HyDelta 2

WP11 – Labour market and training implications of hydrogen

D11.1 – The future requirements for HBO, WO and postgraduate personnel in the hydrogen industry

Status: final

Dit project is medegefinancierd door TKI Nieuw Gas | Topsector Energie uit de PPS-toeslag onder referentienummer TKI2022-HyDelta.

Document summary

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Document history

Version	Date	Author	Affiliation	Summary of main changes
1	04-Feb-2023	Adrian Serna Tamez, Mariska Hulsing	New Energy Coalition	First draft
2	28-Feb-2023	Adrian Serna Tamez, Mariska Hulsing	New Energy Coalition	First revision
3	22-May-2023	Adrian Serna Tamez, Mariska Hulsing	New Energy Coalition	Second version after session at Gasunie and incorporation of comments
4	25-May-2023	Julio Garcia-Navarro	New Energy Coalition	Third version after further comments
5	08-Jun-2023	Julio Garcia-Navarro	New Energy Coalition	Fourth version after a further round of comments from the Expert Assessment Group

Dissemination level

PU	Public	X
RE	Restricted to • Project partners including Expert Assessment Group • External entity with whom a Non-Disclosure Agreement exists	

Document review

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Executive summary

As the Dutch government and organisations continues to implement plans for the production and use of hydrogen in the ongoing energy transition, there is an expected surge in demand for human capital with hydrogen-related skills at applied universities (HBO), universities (WO), and postgraduate levels. While it's true that some of these skills can be transferred from existing sectors such as natural gas network operators and renewable energy developers, the scale of the government's plans to rollout hydrogen at large scale means that a mismatch between the supply and demand of specialized personnel across various disciplines is likely to arise.

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.

In this work, we present an estimation of the number of trained personnel that will be needed in the hydrogen transport industry in the Netherlands, where we found that between 1,800 and 4,700 full time jobs could be required in 2030 for the construction of hydrogen distribution systems or work in commissioning hydrogen transport to the built environment, and between 4,200 and 12,500 full time jobs could be made available to work in the operation and maintenance of such networks. These values are heavily dependent on the degree of uptake of hydrogen in the built environment.

Moreover, we carried out a series of interviews with stakeholders in the hydrogen industry in the Netherlands, and we identified the most important hard skills that are needed by trained personnel in the hydrogen industry. The interviews and analysis revealed that engineering skills, across various disciplines, were the most frequently mentioned.

Next to the stakeholder interviews, we analysed the current job postings on a popular job posting website, where we identified 40 job postings that are specifically recruiting hydrogen professionals. We proceeded to carry out an analysis regarding the most common hard and soft skills requested by the job postings, as well as the levels of education needed to fulfil those vacancies. We found that most of the vacancies are looking for engineers with either a Bachelor's Degree (that can also be understood as HBO training) or a Master's Degree (WO training) in engineering disciplines, with Chemical engineering being the most frequently asked (followed by mechanical and electrical engineering).

We finalise this report by adding a series of recommendations for different stakeholders (educators, industry and government) on how to enhance hydrogen in the existing curricula and what practices could ensued that sufficient trained personnel in the area of hydrogen are made available in the following years to fulfil the expected rise in job openings in the energy transition and hydrogen in particular, thereby preventing potential gridlocks caused by a lack of specialized personnel.

Samenvatting

Aangezien de Nederlandse overheid en organisaties steeds meer plannen implementeren voor de productie en toepassing van waterstof ten behoeve van de energietransitie, is de verwachting dat er steeds meer vraag komt naar menselijk kapitaal met kennis en vaardigheden op het gebied van waterstof, zowel op HBO-, WO- als postacademisch/post-hbo-niveau. Hoewel een deel van deze kennis en vaardigheden vanuit bestaande sectoren kan worden overgedragen, zoals exploitanten van aardgasnetwerken en ontwikkelaars van hernieuwbare energie, betekent de aard van de plannen van de overheid om waterstof op grote schaal uit te rollen waarschijnlijk dat vraag en aanbod op het gebied van gespecialiseerd personeel in diverse disciplines niet op elkaar aan zullen sluiten.

Het doel van deze studie was om kwalitatief onderzoek te doen naar de vaardigheden en competenties die Nederland nodig heeft voor geschoolde arbeidskrachten op HBO-, WO- en postacademisch/post-hbo-niveau in de waterstoftransportsector. Hierbij lag de focus op de vaardigheden en training die nodig zijn voor exploitatie van het gasnet.

In dit document geven we een overzicht van het aantal geschoolde arbeidskrachten dat naar schatting nodig is voor het transport van waterstof in Nederland. Uit onze cijfers blijkt dat er in 2030 waarschijnlijk tussen de 1800 en 4700 voltijdbanen nodig zouden zijn voor de aanleg van waterstofdistributiesystemen en werkzaamheden ten behoeve van het transport van waterstof naar de gebouwde omgeving. Daarnaast zouden er nog eens tussen de 4200 en 12.500 voltijdbanen nodig zijn voor de exploitatie en onderhoud van dergelijke netwerken. Hoe deze cijfers in werkelijkheid zullen uitpakken is sterk afhankelijk van de mate waarin waterstof daadwerkelijk in de gebouwde omgeving gebruikt zal gaan worden.

Ook hebben we een reeks interviews gevoerd met stakeholders in de waterstofindustrie in Nederland en hebben we de belangrijkste harde vaardigheden in kaart gebracht waarover geschoolde arbeidskrachten in de waterstofsector moeten beschikken. Uit de interviews en de analyse kwam naar voren dat in dit verband de verschillende technische disciplines het vaakst werden genoemd.

Naast de interviews met stakeholders hebben we ook gekeken naar de actuele vacatures op een populaire vacaturewebsite, waarbij we 40 vacatures vonden waarin specifiek gevraagd werd naar professionals op waterstofgebied. Vervolgens hebben we gekeken welke harde en zachte vaardigheden het meest werden gevraagd in de vacatures, en het vereiste opleidingsniveau voor de vacatures. Hieruit bleek dat er vooral gevraagd werd naar technici met ofwel een bachelordiploma (c.q. een HBO-opleiding) of een masterdiploma (WO-opleiding) in technische disciplines, waarbij de meeste vraag was naar chemische technologie (gevolgd door werktuigbouwkunde en elektrotechniek).

Tot slot bevat het rapport een reeks aanbevelingen voor diverse stakeholders (onderwijsinstellingen, bedrijfsleven en overheid) over hoe het onderwerp waterstof beter kan worden geïntegreerd in de huidige curricula en wat er moet gebeuren om ervoor te zorgen dat er in de komende jaren voldoende geschoolde arbeidskrachten op het gebied van waterstof beschikbaar zijn teneinde te voldoen aan de verwachte toename van het aantal vacatures in het kader van de energietransitie - en waterstof in het bijzonder- en zo te voorkomen dat de transitie stagneert.

