Hydrogen Education for a Decarbonized Global Economy (H₂EDGE) have emerged, supported by the Department of Energy (DOE)'s Hydrogen and Fuel Cell Technology Office and the Low-Carbon Resources Initiative to advance university instruction and professional development [5, 6]. Although major

initiatives such as the EU Hydrogen Skills Strategy, U.S. DOE Hydrogen Program workforce planning, and national skill frameworks stress the urgency of developing a hydrogen-capable workforce, existing education and training systems have not expanded at the same pace as technological innovation. This has resulted in fragmented curricula, inconsistent training quality, and an underdeveloped vocational pipeline, creating uncertainty about whether current learning ecosystems can support large-scale hydrogen deployment [7, 8].

Despite the proliferation of policy frameworks and competency models, there is a lack of empirical evidence to interpret the objectives, technical focus, modality, accessibility, assessment, or completion verification of publicly available hydrogen training for professionals. This study focuses specifically on the hydrogen PD training course landscape. Unlike university engineering programs accredited by the Accreditation Board for Engineering and Technology (ABET) [9], hydrogen PD offerings are not degree-granting and are not governed by formal academic program criteria. While academic programs and professional education play complementary roles in engineer development, their objectives, structures, and evaluation criteria are distinct. Publications on hydrogen education outline required competencies, including hydrogen safety, system design, fuel cell integration, infrastructure operations, and policy literacy. However, those domains do not systematically document what courses are currently offered, which thematic domains they cover, how capabilities are assessed, or who provides them [10, 11]. Without comprehensive mapping, it remains unclear whether existing course offerings align with documented workforce needs or whether gaps persist across technical, scientific, economic, and cross-cutting domains.

To address this need, this study proposes a scalable approach to specifically assess education and training content for adult professionals by utilizing web scraping and thematic analysis to identify and classify hydrogen professional courses, examine their distributions across thematic categories, and compare course providers, including Massive Open Online Course (MOOC) platforms, professional organizations, industry research institutes, and training providers. By establishing a data-driven profile of the current hydrogen training ecosystem, the study acts as a model to encourage standardized analysis of course offerings and contributes foundational evidence that can guide strategic planning in hydrogen workforce development.

2. Literature Review

2.1 Foundations of Hydrogen Professional Development

Hydrogen professional training operates within a distinct educational ecosystem that differs fundamentally from degree-granting academic programs. Hydrogen-related PD learning opportunities included short courses, online modules, webinars, seminars, workshops, and conference-based training. PD courses are typically structured to provide continuing education tied to licensure renewal, commonly structured around Professional Development Hours (PDH) or Continuing Professional Competency (CPC) expectations coordinated through state licensing systems and organizations such as the National Council of Examiners for Engineering and Surveying [12]. Importantly, effective professional learning for engineers centers on engagement, lifelong learning competencies, and competency-based outcomes [13]. Engagement is fostered through social, practice-oriented environments that connect engineers with peers and industry experts to address real-world hydrogen challenges. Given the rapid evolution of hydrogen technologies and regulations in the early 2020s, self-regulation, adaptability, and

information literacy are essential. Differing from cumulative academic progression, professional development prioritizes demonstrable, practice-relevant competencies through active, project-, and problem-based learning. PD formats range from short-term modules to year-long programs, with short, modular training particularly suited to rapidly emerging hydrogen fields, where timely, applicable knowledge is critical [13].

In contrast to university degree programs and trade certifications, hydrogen PD courses are effective when deliberately segmented to meet distinct participant needs, instead of being designed for a uniform academic learner profile. Three primary groups are target participants for hydrogen PD. First, practicing engineers, particularly licensed Professional Engineers, seek technically rigorous, practice-relevant training to maintain licensure while updating competencies in areas of safety, codes and standards, system design, and regulatory context [12]. For this group, technical depth, direct applicability to current practice, and credible documentation of course completion are essential. Second, non-licensed technical professionals (e.g., project managers, technicians, policy analysts, faculty, or engineers outside licensure jurisdictions) pursue PD for skill enhancement, role transition, or cross-disciplinary fluency [9]. Courses for this segment often combine introductory foundations with applied concepts, case studies, and systems-level perspectives on emerging and existing hydrogen technologies. Third, the general public and non-technical stakeholders are served through offerings that emphasize foundational literacy, safety awareness, and broader societal or environmental implications, typically with reduced technical depth and limited assessment requirements [14]. Recognizing these segments is important for interpreting PD course availability and content, as the curriculum may not serve all audiences equally.

2.2 Empirical Studies of Hydrogen Workforce and Training Needs

While there is significant uncertainty on the pace and scale of hydrogen production and use, empirical studies on clean-energy workforce development consistently indicate that training provision is lagging projected labor demand and that educational offerings are fragmented across sectors. Industry-focused work from China and Australia shows that enterprises view collaboration with education providers as essential, although this relationship is not yet developed by stakeholders. Zheng, et al. [15] found that hydrogen firms' willingness to engage in industry–education integration is strongly driven by perceived resource benefits and constrained by cost risks, while Beasy, et al. [16] reported that nearly 90% of Australian hydrogen stakeholders consider hydrogen training necessary yet identify substantial gaps in the topics covered. Case studies of national clean energy systems further emphasize the need for coordinated knowledge infrastructures and programs. Dawood, et al. [17] argued for an Australian hydrogen knowledge-sharing platform to overcome siloed project information. McCoy, et al. [18] projected large employment growth in hydrogen exports and associated infrastructure. Global modeling showed that clean energy will generate net job gains, but is already constrained by shortages in STEM and vocational skills [19]. At the micro level, education-intervention studies demonstrate that targeted hydrogen assignments and laboratory courses can significantly improve students' technical knowledge, safety awareness, and willingness to engage with hydrogen technologies [20, 21]. Emerging modalities like VR-based training in energy audits highlight scalable approaches to experiential learning when access to physical infrastructure is limited [22].

Beyond hydrogen-specific content, broader engineering and energy-transition research clarifies the kinds of competencies that hydrogen professional courses need to address and how provider contexts and learner pathways shape workforce development. Work on transversal and role-specific competencies [23, 24] shows that employers prioritize problem solving, communication, client focus, and role-tailored profiles, underscoring the need for hydrogen training that integrates technical, safety, and sociotechnical skills. Studies of vocational and climate craft careers [25] and regional transition policies [26] highlight both the critical importance of tradespeople and community colleges for low-carbon infrastructure and the persistent cultural and structural barriers that make these pathways appear unattractive or ill-fitting to many young people. Sociotechnical transition research on hydrogen fuel cells [27] and macro-level analyses of artificial intelligence (AI) and new energy systems [28] similarly stress that policy environments, labor supply characteristics, and stakeholder expectations determine how quickly new technologies diffuse and whether workforce pipelines keep pace.

The empirical literature identifies what skills are needed and where system-level gaps exist, but it does not systematically map the actual landscape of publicly available hydrogen professional courses, nor does it compare how different provider categories (MOOCs, private training firms, industry institutes, professional societies, and universities) distribute offerings across safety, technology, policy, science, and cross-cutting energy-transition domains. The present study outlines an approach to address this gap by using web-scraping and thematic analysis to characterize the volume, thematic focus, and provider patterns of hydrogen-related professional courses, thereby linking macro-level workforce projections and competency frameworks to the concrete training opportunities currently accessible to learners and employers.

2.3 Insight from Systematic Industry Workforce Reports

Across international standards bodies, government programs, and hydrogen workforce development initiatives, industry reports uniformly emphasize that the emerging hydrogen economy demands a highly skilled, safety-oriented, and technologically adaptive workforce. Foundational documents such as ISO or TR 15916 [29], the U.S. DOE Hydrogen Program [30], and the IEA Hydrogen TCP [1] establish core expectations for hydrogen-specific knowledge, including thermophysical properties, storage behavior, safety risks, electrolysis systems, and fuel cell operation. These frameworks highlight hydrogen's unique hazards (e.g., wide flammability ranges and material embrittlement), and call for training programs that integrate technical competence, regulatory compliance, and operational safety. Similarly, ABET's Engineering Accreditation Criteria [9] reinforces competency-oriented education emphasizing experimentation, risk mitigation, ethical and professional responsibility, and communication competencies that align closely with hydrogen workforce needs. Yet, despite defining what learners need to know, these documents do not identify which professional courses are actually available, who provides them, or how they are distributed across the hydrogen value chain.

Industry workforce strategies from multiple regions further demonstrate the scale and urgency of hydrogen skills development. Reports such as the Canadian Hydrogen Workforce Assessment [3], the UK Energy & Utility Skills Hydrogen Competence Framework [31], the Hydrogen Skills Alliance Framework [7], and the EU Green Skills for Hydrogen Initiative [32] provide detailed mappings of job roles, competency domains, and technical performance expectations. In the United States, these efforts are mirrored by programs such as the EPRI-led H2EDGE initiative [5], which targets university and professional curricula, and H2Skills, which

focuses on vocational training and safety standards for technicians. These international frameworks consistently identify acute shortages in technicians, system integrators, safety specialists, and engineers capable of supporting the hydrogen transition.

Similarly, the Scottish Hydrogen Skills Action Plan [33] and Europe's Clean Hydrogen Joint Undertaking Skills Agenda [32] highlight fragmentation in training availability, inconsistent credentialing pathways, and uneven regional access. These reports advocate modular micro-credentials, blended learning, simulation training, and cross-sector upskilling to bridge near-term workforce gaps. However, despite offering comprehensive competency blueprints, they acknowledge that current hydrogen education offerings are scattered and uncoordinated.

These systematic reviews and industry reports reveal a critical gap in systematic analysis and review of professional courses. Although some hydrogen-related competencies and workforce needs are well-articulated, there is no empirical mapping of the professional courses currently offered across universities, MOOCs, industry training firms, or professional organizations. Existing course frameworks and technical guides implicitly illuminate a training ecosystem whose scope, thematic coverage, provider patterns, and accessibility remain undocumented. By empirically documenting the training *provided*, this study offers foundational evidence necessary to interpret workforce development trends and evaluate the alignment between course offerings and the hydrogen skills agenda outlined in international standards and industry workforce reports.

2.4 Systematic Reviews of Hydrogen Workforce and Education

Hydrogen education and workforce development literature consistently shows a widening gap between rapidly advancing hydrogen technologies and the availability of structured training and curricula. Systematic reviews and policy analyses [10, 11, 34-36] point to recurrent needs for knowledge and skills in hydrogen properties, safety, production, storage, transport, fuel cell systems, and systems integration, alongside professional competencies such as communication, teamwork, decision-making, and problem-solving. At the same time, national and regional energy-transition studies [37-39] highlight hydrogen's growing role in decarbonization, multi-energy systems, and industrial applications, stressing the need for complex integration of energy policy and greenhouse gas emissions markets alongside large-scale capacity building, vocational pathways, and re-training frameworks. Yet these reviews also emphasize that hydrogen and fuel cell content remains fragmented across education systems, underrepresented in curricula, and weakly linked to empirically validated learning outcomes. Despite conceptual work on competencies, employability, societal acceptance, and clean energy workforce transitions, there is almost no empirical mapping of the actual hydrogen professional course ecosystem, what courses exist, which themes they cover, and who provides them. Existing reviews do not systematically catalog publicly available hydrogen professional courses, nor do they compare offerings across provider categories such as MOOCs, industry training companies, industry research institutes, and professional organizations.

2.5 Research Objective

The purpose of this study is to systematically identify and analyze publicly available hydrogen-related professional courses using web-scraping and thematic analysis. By mapping course offerings across thematic domains and provider categories, the study aims to validate this approach to reveal patterns in the current hydrogen training ecosystem and evaluate how well

existing educational provision aligns with evolving workforce needs. This analysis addresses a critical empirical gap by providing an original overview of hydrogen professional course availability, distribution, and providers. To investigate the hydrogen training ecosystem, three research questions will be addressed:

Research Question 1. What hydrogen-related professional courses are publicly available, and how are these offerings distributed across thematic domains?