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1. Introduction

The energy transition has been gaining importance and momentum on the agendas of governments and organizations worldwide in an effort to slow down climate change; the Netherlands, along with many other countries, has set ambitious goals to reduce greenhouse gas emissions towards 2050 [1]. Hydrogen has been gaining particular attention in the last years as a means to achieve these emission reduction targets worldwide, due to its versatility as an energy carrier, its potential to decarbonize hard-to-abate sectors (i.e., that cannot be electrified), and its ability to store intermittent renewable energy in order to match supply and demand and provide flexibility to the energy systems.

This unprecedented transition to clean hydrogen and its potential uses in different sectors requires not only a technological, economic, and political shift, but also the development of human capital with the skills, competencies, and expertise needed to design, build, operate, and maintain the new technologies and infrastructure required for a hydrogen economy.

One of the most important recent developments in the Netherlands is the development of the "Dutch Hydrogen Backbone"[1], where the Dutch Natural Gas Transmission System Operator Gasunie has started activities to develop a high-pressure hydrogen transport network that will connect the main industrial clusters in the country as well as potential import and export locations, enabling the transport of millions of tons of hydrogen per year [2].

Furthermore, the natural gas distribution system operators in the Netherlands[2] have started efforts to gain knowledge and elucidate the potential of hydrogen for the decarbonization of smaller consumers such as the built environment. Over the past years they have been continuously developing a series of hydrogen pilots in different municipalities in the Netherlands [3], where they are testing the safety of hydrogen distribution (via retrofitting the existing natural gas distribution network) as well as consumption in houses in the locations such as Rozenburg, the Green Village, Uithoorn, and most recently Lochem, where since December 2022 there are 12 monumental houses being heated by 100% hydrogen instead of natural gas [4].

The development of transport infrastructure as well as distribution infrastructure for hydrogen are unprecedented and, as such, will represent a challenge for the natural gas network operators in the Netherlands.

This challenge can be further amplified by the effect the Covid-19 pandemic had on the Dutch labour market. According to the Central Bureau for Statistics, between the first half of 2020 (when the lockdowns started) first quarter of 2023, the number of job vacancies in the Netherlands increased by 230%, following a sharp increase in job vacancies between 2020 and 2023 with respect to the trend in the labour market between 2017 and 2019 [5]. Furthermore, the unemployment in the Netherlands in 2023 is at its lowest point of the last 10 years [6].

Energy transition-related jobs have been particularly affected by the labour shortage in the Netherlands. According to the labour market indicator of ABN AMRO, there is a shortage of installation technicians, people working in the home insulation sector as well as personnel in the construction industry [7]. Moreover, ABN AMRO reports that there is a personnel shortage in the energy transition sector, where as many as 36% of the vacancies have remained unfulfilled in the last months [7].

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[1] The study that led to this decision is called the HyWay27, prepared by PWC under commission by Gasunie [17].
[2] Alliander, Coteq, Enexis, Rendo, Stedin, and Westland Infra.

All this highlights the fact that if underestimated, the shortage of trained personnel can stagnate the development of the energy transition in the Netherlands, and consequently the development of hydrogen infrastructure. For this reason, it is important that the labour market adapts in time namely, to attract students to energy transition topics as well as to develop training profiles that will ensure that qualified personnel fulfil these vacancies with sufficient and adequate knowledge.

Different studies have been conducted to determine the types of trained personnel required to meet the demand for human capital[3] of a hydrogen economy under various growth scenarios [8] [9]. These studies are primarily focused on vocational training (MBO[4] in Dutch tertiary education system); to our knowledge there have not yet been studies conducted around the types of trained personnel on the applied university (HBO[5] in the Dutch tertiary education system), university (WO[6] in the Dutch tertiary education system), and postgraduate education (MBAs, executive trainings, etc.).

Goal and structure of this report

The goal of this study was to qualitatively examine the skills and competences needed for trained personnel in the HBO, WO, and postgraduate education 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. The next paragraphs detail the contents of this report.

First, we conducted an inventory of skills and competences by interviewing various stakeholders, using a stakeholder's map to identify key players in the hydrogen economy (see Appendix A: Stakeholder map). We utilized existing quantitative research from other hydrogen sectors (e.g., the hydrogen production industry) as a reference [8] and focused on the Netherlands, for job functions at the HBO, WO, and postgraduate levels. The data was further supplemented by carrying out a quantitative analysis of job vacancies posted on an employment website.

Later, we carried out an inventory of currently available education focused on hydrogen through online research at the selected levels of education. This resulted in a compiled list of educational offerings in the Netherlands (see

[3] In the Dutch education sector, the development of trained personnel is referred to as the "Human Capital Agenda (HCA)"
[4] Middelbaar beroepsonderwijs in Dutch
[5] Hoger beroepsonderwijs in Dutch
[6] Wetenschappelijk onderwijs in Dutch

Appendix F: Overview of hydrogen related education in the Netherlands at HBO, WO and postgraduate levels).

Finally, we conclude by presenting recommendations to help solve the shortage of trained personnel in the HBO, WO, and postgraduate levels in the hydrogen transport industry, with a particular focus on the Dutch natural gas system operators. These recommendations are complemented on perspectives obtained from semi-structured interviews with stakeholders and students, considering their motivations and viewpoints.

2. Trained personnel needed for the hydrogen economy and the gas transport industry in the Netherlands

A common definition of skills and competencies is essential for guiding the development of human capital in a focused and cohesive manner. Per definition, human capital refers to the economic value of a worker's experience and skills; human capital is perceived to increase productivity and thus profitability of an organization [10]. Skills can therefore be seen as the backbone of human capital. Skills not only add to the profitability of an organization, but also meet the personal development needs of the workforce. The human capital of any organization requires continuous development (i.e., investment) through education or reskilling, whether in an institution or on-site (i.e., 'on-the-job').

Skills can be broadly categorized into two main types: hard skills and soft skills. Hard skills refer to the specific technical skills and knowledge required to perform a particular job [11]. On the other hand, soft skills are personal attributes that enable individuals to work effectively with others, such as communication skills, teamwork, problem-solving, and leadership abilities [12]. While hard skills are critical to ensure an employee can perform their job, soft skills are increasingly recognized as essential for creating a successful and productive workforce. Soft skills can help employees obtain a wider overview of their jobs and, as a result, employees with a good level of development of soft skills can approach better complex interpersonal relationships, work collaboratively with others, and adapt to rapidly changing work environments. Ultimately, both hard and soft skills are necessary for maximizing human capital and ensuring productivity and personal growth in the workforce [13].

Across various sectors in the renewable energy field, the lack of sufficient hard-skilled personnel to enable the energy transition is often referred to as a 'skills gap.' This gap poses a risk to the timely development of a zero emission economy by 2050. Reports on the subject typically focus on the quantitative aspects of the labour force, referring to technically skilled personnel (i.e., those with vocational training or MBO level education) involved in develop, operate, and maintain renewable assets. However, little attention has been given to highly skilled human capital (i.e., those with HBO, WO, and postgraduate degrees)[7].