Research Question 2. To what extent do learning providers offer the hydrogen-related courses, and what does this distribution suggest about the hydrogen workforce development trend?

Research Question 3. How do provider categories differ in the distribution of hydrogen-related courses across thematic domains?

3. Method

3.1 Data Sources and Sampling

The goal of this study was to develop a methodology to systematically map the landscape of hydrogen-related online and professional learning opportunities. The unit of analysis was purposive sampling from eight training course providers, including industry training modules, professional development programs, and MOOCs. As regards the codes of course offerings, American Institute of Chemical Engineers, Linde, and Det Norske Veritas were coded as Professional Organization; Udemy and Coursera were coded as MOOC Provider; Electric Power Research Institute and Gas Technology Institute were coded as Industry Research Institute; Renewable Energy Institute was coded as Training Provider.

For each site, the keyword “hydrogen” was used to search the provider’s internal search engine to identify potentially relevant courses. R programming was utilized to collect text results from internet pages. Across all providers, this process yielded a dataset of hydrogen-related course titles and associated metadata (e.g., provider name, URL), which formed the basis for subsequent qualitative coding and analysis.

3.2 Web-Scraping Procedure

All web-scraping and initial data processing were conducted in R using a combination of the *rvest*, *chromote*, *httr*, *dplyr*, *stringr*, *purrr*, and *tibble* packages. The web-scraping was efficient for less dynamic per-page and simple multiple-page course lists. By employing the iterative process across multiple URL searches, a single dataset would be produced by binding all courses for each provider. Many platforms contained dynamically loaded content, so the lengthy visible text, such as course content and objectives, was subjected to extraction. For platforms with less dynamic search pages, the text requests would be easier to fetch with a realistic browser user-agent string to avoid being blocked by the server. Technically, different portals or providers were protected by different JavaScript or programming-related techniques. Therefore, the syntax to extract the course details was different for each course provider.

From a data collection perspective, it is important to note that many provider websites did not allow reliable, automated extraction of detailed course content beyond high-level metadata. While the scraping pipeline consistently captured stable elements (e.g., course title, URL), the course descriptions, syllabi, modules, or interactive content were typically not accessible or were technically difficult to extract at scale. Many of these elements are rendered dynamically, hidden behind scripts, which makes them hard to capture using automated HTML parsing alone.

As a result, the dataset from web-scraping was understood as a sampling frame of hydrogen-related course offerings, based primarily on titles and URLs, rather than a complete record of each course's internal curriculum. The hydrogen course evaluation should also rely on manually extracting the course details from the portals. Therefore, retaining the exact course URLs enables follow-up manual review of selected courses where deeper content analysis is required.

3.3 Data Cleaning

After scraping, course records from all providers were merged into one consolidated dataset in R using *dplyr*. The data cleaning steps were applied. The duplicated courses were removed to avoid double-counting by the same provider. If providers shared the same course name, one of the course names was renamed to distinguish. At the end of the cleaning stage, the dataset consisted of 164 hydrogen-related courses, representing a range of providers, e.g., MOOC platforms, training providers, industry research institutes, and professional organizations.

3.4 Thematic Coding and Qualitative Analysis

The second phase of the study involved qualitative coding of the scraped course titles and, when available, course descriptions, to characterize the focus of hydrogen education across the sampled offerings. Drawing on DOE Hydrogen Program frameworks as well as the broader literature on hydrogen technologies and energy transition, we developed a deductive and inductive coding framework with six overarching themes (Table 1).

Coding was carried out in R and Excel using the exported dataset. Frequencies of courses within each theme were then calculated to identify patterns in the distribution of hydrogen-related learning across providers and topic areas. In addition, cross-tabulations were examined to determine the distribution of thematic course categories by providers.

Table 1

Thematic Categories of Hydrogen Professional Development Courses

Theme	Corresponding DOE Program ^a	Description
Theme 1 Hydrogen Safety, Risk Management,	Safety, Codes & Standards / Safe Use of Hydrogen / Hydrogen Safety R&D	Cover safe handling, storage, transport and use of hydrogen; hydrogen properties, leak

Theme	Corresponding DOE Program ^a	Description
and Emergency Response		detection, venting, flame detection, material compatibility.
	Safety Review and Oversight (e.g., Hydrogen Safety Review Panel)	Institutional oversight and safety review of DOE-funded hydrogen projects; ensures compliance with safety guidelines.
Theme 2 Hydrogen Technology, Engineering System, and Operation	Hydrogen Production Technologies	Include R&D on diverse hydrogen production pathways (e.g., electrolysis, renewable, fossil, nuclear) under net-zero-carbon or low-carbon strategies.
	Hydrogen Storage and Delivery / Storage Systems / Infrastructure and Distribution	Cover advanced hydrogen storage (e.g., compressed, cryogenic, chemical, material-based), delivery and distribution systems, as well as transport infrastructure.
	Fuel Cell Technologies / End-Use Systems (e.g., transportation, stationary, portable)	Include hydrogen-to-power systems: fuel cells for mobility, stationary power, portable power as part of DOE's end-use / technology validation.
	Systems Development / Integration, Infrastructure / Deployment Planning	Cover system-level activities: integration of production, storage, delivery, fuel cells, infrastructure, and deployment planning.
Theme 3 Hydrogen Economy, Policy, Market, and Business Application	Systems Analysis, Market, Strategy and Deployment Planning	Involve economic / market analysis, deployment strategy, workforce and supply-chain development, overcoming market & institutional barriers.
	RD&D Demonstration / Technology Validation / Industry End-use Deployment	Focus on validating hydrogen technologies in real-world applications, key for scaling market adoption and business cases.
Theme 4 Hydrogen Science, Fundamentals, and Chemistry	Foundational Research / Basic Science (e.g., materials, chemistry, fundamental hydrogen behaviors)	Include fundamental chemistry, materials science, hydrogen behavior (e.g., leaks, embrittlement), purity and quality issues, underpin all technology development.
Theme 5 Cross-Cutting Renewable Energy System, and Energy Transition	Integration across energy sectors / Systems Development / Integration / Infrastructure / Systems-level planning	Include coupling hydrogen with renewable electricity, grid / energy systems integration, hydrogen as storage / energy carrier, multi-sector energy transition planning.

Theme	Corresponding DOE Program ^a	Description
Theme 6 Hydrogen Applications and End-Use Integration	Case Studies, Technology Validation / Deployment Projects / Sector-specific Applications (e.g., industry, transport, power, commercial)	Focuses on the practical implementation and utilization of hydrogen systems within specific sectors (e.g., mobility, power generation, heavy industry), emphasizing integration and deployment and including use-case analysis, pilot project validation, and sector-specific operational strategies.

Note. ^a U.S. Department of Energy Hydrogen Program [2]

3.5 Ethical and Technical Considerations

All data used in this study were obtained from publicly accessible web pages without bypassing authentication, paywalls, or technical protections. The scraping scripts respected the intended use of the websites by limiting request frequency and using standard user-agent strings. No personal or learner-level data were accessed or stored. Because the analytic focus is at the course and provider level, and all offerings are publicly advertised, the risk of harm to individuals is minimal.

4. Results

A total of 164 professional courses were extracted from eight course websites. The courses were coded into six themes (Table 1). The courses that offered the training were categorized into four types, including MOOC Providers, Training Providers, Industry Research Institutes, and Professional Organizations.

4.1 Distribution of Hydrogen-Related Professional Courses Across Thematic Domains

The frequency distribution indicates that hydrogen safety-related courses are comparably prevalent, showing the emphasis on risk management, regulatory compliance, and foundational safety competencies (Table 2). This result stems from the study's sample selection, as these organizations focus directly on safety-related courses and may not be representative of broader, sector-wide trends. Technical training in hydrogen technologies and engineering systems also represents a substantial portion of offerings, reflecting workforce demand for skills in production, storage, transport, and system operations. Cross-cutting energy-transition topics appear prominently as well, indicating recognition that hydrogen roles increasingly require systems-level understanding of integration with renewables, sector coupling, and decarbonization pathways. Domain-specific niche courses occupy a moderate share, pointing to emerging but uneven development of specialized industry applications. In contrast, hydrogen economy and policy-oriented courses constitute the smallest share of offerings. The potential underrepresentation of this topic area reveals a notable gap in training related to hydrogen economics, certification, governance, and strategic deployment. To conclude, the sampled training landscape reveals meaningful representation across all thematic categories, indicating that foundational courses are accessible across safety, technical, policy, and business domains.

However, while content availability is widespread, the variation in depth and focus suggests that the primary challenge is not a lack of resources, but rather the need to align these diverse offerings with standardized learning frameworks and defined workforce objectives.

Table 2

Frequency Distribution of Hydrogen Professional Courses by Thematic Category

Theme	Thematic Category	n	%
1	Hydrogen Safety, Risk Management, and Emergency Response	41	25.00
2	Hydrogen Technology, Engineering System, and Operation	30	18.29
3	Hydrogen Economy, Policy, Market, and Business Application	15	9.15
4	Hydrogen Science, Fundamentals, and Chemistry	27	16.46
5	Cross-Cutting Renewable Energy System, and Energy Transition	28	17.07
6	Hydrogen Applications and End-Use Integration	23	14.02
	Total	164	100.00

4.2 Distribution of Hydrogen-Related Professional Courses Offered by the Provider

The sample set evaluated eight course providers, and they are attributed to four coding categories (Table 3). American Institute of Chemical Engineers (n = 71), Linde (n = 19), and Det Norske Veritas (n = 11) were coded as Industry or Professional Organization; Udemy (n = 45) and Coursera (n = 6) were coded as MOOC Provider; Electric Power Research Institute (n = 6) and Gas Technology Institute (n = 3) were coded as Industry Research Institute; Renewable energy institute (n = 3) was coded as Training Provider.

This pattern indicates that the category of professional organization is playing a leading role in hydrogen professional education. MOOC providers are also playing a central role in shaping workforce competencies and disseminating specialized knowledge, implying growing interest in scalable, open-access hydrogen education, but still reflecting a smaller role relative to professional societies. Industry research institutes and general training platform providers account for a smaller share of identified courses.

Table 3

Frequency Distribution of Hydrogen Professional Courses by Provider

Provider	Provider Category	n	%
1	Industry or Professional Organization	101	62.00
2	MOOC Provider	51	31.00
3	Industry Research Institute	9	5.50
4	Training Provider	3	1.80

Provider	Provider Category	n	%
	Total	164	100.00

4.3 Distribution of Thematic Categories of Hydrogen-Related Professional Courses by Provider

Based on the evaluated sample, professional organizations compose the largest share of courses across all six thematic domains (Table 4 & Figure 1). The representation was highest in Safety, Risk Management, and Emergency Response (35.64%), followed by substantial contributions across technology, science, and domain-specific topics. This distribution reflects a common approach to integrating safety within all training programs as well as the observation that standards-aligned and compliance-oriented training content is particularly focused on hydrogen safety. MOOC providers contributed a moderate proportion of courses across multiple domains, with their highest representation observed in Cross-Cutting Renewable Energy Systems and Energy Transition (31.37%). MOOCs also contributed a notable number of courses in hydrogen science and fundamental topics. Industry research institutes were represented at lower frequencies across domains. The main presence is in Technology, Engineering Systems, and Operations. Training providers comprise the smallest number of courses in the evaluated dataset.

4.4 Effect Size for the Association Between Course Provider and Thematic Category

The strength of association between the hydrogen professional course provider type and course theme was quantified using Cramér's V , which is an effect size measure derived from the chi-square contingency table between two nominal categorical variables. The benchmarks for categorical values of approximately 0.10, 0.30, and 0.50 were interpreted as small, moderate, and large associations [40]. The moderate correlation ($V = .26$) explains that different course providers tend to correlate with distributed thematic categories.