The development of a hydrogen economy in the Netherlands has brought the human capital factor into the spotlight. As an example, the research by Leguijt and colleagues has estimated the labour demand accordingly to a low and high-demand scenario, based on estimations of potential use of hydrogen in the built environment in the Netherlands as well as considering the whole value chain [8]. The table below showcases the results of the study of Leguijt et al.

Table 1. Estimated number of jobs related to the construction and operation of hydrogen distribution installations in the Netherlands in 2030, 2040, and 2050, and estimated hydrogen consumption in the Dutch built environment (houses and commercial buildings). Source: [8]. For reference, in 2021 the total final energy consumption in the Dutch built environment was 680 PJ [14].

Parameter	2030	2040	2050
Jobs related to construction and grid installations (one-off activities)	1,800-4,700 FTEs8	2,000-13,000 FTEs	2,200-20,000 FTEs
Jobs related to the maintenance of operation	4,200-12,500 FTEs	9,200-43,000 FTEs	14,200-72,600 FTEs

[7] This research is meant to be supplemental to the research carried out by Kiwa technology, where they looked at the requirements for personnel and training for the MBO level [9].
[8] FTE = full-time equivalent, which according to the European reference corresponds to 1,720 working hours per year.

of assets (continuous employment)			
Estimated scenarios for hydrogen consumption in the Built Environment in the Netherlands	10-40 PJ (69-277 kton H2/year)	132-317 PJ (916-2,201 kton H2/year)	254-593 PJ (1,763-4,118 kton H2/year)

Nevertheless, limited literature was found available that provides detailed information on the required skills for the highest levels of education within the hydrogen workforce. This information can help take a proactive and strategic approach to meet the rapidly evolving demands of the sector, potentially avoiding any human capital gridlocks in the development of the hydrogen economy.

3. Stakeholder mapping

The starting point of this research was a stakeholder map of a hydrogen economy, adapted from the work by Schlund and colleagues [15], with additional information specific to the Dutch situation Four different main sectors were considered: government, network operators, industry, and educational institutions. A summary of the stakeholder map for this study can be found below (for more details see Appendix A: Stakeholder map).

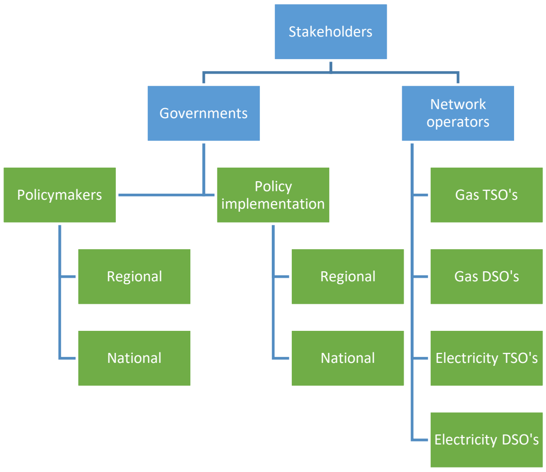

Figure 1. Stakeholder map of this study regarding the skills required for trained personnel in the hydrogen sector in the Netherlands, with a focus on the gas network operators. Source: own made based on the work by Schlund et al. [15].

On the government side, a distinction was made between policy makers and those responsible for policy implementation at both regional and national levels. In between government and industry, network operators were placed due to their organizational structure. Additionally, a differentiation was concluded between industry stakeholders involved in the value chain of low carbon hydrogen (i.e., from production to end use), and between technology and service providers. Finally, the educational sector was divided into the three levels of study, focus of this research: HBO, WO, and postgraduate education.

4. Skills needed for the hydrogen economy

Based on the stakeholder map, semi-structured interviews were conducted with some of the main stakeholders, in order to elucidate their perception on the particular skills required to work in the energy transition in the Netherlands, with a focus on hydrogen transport. A total of 19 interviews[9] with 14 different organizations were carried out, which provided valuable insights on the types of skills perceived by different stakeholders (including government, energy companies, network operators, and research and education institutions). The interviews covered three main themes:

1) The internal perspective of the interviewee's organization related to the current and future skills needed.
2) The external perspective around the stakeholders they interact with and similar considerations
3) Recommendations to address the 'skills gap' related to a hydrogen economy.

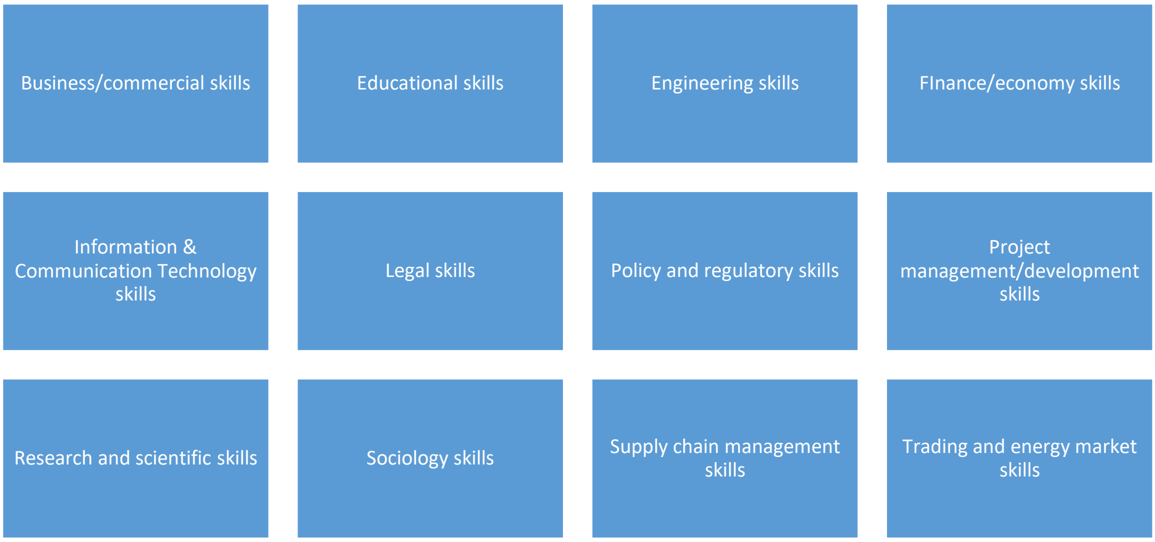

Figure 2. Overview of the identified skills required for HBO and WO levels in the Netherlands, as identified through the stakeholder interviews. Note: the skills are presented in alphabetical order.

The following headings list the most important skills identified during the interviews and the rationale behind their importance; the skills are presented in alphabetical order.

Business/commercial skills

As hydrogen becomes a more widely used energy source, businesses play a critical role in developing, managing, and operating hydrogen production and distribution companies. To accomplish this, business managers must have a comprehensive and multidisciplinary understanding of the technical, economic, and regulatory aspects of the hydrogen industry. They must also be able to correctly approach complex financial and legal frameworks and identify investment opportunities to stimulate the growth of the hydrogen economy. Moreover, businesses are essential in developing and implementing hydrogen-related products and services in the early stages of the hydrogen economy.

[9] The complete list of stakeholders interviewed can be found in Appendix B: Interviewed organisations.

This requires a strategic approach to market research and a deep understanding of the needs and preferences of customers, off-takers, users, and other stakeholders relevant for the operation of the organisation.

Educational skills

One crucial aspect of the hydrogen economy is the development of a skilled workforce. To achieve this, professionals with educational skills will play an essential role 'educate the educator'. Designing and developing effective curricula to train the necessary human capital requires a deep understanding of the subject matter, as well as an ability to be engaging and create effective learning experiences. Educators will need to be knowledgeable about hydrogen technology and its potential applications, as well as have expertise in learning strategies. By developing effective educational programs, the hydrogen industry will be able to build a skilled workforce that can support its growth and development. Educational skills are, therefore, an essential component of the hydrogen economy, as they will enable individuals to gain the necessary knowledge and skills to succeed in the industry.

Engineering skills

Needed for designing, constructing, and maintaining hydrogen production facilities, including very specific technology like electrolysis plants and fuel cells for various applications. They are also needed to design, build, and maintain the infrastructure for hydrogen storage and transportation. A particular requirement within engineering skills is the knowledge of the safety aspects around hydrogen. Hydrogen is a highly flammable gas that can be explosive under certain conditions, so safety measures and precautions are essential to prevent accidents and ensure the protection of workers, the public, and the environment. Environmental, Health, and Safety (EHS) skills are paramount for all stakeholders when handling hydrogen gas to identify and assess hazard risks, to implement safety procedures, and to comply with regulations and standards.

Finance/economy skills

These skills are required to develop developing business plans and investment proposals related to the hydrogen economy. These involve assessing the costs and benefits of different technologies and projects, estimating potential revenue streams, and projecting financial performance over time. The development and deployment of hydrogen technologies also requires significant investment, and individuals with investment and financing skills would be needed to help secure funding from public and private sources. As in all project financing, hydrogen-related projects involve various risks, such as technology risk, market risk, and regulatory risk. Effective risk management skills are necessary to identify, assess, and mitigate these risks. On the economy side, analyses are needed to understand the costs and benefits of different hydrogen technologies and their potential impacts on local and global economies.

Information and Communication Technology (ICT) skills

As the hydrogen industry becomes more digitally connected, individuals with skills in ICT would be needed to design, develop, and maintain the technology infrastructure necessary to support the industry. These are needed to develop software applications such as for the automation required in hydrogen infrastructure for example to implement digitalization in network management, analyze data that can be used to optimize operations, and develop and implement cybersecurity measures.

Legal skills

Like any industrial development, a hydrogen economy must comply with various legal and regulatory requirements at the local, national, and international levels. Legal skills are important to understand the applicable laws and regulations in order to obtain the necessary permits to develop hydrogen projects. Additionally, these skills are essential for negotiating and advocating with regulatory agencies and other stakeholders to ensure compliance. Lastly, legal skills are required for negotiating and managing contracts with stakeholders.

Policy and regulatory skills

Policy makers, implementers, and regulators play a critical role in creating laws and regulations that support the growth of hydrogen production and use. This includes developing incentives and policies to encourage the economic viability and adoption of low carbon hydrogen. Additionally, they are responsible for establishing regulations related to the entire value chain. To accomplish this, the workforce needs to be skilled in understanding what the current political framework around hydrogen is, as well as what are the instruments that exist to e.g., subsidize or regulate the market. By developing effective policies and regulations as well as understanding them, they can help create a stable and predictable regulatory environment that supports the growth of a sustainable hydrogen economy.

Project management/development skills

The successful implementation of a hydrogen economy will require massive infrastructure projects, and project management skills is critical in order to plan, coordinate, and execute these projects. This is particularly crucial during the early stages of the development of hydrogen-related projects, when there is little prior experience in similar projects and therefore the success of early projects (pilots, demonstrations, etc.) can further influence and help roll out other projects.

Research and scientific skills

Needed to research and develop new and more efficient methods for producing, transporting, and utilizing hydrogen. Research and scientific skills are also needed to develop and test new and safe materials and technologies. Additionally, scientific skills are required to develop research and modelling in all other disciplines involved in the hydrogen economy, such as financial, economic, policy, safety and regulatory fields.

Sociology skills

The energy transition will have significant social impacts, including changes to the workforce, new opportunities for innovation and entrepreneurship, and potential social inequalities. Individuals with skills in sociology is needed to assess and address these impacts. Moreover, identifying and addressing potential social and cultural barriers to the adoption of hydrogen technologies need to be identified, to promote public understanding and support for the transition to a hydrogen-based energy system[10].

Supply chain management skills

These skills are necessary to manage the entire process, from sourcing and production to logistics and distribution of technologies. Effective supply chain management involves successfully negotiating contracts, managing inventory, forecasting demand, and optimizing transportation and storage networks. An effective supply chain management system is crucial to ensure that the production and distribution of hydrogen remain efficient and cost-effective, which, in turn, will contribute to the growth and success of the hydrogen economy. The importance of supply chain management skills becomes even more critical if a global hydrogen economy develops, given the complex dynamics and significant disruption risks this event can represent.

Trading and energy market skills

As hydrogen becomes a widely traded commodity, individuals possessing expertise in trading and financial markets will play a significant role in facilitating the buying and selling of hydrogen,

[10] As an example of ongoing research related to the societal embeddedness of hydrogen transport, the reader is encouraged to consult the research done within the HyDelta program [18].

particularly after the establishment of a hydrogen exchange. These individuals will need to have a comprehensive understanding of market dynamics and the geopolitical factors that influence a potential global market. Therefore, a deep understanding of the complexities of the hydrogen market is essential to ensure that trading activities are conducted effectively and efficiently.

Final words on the skills described above

It is worth noting that while most of the necessary skills for the hydrogen economy already exist through existing educational programs and applications in other fields (e.g., chlorine production through electrolysis, or thermodynamics principles of gases) the interaction between the hydrogen economy and other sectors makes them unique and challenging. For instance, professionals need to understand the renewable electricity field in addition to the hydrogen and gas markets, since they all come together in determining the prices and costs of hydrogen coming from an electrolyzer. Therefore, individuals with a combination of interdisciplinary skills and the ability to think systemically will be essential to successfully fill various roles in the hydrogen economy. They must be critical and creative thinkers to solve complex problems and navigate the rapidly changing landscape of the industry.