Table 4

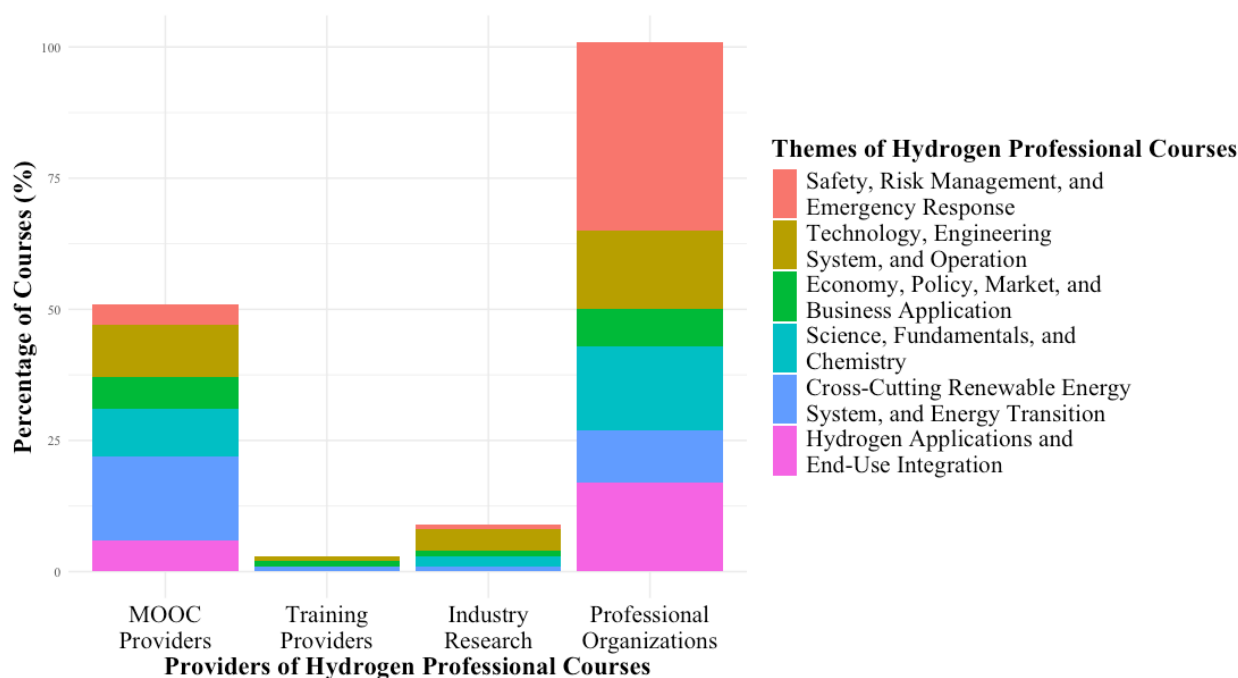
Contingency Table of Thematic Categories of Hydrogen Professional Courses by Provider

	Industry Research Institutes		MOOC Providers		Industry or Professional Organizations		Training Providers	
	n	%	n	%	n	%	n	%
Safety, Risk Management, and Emergency Response	1	11.11	4	7.84	36	35.64	0	0.00
Technology, Engineering System, and Operation	4	44.44	10	19.61	15	14.85	1	33.33
Economy, Policy, Market, and Business Application	1	11.11	6	11.76	7	6.93	1	33.33
Science, Fundamental, and Chemistry	2	22.22	9	17.65	16	15.84	0	0.00

	Industry Research Institutes		MOOC Providers		Industry or Professional Organizations		Training Providers	
	n	%	n	%	n	%	n	%
Cross-Cutting Renewable Energy System, and Energy Transition	1	11.11	16	31.37	10	9.90	1	33.33
Hydrogen Applications and End-Use Integration	0	0.0	6	11.76	17	16.83	0	0.00

Figure 1

Distribution of the Thematic Categories of Hydrogen Professional Courses by Provider



5. Discussion

5.1 Thematic Domains of Hydrogen Professional Courses across Different Providers

The findings demonstrate the applicability of a systematic, scalable approach for standardized content assessment across heterogeneous hydrogen professional course offerings. The descriptive findings in Table 4 and Figure 1 revealed a positive representation of hydrogen professional coursework provided by different entities across the spectrum of the hydrogen value chain. By integrating computational web scraping with thematic classification, the results explained that educational offerings were actively distributed across all six thematic categories, providing that learners have access to a diverse curriculum that ranges from hydrogen science and core technology to strategic market analysis and sector-specific applications. The professional course availability reflected that training providers are responding to the multi-

disciplinary nature of the hydrogen economy, establishing an accessible hydrogen profession in safety, engineering, and business competencies.

When applied to the evaluated dataset, the approach reveals clear differences in thematic emphasis across provider types. Professional organizations account for the largest share of courses across multiple domains, particularly in safety, risk management, and emergency response (35.64%). This pattern reflects the mission-driven roles of these organizations within the analyzed materials, which aligns with prior literature indicating that safety, standards, and regulatory compliance training in high-risk energy sectors is frequently developed by specialized professional bodies [29, 41]. Safety and systems integration as core domains in hydrogen deployment can support technical rigor while potentially shaping curricular scope [11].

The MOOC providers illustrated that cross-cutting energy-transition domains (31.37%) contributed the largest share of coursework, with moderate representation in technology, science, and fundamental-related courses, whereas they showed the lowest presence in safety-intensive or regulatory-focused themes. Some international reports suggested that safety-critical training was more frequently delivered through professional societies or industry-affiliated providers [1, 3]. The workforce studies revealed there was a challenge of teaching highly specialized technical, safety-critical, or regulatory content effectively in large-scale, self-paced online formats [10, 34]. This distribution mirrors broader trends in open-access technical education and illustrates how the method can detect systematic differences in content focus across delivery platforms [8].

Industry research institutes as well as training providers appear less frequently, contributing smaller proportions of courses across thematic categories. Industry research institutes contribute modestly in technology, engineering systems, and operation (44.44%), reflecting their role in bridging research, demonstration, and industry upskilling [2, 42]. Training providers offered the fewest courses, but maintain representation across applied technical domains. Rather than indicating absence or insufficiency, the findings demonstrate how the proposed framework can be used to map course patterns across provider categories and identify areas where additional program types may warrant focused analysis. Workforce frameworks from the U.S. DOE [2, 30], Canada [3], and the EU [4, 32, 41] emphasize applied, hands-on, and vocational competencies as important elements of hydrogen-sector readiness, underscoring the relevance of extending this analytical approach to training formats centered on experiential learning [43].