Moreover, the development of a hydrogen economy will require a diverse range of skills and knowledge to support its growth according to the development timeline. While the current focus is on research and project development, the implementation and maintenance of hydrogen infrastructure, as well as the commercialization and marketing of hydrogen products, will be crucial for the industry's successful development in the medium term. Professionals with expertise in areas such as engineering, construction, project management, marketing, and business development will play an important role in the development of a hydrogen economy. Specialized roles such as hydrogen systems designers, people who maintain the gas networks, and hydrogen safety experts will be in high demand as the industry expands.

It is also worth mentioning that a hydrogen economy will create new opportunities for entrepreneurs and start-ups to innovate and create new technologies and business models to support the industry's growth. This will require individuals with skills in entrepreneurship, financing, and business incubation, creating a diverse range of job opportunities in the hydrogen sector.

Although the research did not specifically focus on soft skills, they were often highlighted as essential to the successful development of a particular job function. However, one could say that these skills apply more generally to all jobs in the labor market, varying slightly depending on the type of job.

5. Data analysis from job openings

To validate the results obtained from the interviews and gain further insights on the current labour market, information from a jobs website was analysed. For this, the vacancies posted on LinkedIn were quantitatively analysed . We focused on active vacancies (i.e., vacancies that were still on LinkedIn when the study was done) on the second half of January 2023, when the study was done. Although the data obtained through this analysis is limited due to the fact that not every company posts their job openings on this platform and possibly due to the timing of the data analysis (this was after the Covid-19 period), these results provide good insights into the current labour market.

Methodology

The methodology used was as follows. A list of vacancies containing the search words 'hydrogen' and 'waterstof' was compiled from the data analysis. After removing duplicates, 285 job listings were identified. Out of these, 42 jobs were found to have the search words 'hydrogen', 'electrolyzers' and 'fuel cell' both in English and/or Dutch in their title, confirming that the vacancies were exclusively focused on the hydrogen field[11]. After excluding jobs at the vocational level, a total of 40 job posts were studied further to analyse job descriptions and skills that the current market is seeking.

Results

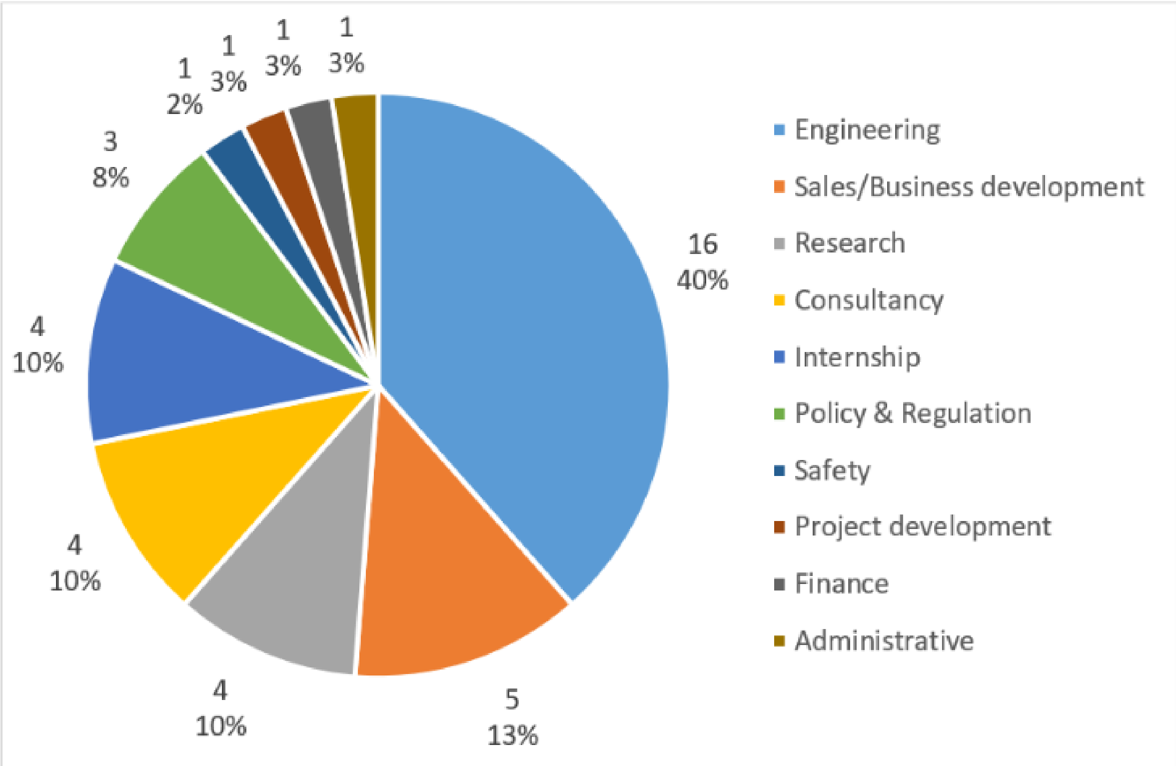

Figure 3. Breakdown of analysed job openings according to the type of job.

Out of the 40 jobs analysed, the majority were found to be focused on the engineering field (Figure 3). These engineering roles included product, electrical, mechanical, systems, maintenance, process, and materials engineering. This suggests a significant demand for engineers who are knowledgeable about technology and the process side of hydrogen. This finding differed slightly from the responses obtained

[11] It is important to mention that there was no differentiation made between jobs in the production, consumption, and transport industries; the focus was mainly on discerning the jobs that were specific for the hydrogen sector.

from the interviews, where stakeholders emphasized a larger need for project developers/managers, researchers, and commercial-related jobs at this moment in time. One possible explanation for this discrepancy is that these types of roles may have been filled in the recent past, and there is currently a trend towards the jobs needed to develop the projects being considered at the moment. Another possible explanation is that there is a discrepancy between the job market (represented by the jobs found on LinkedIn) and the perception from the interviewees, where the latter may have 'old-school' thinking by assuming that more project managers are needed instead of engineers and technicians.

Moreover, with a changing energy landscape (e.g., new forms of energy transport becoming increasingly important in our economy) and in particular with the advent of hydrogen as a major commodity to be produced, consumed, and transported, new working methods and work instructions are required. As such, this changing landscape requires a different approach when it comes to e.g., safety issues.

Nonetheless, business development, sales, and research roles were still the second most frequently found positions, highlighting the importance of skills required to bring these projects to reality and to innovate in all technologies related to hydrogen.

Lastly, there was a small number of jobs mentioned in other fields such as policy and regulation, safety, finance, and administration, indicating that there are also opportunities for professionals in these areas to contribute to the development of the hydrogen economy. However, it is worth noting that safety and regulation roles were strongly emphasized by natural gas transport and distribution system operators in the stakeholder interviews. These interviewees expressed a strong need for experts in the safety aspects of hydrogen, as it is an important consideration due to the flammable and ignition characteristics of hydrogen. Nevertheless, the safety aspect can be considered to be of ultimate importance for many, if not all, stakeholders[12].