When situated within the broader energy transition landscape, this study signified a comparatively strong emphasis on safety and risk management, regulatory sensitivity, renewable energy system integration, and fundamental technology and science, which showed the technical complexity and regulatory sensitivity of hydrogen deployment [29, 31]. In contrast, more mature renewable sectors such as solar and wind have benefited from longer-standing curricular integration within engineering programs and workforce frameworks [1]. The rapid policy acceleration and infrastructure expansion of hydrogen development potentially led to the prominent standards-aligned PD educational modular offerings [2, 44].

Additionally, these course matrices surfaced thematic imbalances that can be examined more closely in future studies. Safety and technical topics appear more frequently than economy- or policy-oriented courses, reinforcing that applied technical competence is central to hydrogen workforce development. Although a full comparative content analysis across energy domains is beyond the scope of this work, these findings may serve as crucial indicators in hydrogen

curriculum review and continuous improvement processes, particularly to higher education institutions' ABET-accredited programs [9].

5.2 Implications for Hydrogen Curriculum Design and the Workforce Pipeline

The findings of this study highlight that professional organizations and private training providers account for the largest share of hydrogen-specific offerings, followed by MOOCs and industry research institutes. This distribution of hydrogen professional training indicates that hydrogen workforce development works as a multi-actor in an interconnected system rather than a single institutional pathway. This ecosystem reflects broader workforce assessments and hydrogen skills strategies that emphasize multi-level training pathways spanning foundational education, vocational preparation, and continuing professional development [3, 7, 44]. Although this study centers on PD rather than degree-granting programs, the findings have meaningful implications for universities, professional societies, and training providers.

Universities may refer to PD course insights of thematic concentration to strengthen curriculum mapping, elective offerings, capstone design topics, laboratory modules, and interdisciplinary energy systems coursework in alignment with emerging hydrogen competencies identified in national and international skills frameworks [31, 45]. The thematic findings of hydrogen safety, systems integration, engineering operations, and regulatory context provide signals for curriculum enhancement aligned with industry needs within higher education. Professional development trends can also serve as external indicators during ABET continuous improvement processes. ABET's emphasis on outcomes such as problem-solving, engineering design, communication, ethics, and lifelong learning [9] aligns conceptually with the practice-oriented competencies emphasized in hydrogen professional development. PD patterns provide practical insight into evolving industry skill demands along with accreditation structures.

Professional societies appear prominently in the hydrogen training landscape, especially in delivering content related to safety standards, engineering systems, and operational practice. Their central role of technical standards and conveners of practitioner communities positions them to translate evolving regulatory and technological developments into accessible, practice-relevant instruction [12, 29]. The findings of this study can support societies in assessing thematic balance, identifying competency gaps, and aligning offerings with broader hydrogen skills strategies [7, 44]. By integrating competency frameworks into structured PD pathways, societies can strengthen technical credibility and public safety within hydrogen deployment.

Training entities and industry research institutes demonstrate agility in delivering specialized, short-duration hydrogen education aligned with rapidly evolving technologies and standards. Their proximity to deployment initiatives enables rapid dissemination of applied knowledge, e.g., [1, 2, 42], such as national hydrogen programs and industry-led decarbonization efforts. The thematic analysis in this study can assist these providers in identifying overrepresented and underdeveloped topic areas, designing tiered learning pathways, and aligning documentation mechanisms with continuing competency expectations. As hydrogen employment expands globally [1], industry-aligned training providers will remain critical actors in bridging innovation, workforce readiness, and safe implementation.

5.3 Distinguishing Professional Development from Academic and Trade Accreditation

It is essential to clarify that, because this study focuses on PD in engineering, degree-granting academic standards are not applied as evaluative benchmarks. ABET accreditation is

intended to assess degree-granting programs rather than short-form professional training courses and does not govern state licensure continuing education requirements. Although some PD providers, including university continuing education units, may incorporate outcomes-based principles, the regulatory framework for Professional Development Hours (PDH) and Continuing Professional Competency (CPC) is primarily situated within state licensing systems rather than academic accreditation structures.

It is also important to distinguish between training designed for practicing engineers and programs intended to develop and certify hydrogen technicians. Hydrogen PD courses are modular, practice-oriented, and frequently aligned with PDH requirements for licensed engineers. In contrast, technician certification programs operate within different governance, credentialing, and instructional frameworks. For example, technical trade certifications are typically delivered through community colleges, trade schools, or structured apprenticeship pathways. While professionals may seek specific technical accreditation to improve their knowledge of hydrogen, for example, through the CHS Fundamental Hydrogen Safety Credential from AIChE included in this study, most trade certification programs are generally designed for occupational entry preparation rather than continuing professional competency. Because the structural purpose, audience, and regulatory context differ between technician training and engineer continuing education, a full comparative analysis is beyond the scope of this study.

6. Limitations

This study evaluates hydrogen-related training offerings within a professional development framework. The objective is not to assess student learning outcomes, but rather to validate a systematic approach for examining the topics and structural features of this diverse and largely unstandardized educational modality. To support appropriate interpretation, the initial findings identify general professional course design principles and licensure-relevant criteria across a selected subset of hydrogen-focused PD courses to demonstrate the utility of the approach and highlight emerging trends. The scope of this analysis does not extend to a comprehensive evaluation of instructional frameworks or learner outcomes.

Other limitations apply when interpreting the findings of this study. First, the outcomes are based on a limited subset of publicly accessible course offerings. The sample size and scope of the sampling strategy did not include community colleges, trade schools, apprenticeship programs, or industrial training centers. Second, training delivered internally within companies, government agencies, or through proprietary platforms could not be captured. The initial data collected underestimates the full scope of hydrogen workforce education. Thirdly, the study does not map course themes to specific occupational roles, such as technicians, operators, mid-skill workforce, or to formal competency frameworks. The professional hydrogen courses with cross-cutting technical content would require job-task analyses and employer validation, which is beyond the scope of this work.