[12] Undoubtedly, intime, the demand of specific jobs such as safety will increase quickly.

Hard skills

As a second step in the analysis, we compared the educational background requested in the vacancies we analysed, and extracted the types of skills that are requested for different WO-level education (Bachelor's degrees, Master's degrees, and PhD degrees). Specifically, the results show the frequency at which specific bachelor's, master's, and PhD degrees were mentioned in these job openings.

Figure 4. Breakdown of degrees and disciplines requested in the analysed job openings. (Top) the level of education required in all the 40 job listings analysed, for Bachelor's (top left), Master's (top centre), and PhD degrees (top right). (Bottom) Breakdown of the specific degrees required in the 40 job listings analysed, for Bachelor's (bottom left), Master's (bottom centre) and PhD degrees (bottom right). Note: the count of required background studies in job listings may have included more than one type of degree, which is the reason the total sum of count can be higher than 40.

From Figure 4, it seems that engineering-related degrees were still required at a larger proportion than the rest of the degree types shown in Figure 4. This indicates that individuals with an engineering-related degree will likely have more opportunities and be in higher demand in all type of roles in the hydrogen sector.

Only a small percentage of job postings require a PhD degree in an engineering-related discipline, suggesting that a higher education beyond a Master's degree may not be a common requirement for most hydrogen-related jobs. On the other hand, job postings that require a master's degree indicate that a higher level of education may lead to more job opportunities in the hydrogen industry. Highlighting the fact that individuals with advanced knowledge and skills are in demand likely due to the complex nature of hydrogen-related systems.

At the discipline level, chemical engineering is the most frequently required background of study in the job postings. This may suggest the need for a deep understanding of chemical reactions, thermodynamics, and process engineering, which are all areas of expertise needed at hydrogen production and utilization jobs. In addition to chemical engineering, electrical engineering and mechanical engineering are also frequently required likely due to their relevance to the design, development, and maintenance of hydrogen equipment and systems.

The complete List of hard skills identified in the job listings analysed can be found in

Appendix D: Mentioned hard skills in the hydrogen-related job openings analysed.

Soft skills

As previously mentioned, although the analysis of soft skills was not the primary focus of this study, it is crucial to incorporate soft skills in the development of personnel required in a hydrogen economy to ensure successful job performance. The most frequently mentioned soft skills in the 40 job postings analysed can be found in

Appendix E: Mentioned soft skills in the hydrogen-related job openings analysed.

Based on the information gathered, it is evident that communication skills are highly valued and sought in the labour market, confirming the responses obtained during the interviews. This highlights the importance of being able to effectively convey information and ideas in the workplace, as it is crucial for successful collaboration, productivity, and building relationships with clients and colleagues. Additionally, English proficiency is also highly valued, probably due to the characteristics of Netherlands as a country but also due to the global nature of the emerging green hydrogen industry.

Important soft skills include teamwork, personnel management, and stakeholder management, all of which are critical for achieving organizational goals and delivering results. The list also includes several soft skills such as self-motivation, adaptability, and being results-oriented, which are becoming increasingly important in a rapidly changing job market. These findings can be used by job seekers to identify the most sought-after skills in their industry, and by employers to prioritize the development of these skills in their workforce.

6. Overview of current educational offerings at higher education institutions

Hydrogen-related education in the Netherlands

Energy-related education in the Netherlands covers a wide range of subjects, including sustainable energy systems, renewable energy sources, energy management, and energy efficiency. Several universities and colleges in the country offer both undergraduate and graduate programs in these fields, with some notable institutions including Delft University of Technology, Eindhoven University of Technology, and the University of Twente.

Hydrogen-related education in the Netherlands is rapidly growing. The country is actively pursuing the development and implementation of hydrogen technology, especially in the Northern Netherlands. Several universities and colleges in the Netherlands offer programs in hydrogen technology, fuel cells, and related subjects. In addition to the aforementioned universities, other institutions such as Utrecht University provide a more multidisciplinary outlook. The technical universities offer undergraduate and graduate programs in energy engineering, chemical engineering, and other related fields, with a specific focus on hydrogen technology.

Next to classroom-based learning, there are hands-on training programs, workshops, and courses available for professionals who want to enhance their knowledge of energy. There are also research institutes and organizations dedicated to advancing energy and hydrogen research and development. The Netherlands Organisation for Applied Scientific Research (TNO) is a leading research institute in hydrogen technology, and the Netherlands Enterprise Agency (RVO) provides funding and support for hydrogen-related projects.

The Netherlands as a whole has a strong focus on sustainable energy and a developing education system for hydrogen technology that provide a good steppingstone for achieving the great scale of future hydrogen goals in terms of human capital. This emerging and well supported system can also help drive innovation and progress in this area. This chapter provides an overview of the current education at a national level.

Hydrogen education inventory

The Netherlands has a total of 43 universities of applied sciences (HBO level) and 13 universities (WO level), which include 3 Universities of Technology (TUs). In order to map out the existing education on the subject of the energy transition and hydrogen, an analysis of the current educational offer was conducted on the websites of the educational institutes[13]. Additionally, the qualitative interviews were used to provide a more in depth look into the educative perspective of learning about hydrogen and providing sufficient human capital for the evolving hydrogen economy.

The hydrogen related education ranges from short courses and workshops to full track degree programs. Students can choose from a range of disciplines, including engineering, chemistry, physics, and environmental sciences. Many universities, such as Delft University of Technology, the University of Groningen, and the Eindhoven University of Technology, offer courses and programs in hydrogen technology, covering areas such as hydrogen production, storage, and utilization, fuel cells, hydrogen

[13] The complete overview is provided in
Appendix F: Overview of hydrogen related education in the Netherlands at HBO, WO and postgraduate levels.

safety, and hydrogen policy and economics. Moreover, there are training centres and institutes, such as the Dutch Hydrogen Platform, RVO and the Dutch Institute for Fundamental Energy Research (DIFFER) for instance, that provide research aid and opportunities, practical training in hydrogen technology and applications. These educative opportunities can equip students and professionals with the knowledge and skills needed to contribute to the development and implementation of hydrogen, making them well-positioned to take advantage of the growing demand for hydrogen expertise in the Netherlands and beyond.

Finally, there are several postgraduate options available that focus on hydrogen and can help stakeholders retrain their personnel who are expected to transition towards hydrogen. One of these postgraduate courses is the one offered by Brunel together with the New Energy Business School (the former Energy Delta Institute)[14]. This is a very recent postgraduate program that is aimed at experienced professionals in technical and legal areas, who want to increase their knowledge in the area of hydrogen and the energy transition. It consists of a series of lectures given over a 6-month period where all areas of hydrogen (and some areas of the energy transition) are covered: technologies, geopolitics, system integration, hydrogen transport, legal and regulatory aspects of hydrogen, etc., with also some focus on developing soft-skills of the participants.