The technique of web-scraping relies on the accuracy and completeness of website information, which can vary across providers and may not consistently report course duration, instructional methods, or learning outcomes. The coding process was influenced by interpretive judgments, particularly for courses with ambiguous or overlapping content. Critically, the provider categories used in the study could not represent a more complex hydrogen ecosystem.

As such, these results may not be interpreted in the broader hydrogen educational landscape. These limitations propose that the analysis is viewed as a systematic snapshot rather than a comprehensive map of all hydrogen-related training trajectories. Future research can extend to a larger, more diverse framework to investigate specific segments of hydrogen education and training in greater depth and with greater representativeness.

7. Conclusion

This study presents a systematic mapping of publicly available hydrogen professional courses using web-scraping and thematic analysis, demonstrating how a structured approach can be used to categorize and quantitatively analyze hydrogen training content across thematic providers and domains. The application of this methodology reveals positive representation across all thematic categories, confirming that foundational content is accessible across a diverse range of provider types. However, the analysis also identifies a critical gap despite widespread content availability. There is a notable lack of defined learning objectives and inconsistent alignment with standardized learning frameworks. This fragmentation limits the scalability of training programs and the industry's ability to track training outcomes and assess workforce readiness.

With an emphasis on methodological rigor rather than landscape-level generalization, this study demonstrates the utility of a scalable empirical approach for evaluating hydrogen education offerings. The findings reinforce that effective hydrogen workforce development depends on coordinated contributions from universities, professional societies, and independent training providers. To support the growing complexity of the hydrogen value chain, future efforts should prioritize aligning professional development curricula with industry-relevant competencies, enabling more coherent, measurable, and workforce-ready training pathways that support the sustainable growth of the hydrogen economy.

References

- [1] International Energy Agency, "IEA Hydrogen Technology Collaboration Programme: Annual report," 2023.
- [2] (2024). *U.S. Department of Energy Hydrogen Program*. [Online] Available: <https://www.hydrogen.energy.gov/>
- [3] (2022). *Canadian workforce requirements for advancing a hydrogen economy: Hydrogen workforce assessment tool*.
- [4] EU GreenSkillsforH2 Consortium, "European Hydrogen Skills Strategy," 2023.
- [5] Electric Power Research Institute, "Low-Carbon Resources Initiative," ed. Electric Power Research Institute, 2024.
- [6] Gas Technology Institute & Electric Power Research Institute, "Low-Carbon Resources Initiative," ed. Gas Technology Institute,, 2020.
- [7] Hydrogen Skills Alliance, "Hydrogen skills framework," United Kingdom, 2022.
- [8] E. National Academies of Sciences, and Medicine,, *Transforming undergraduate STEM education: Supporting equitable and effective teaching*. The National Academies Press, 2025.
- [9] *Criteria for accrediting engineering programs*, Accreditation Board for Engineering and Technology, 2023.
- [10] R. McHenry, S. Krishnan, and L. Tuck, "Knowledge, skills, and attributes needed for developing a hydrogen engineering workforce: A systematic review of literature on hydrogen engineering education," (in English), *Int. J. Hydrog. Energy*, Review vol. 72, pp. 380-387, Jun 2024, doi: 10.1016/j.ijhydene.2024.05.380.
- [11] C. Winberg *et al.*, "Developing employability in engineering education: a systematic review of the literature," (in English), *Eur. J. Eng. Educ.*, Review vol. 45, no. 2, pp. 165-180, Mar 2020, doi: 10.1080/03043797.2018.1534086.
- [12] National Council of Examiners for Engineering and Surveying. "Member licensing board directory." <https://ncees.org/about/member-licensing-board-directory/> (accessed).
- [13] J. B. Chen, X. Y. Du, D. Jiang, A. Guerra, and B. Norgaard, "A review study with a systematic approach: pedagogical development for educators in higher engineering education," (in English), *Eur. J. Eng. Educ.*, Review vol. 49, no. 2, pp. 299-329, Mar 3 2024, doi: 10.1080/03043797.2023.2290032.
- [14] International Energy Agency, "World energy employment 2023," 2023.
- [15] W. X. Zheng, X. Zheng, and X. M. Zhu, "Promoting integration of industry and vocational education: Exploring stakeholder intentions of hydrogen energy industry," (in English), *Int. J. Hydrog. Energy*, vol. 52, p. 11, Jan 2024, doi: 10.1016/j.ijhydene.2023.06.072.
- [16] K. Beasy, S. Emery, K. Pryor, and T. A. Vo, "Skilling the green hydrogen economy: A case study from Australia," (in English), *Int. J. Hydrog. Energy*, vol. 48, no. 52, pp. 19811-19820, Jun 2023, doi: 10.1016/j.ijhydene.2023.02.061.
- [17] F. Dawood, G. M. Shafiullah, and M. Anda, "A hover view over Australia's Hydrogen Industry in recent history: The necessity for a Hydrogen Industry Knowledge-Sharing Platform," (in English), *Int. J. Hydrog. Energy*, vol. 45, no. 58, pp. 32916-32939, Nov 2020, doi: 10.1016/j.ijhydene.2020.09.122.
- [18] J. McCoy, D. Davis, E. Mayfield, and M. J. Brear, "Labour implications of the net-zero transition and clean energy exports in Australia," (in English), *Energy Res. Soc. Sci.*, vol. 112, p. 20, Jun 2024, Art no. 103506, doi: 10.1016/j.erss.2024.103506.