Student motivation and study program choice

The process of choosing a study program is a critical decision for students, as it has the potential to impact their future career prospects and overall life trajectory. The factors that influence this decision-making process are complex and multifaceted, with individual, social, and environmental factors all playing a role. To better understand this process, qualitative research methods such as semi-structured interviews can provide valuable insights into the experiences, attitudes, and perceptions of students when choosing a study program. To this end, informal interviews and a survey were conducted with nine students from different backgrounds, all of whom were participants of the previous editions of the Post HBO Hydrogen training of Brunel and New Energy Business School[15]. These interviews provided in-depth information about the experiences of students regarding their (past) study program choices.

Reflections on current and future hydrogen education

There are ambitious plans in the Netherlands to become a hydrogen hub and a leader in hydrogen technology and innovation. This vision will require a skilled workforce with expertise in various aspects of hydrogen, from production to distribution and utilization. It is expected that the demand for hydrogen education and training will continue to grow, and universities and training centres will need to adapt and expand their programs to meet the needs of the industry and job market.

Notably, the list with hydrogen education provided can be seen as indicative. During the stakeholder interviews, programme managers of institutes on both universities and universities of applied sciences have indicated that there is a lot more happening within education on innovative sciences like hydrogen than can be measured or formally documented. Lecturers are responsible for ensuring that their courses are relevant, engaging, and up to date with industry trends. In the case of the hydrogen industry, which is rapidly growing and evolving, there are many challenges and opportunities that can be used as a basis for course material and projects. For instance, lecturers can explore the technical, economic, and environmental aspects of hydrogen production, storage, and transportation in specific

[14] https://www.brunel.net/nl-nl/waterstof

[15] The background of the students surveyed is very broad, with some students having experience in the hydrogen transport industry, others in the energy sector, with a few more coming from governmental agencies and energy companies.

assignments at energy related studies. They can also examine the policy and regulatory frameworks that govern the hydrogen industry, as well as the social and cultural factors that influence public acceptance and adoption of hydrogen technologies.

Various hydrogen lectorates are starting on all levels of higher education and on learning community level. The industry is working on complex challenges in the evolving hydrogen economy and there are multiple perspectives that need to be considered. Learning communities with a multi-level approach are an excellent way to study the lifelike complexities of the field. Professionals (and students) from different backgrounds speak different languages and have different ways of problem solving. By working on a project in a learning community, students from different backgrounds are brought together, fostering multi-discipline communication skills, and working in teams additionally to the hard skill learning outcomes. Institutions such as EnTranCe and Saxion Hogeschool are examples of institutes who offer this kind of learning initiative.

One of the key ground principles of creating a successful learning community using lifelike challenges is good communication with the industry and other stakeholders. Some of the interviewed experts reported issues on this aspect of their work. There is a lot of time and dedication necessary to foster connections between educational institutes and the industry, which are luxuries a teacher or lecturer does not often have. Some institutes have solved this problem by hiring lecturers or lectorates who have an extensive professional network. This may really help the connection and communication between education and industry.

7. Conclusions

The energy transition has been gaining importance and momentum on the agendas of governments and organizations worldwide in an effort to slow down climate change; the Netherlands, along with many other countries, has set ambitious goals to reduce greenhouse gas emissions towards 2050 [1]. Hydrogen has been gaining particular attention in the last years as a means to achieve these emission reduction targets worldwide, due to its versatility as an energy carrier, its potential to decarbonize hard-to-abate sectors (i.e., that cannot be electrified), and its ability to store intermittent renewable energy in order to match supply and demand and provide flexibility to the energy systems.

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.

In this work, we present an estimation of the number of trained personnel that will be needed in the hydrogen transport industry in the Netherlands, where we found that between 1,800 and 4,700 full time jobs could be required in 2030 for the construction of hydrogen distribution systems or work in commissioning hydrogen transport to the built environment, and between 4,200 and 12,500 full time jobs could be made available to work in the operation and maintenance of such networks. These values are heavily dependent on the degree of uptake of hydrogen in the built environment

Existing education in the Netherlands in the form of electives, tracks, and specializations at HBO, WO, and postgraduate levels focused on the energy transition and hydrogen, provide a good stepping stone for achieving the future hydrogen goals in terms of human capital. Additionally, with reskilling opportunities for stakeholders such as gas managers expected to evolve into hydrogen, the human capital agenda is well-positioned to meet the given objectives. However, strategic thinking is necessary to act proactively and prevent a potential mismatch between the supply and demand of specialized personnel. This should involve bottom-up actions - starting from raising student awareness and motivation regarding climate change and the energy transition, to network operators and industry encouraging reskilling opportunities - but also top-down measures such as government actions to improve hydrogen-related offerings and improving retraining support, should be implemented.

Given the interactions between hydrogen and many different disciplines, multidisciplinary skill sets are preferred. They can simultaneously decrease the level of uncertainty in hydrogen developments and enable professionals to transfer their expertise to other sectors of the energy transition more easily. Furthermore, given the need for integrated solutions and the interactions between hydrogen and other energy carriers/vectors, a system integration or systems view approach is mainly required by the stakeholders, especially the network operators/industry.

Analysis of the current job market for hydrogen professionals

Based on a qualitative analysis of all the 285 job vacancy postings containing the hydrogen or 'waterstof' word not only in the title of the posting but anywhere in the description, it can be concluded that, at present, most jobs in the hydrogen economy require a broader approach that encompasses various fields of the renewable energy sector in addition to hydrogen. This is more evident from the ratio of job vacancies that include the term "hydrogen/waterstof" in their title to the total vacancies analysed (40/285). The findings highlight the fact that skills that are easily transferable among different sectors of the renewable energy field are highly valued in the current market. Nevertheless, from the insights from the data analysis, we can conclude that a basic understanding of the technical side of hydrogen is required for most jobs in the sector. This means that the basic knowledge from e.g., the (natural) gas industry already sets the basis for understanding hydrogen better. As such, for n(new) students this means that hydrogen-specific knowledge can be added as part of the curriculum of existing educational tracks for new students. In the end, this underscores the importance of engineering-related studies, or studies that include this discipline, as a foundation for working in the hydrogen economy.

In multiple jobs, such as those involving thermodynamics of different gases or in roles such as project managers/developers, many fundamental principles and skills can be applied to different energy sectors, including hydrogen. As a result, conventional energy and other renewable energy sectors and the respective stakeholders are well-positioned to transfer their employees and skills to hydrogen-related projects. This presents an opportunity for retraining existing personnel rather than upskilling a completely new workforce; specially for natural gas stakeholders in the country such as transport and distribution operators. Postgraduate institutions such as business schools could play a significant role in providing specialized training to bridge any knowledge gaps and develop the necessary skills for a successful transition to the hydrogen economy.