- [19] M. Armiento, M. Lelli, C. Andrews, B. Idini, and R. Ruff, "Analysing the global workforce dynamics of the energy transition: main findings from the World Energy Employment report 2023," (in English), *Discov. Sustain.*, vol. 6, no. 1, p. 7, Jan 2025, Art no. 35, doi: 10.1007/s43621-024-00773-7.
- [20] K. Alanne, "A survey of Finnish energy engineering students' knowledge and perception of hydrogen technology," (in English), *Int. J. Hydrog. Energy*, vol. 43, no. 22, pp. 10205-10214, May 2018, doi: 10.1016/j.ijhydene.2018.04.098.
- [21] A. Bailey *et al.*, "Hydrogen Storage Experiments for an Undergraduate Laboratory Course-Clean Energy: Hydrogen/Fuel Cells," (in English), *J. Chem. Educ.*, vol. 92, no. 4, pp. 688-692, Apr 2015, doi: 10.1021/ed5006294.
- [22] B. Kula, A. L. Roxas, K. Cetin, G. Berghorn, and A. Anctil, "Implementation of VR Technology for Energy Audit Training and Workforce Development," (in English), *J. Manage. Eng.*, vol. 41, no. 3, p. 12, May 2025, Art no. 04025002, doi: 10.1061/jmenea.Meeng-6169.
- [23] M. L. Cruz and G. N. Saunders-Smiths, "Using an industry instrument to trigger the improvement of the transversal competency learning outcomes of engineering graduates," (in English), *Eur. J. Eng. Educ.*, vol. 47, no. 1, pp. 30-49, Jan 2022, doi: 10.1080/03043797.2021.1909539.
- [24] S. Craps, M. Pinxten, H. Knipprath, and G. Langie, "Different roles, different demands. A competency-based professional roles model for early career engineers, validated in industry and higher education," (in English), *Eur. J. Eng. Educ.*, vol. 47, no. 1, pp. 144-163, Jan 2022, doi: 10.1080/03043797.2021.1889468.
- [25] M. Aichinger, S. Wehden, J. Ludwig, and F. Creutzig, "'Crafts are great, but not for me': Reconnecting to the skilled trades crucial for building a low-carbon implementation workforce in academised societies," (in English), *Energy Res. Soc. Sci.*, vol. 125, p. 13, Jul 2025, Art no. 104120, doi: 10.1016/j.erss.2025.104120.
- [26] M. Anderson and J. Hicks, "Analysis and recommendation of policies to support the energy transition of West Texas energy communities," (in English), *Extr. Ind. Soc.*, vol. 23, p. 15, Sep 2025, Art no. 101627, doi: 10.1016/j.exis.2025.101627.
- [27] P. Upham *et al.*, "Agency and structure in a sociotechnical transition: Hydrogen fuel cells, conjunctural knowledge and structuration in Europe," (in English), *Energy Res. Soc. Sci.*, vol. 37, pp. 163-174, Mar 2018, doi: 10.1016/j.erss.2017.09.040.
- [28] C. C. Lee, J. N. Li, and J. Y. Yan, "Can artificial intelligence contribute to the new energy system? Based on the perspective of labor supply," (in English), *Technol. Soc.*, vol. 81, p. 13, Jun 2025, Art no. 102877, doi: 10.1016/j.techsoc.2025.102877.
- [29] *ISO/TR 15916: Basic considerations for the safety of hydrogen systems*, International Organization for Standardization, 2023.
- [30] U.S. . (2023). *Hydrogen Program overview*.
- [31] Department for Business, Enterprise and Industrial Strategy. (2021). *Energy & Utility Skills Hydrogen Competence Framework*.
- [32] H. E. European Commission, Hydrogen Europe Research,, "Green skills for hydrogen initiative," 2023.
- [33] (2023). *Scotland hydrogen skills action plan*.
- [34] M. Reijalt, "Hydrogen and fuel cell education in Europe: from when? And where? To here! And now!," (in English), *J. Clean Prod.*, vol. 18, pp. S112-S117, 2010, doi: 10.1016/j.jclepro.2010.05.017.

- [35] H. J. Passow and C. H. Passow, "What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review," (in English), *J. Eng. Educ.*, Review vol. 106, no. 3, pp. 475-526, Jul 2017, doi: 10.1002/jee.20171.
- [36] K. Khanal, N. Kaza, and N. Lowe, "Occupational Transitions into Clean Energy: A Workforce Development Approach Using Occupational Similarity and Unsupervised Clustering," (in English), *Econ. Dev. Q.*, ; Early Access p. 18, Jul 2025, doi: 10.1177/08912424251352743.
- [37] A. Kovac, M. Paranos, and D. Marcus, "Hydrogen in energy transition: A review," (in English), *Int. J. Hydrog. Energy*, ; Proceedings Paper vol. 46, no. 16, pp. 10016-10035, Mar 2021, doi: 10.1016/j.ijhydene.2020.11.256.
- [38] M. Salimi, M. Hosseinpour, and T. N. Borhani, "The Role of Clean Hydrogen Value Chain in a Successful Energy Transition of Japan," (in English), *Energies*, vol. 15, no. 16, p. 19, Aug 2022, Art no. 6064, doi: 10.3390/en15166064.
- [39] I. A. Aditya, T. Wijayanto, and D. F. Hakam, "Advancing Renewable Energy in Indonesia: A Comprehensive Analysis of Challenges, Opportunities, and Strategic Solutions," (in English), *Sustainability*, vol. 17, no. 5, p. 20, Mar 2025, Art no. 2216, doi: 10.3390/su17052216.
- [40] J. Cohen, *Statistical power analysis for the behavioral sciences*. routledge, 2013.
- [41] EU GreenSkillsforH2 Consortium, "Hydrogen Skills Core VET Curriculum," 2024.
- [42] Electric Power Research Institute, "Hydrogen Education for a Decarbonized Global Economy (H2EDGE) initiative," ed. Electric Power Research Institute & U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office: Electric Power Research Institute; U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office; Low-Carbon Resources Initiative, 2024.
- [43] R. Skiba, "Competency standards for emerging hydrogen related activities," *Open Journal of Safety Science and Technology*, vol. 10, no. 02, pp. 42-52, 2020.
- [44] European Hydrogen Observatory, "The hydrogen education and research landscape," 2025.
- [45] Hydrogen Europe, Hydrogen Europe Research, and Karlsruhe Institute of Technology, "Skills agenda for the hydrogen economy," 2023.