The current energy system is moving towards greater integration in order to achieve a zero emission economy. This means that there will be more interaction between different energy sources/vectors and industries, including hydrogen and other sectors. Professionals in these fields will need interdisciplinary skills and a systems-based approach that considers all relevant disciplines related to their work. These skills were highlighted multiple times in interviews with selected stakeholders. Moreover, a workforce with these abilities can also help manage the uncertainty that comes with developing a hydrogen economy. Investing in these skills can help mitigate the risk of losing skilled personnel if hydrogen plans do not materialize as expected. This can have benefits both at the macroeconomic scale as well as at company level namely, by transferring these workers to other renewable energy sectors or departments. These findings are supported by the results of the data analysis of job postings.

The overall findings suggest that the hydrogen economy is a rapidly growing field with a diverse range of job opportunities, requiring the expertise of professionals from various disciplines to work collaboratively to successfully develop a sustainable hydrogen economy. As this field continues to expand, professionals with the aforementioned skills, or more ideally a combination of them, will be needed, making it an exciting area for those interested in sustainable energy solutions and a promising opportunity for job seekers and people wanting to switch careers towards the energy transition.

Skills needed and current educational offerings related to hydrogen

To help taking a proactive approach in the development of hydrogen-related skills and avoid a 'skills gap', a list of the hard skills and their contribution to a hydrogen economy was derived from interviews with various hydrogen stakeholders in this research. From business/commercial, to safety, engineering, legal and digital skills, a range of different skills were identified and described. This list was validated through an analysis of the existing hydrogen-related jobs at a specific point during the development of the research. The interviews and analysis revealed that engineering skills, across various disciplines and including safety skills, were the most frequently mentioned.

Given the interactions between hydrogen and many different disciplines, multidisciplinary skill sets are preferred. They can simultaneously decrease the level of uncertainty in hydrogen developments and enable professionals to transfer their expertise to other sectors of the energy transition more easily. Furthermore, given the need for integrated solutions and the interactions between hydrogen and other energy carriers/vectors, a system integration or systems view approach is mainly required by the stakeholders, especially the network operators/industry.

Existing education in the Netherlands in the form of electives, tracks, and specializations at HBO, WO, and postgraduate levels focused on the energy transition and hydrogen, provide a good stepping stone for achieving the future hydrogen goals in terms of human capital. Additionally, with reskilling opportunities for stakeholders such as gas network operators expected to evolve into hydrogen, the human capital agenda is well-positioned to meet the given objectives. However, strategic thinking is necessary to act proactively and prevent a potential mismatch between the supply and demand of specialized personnel, given the scale of the transition. This should involve bottom-up actions - starting from raising student awareness and motivation regarding climate change and the energy transition, to network operators and industry encouraging reskilling opportunities - but also top-down measures such as government actions to improve hydrogen-related offerings and improving retraining support, should be implemented.

In such global assignment that is the creation of a hydrogen economy, cooperation is a key element on the success of the capacity building. This implies the coordination between all the different sectors and stakeholders interacting in a hydrogen economy, namely, governments, network operators, industry and academia, to ensure that the current demand for particular skills and the offer in the job market are adapted with time as the economy evolves.

Lastly, it is important to recognize that the development of a hydrogen economy workforce should encompass skills related to indirect industries as well (e.g., the water industry due to the upcoming large-scale electrolyzer applications). Furthermore, it is equally important to prioritize the development of soft skills to equip the workforce with the necessary skills for success in the rapidly evolving hydrogen economy.

8. Recommendations to enhance a timely development of the human capital needed in a hydrogen economy

The recommendations to address a potential shortage of hydrogen-related personnel at higher education levels arising from this research are grouped into academic, network operators/industry, and government categories. These recommendations were concluded based on the insights obtained through the stakeholder interviews, the data analysis, and the interviews with students.

For educational institutions stakeholders

1. A focus on multidisciplinary and systems studies should be a priority, given the growing interaction between different fields in the energy transition and the need for cross-disciplinary collaboration in hydrogen-related industries. This can allow easily transferable skills from the different fields of the energy transition sector in case the hydrogen economy does not materialize to the extent of the current plans.
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, can help to attract and retain students in the industry.
3. An effective way to help students familiarize themselves with the hydrogen economy is by incorporating assignments, exercises, or projects related to the topic into existing energy-transition related studies. This approach can be easily implemented and avoids the cost and time-intensive development of fully focused hydrogen-related studies. By providing students with practical applications of the concept, educators can help them gain a better understanding of the hydrogen economy and its significance.
4. Showcasing hands-on learning opportunities can help attract students to technical studies. This provides students with practical experience and helps them see the real-world applications of their education. To do this, highlighting these opportunities in high school, or in marketing materials and career fairs at universities can include tools like virtual reality and hydrogen production learning kits to showcase the 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. By showcasing the practical applications of their education and the potential for employment, students are better able to see the value of their studies.
6. Staying relevant in today's ever-changing technological landscape requires adapting education to the needs of newer generations. This includes incorporating new technologies and teaching methods that meet the demands of modern students. However, education must also prioritize developing both academic and practical skills that can prepare students for the workforce. By focusing on these areas, students can gain the necessary knowledge and expertise to succeed in their chosen fields while keeping their motivation.
7. Providing comprehensive student support services is crucial to ensuring student success. This includes offering a range of services such as tutoring, advising, mentorship programs, and career services to help students navigate the academic and professional world. It is also essential to foster a positive campus culture that creates an inclusive and welcoming environment for all students. This can be achieved by organizing social events, promoting clubs and organizations, and encouraging students to engage with the local community.
8. Lowering tuition fees or offering study scholarships for technical studies can incentivize students to pursue these programs. Such initiatives could include a payback commitment, where graduates share their working experiences with new generations of students. This can provide motivation and insight into potential job prospects.

9. Given the significance of soft skills in the professional world, higher education curricula could benefit from incorporating more soft skills training that is currently in demand in the job market. However, it's important to recognize that this attention should be tailored to the needs of employers, as the value of soft skills can vary substantially across economic sectors. By analyzing the demands of different employers, higher education institutions can provide students with the specific soft skills training they need to succeed in their chosen careers.

For the network operators/industry stakeholders

1. Inter- and extra-company traineeships offer young professionals the opportunity to exchange assignments and work in different departments or even different companies, providing valuable interdisciplinary experience. This type of program can help participants develop all-around skillsets needed for jobs in a hydrogen economy.
2. While there are currently organizations that offer extra-company traineeship opportunities related to the energy transition in the Netherlands (e.g., 'Talent voor Transitie', 'Vonk'), it is also advisable for stakeholders to collaborate directly with each other. This can involve sharing knowledge, resources, and best practices, as well as developing training programs.
3. Engagement between the industry and educational institutions through congresses and other forms of collaboration such as partnerships can facilitate open discussions and better alignment of their respective needs. Additionally, industry involvement through internships and assignments at various educational levels, including high school and elementary school, can motivate students to pursue studies related to a hydrogen economy.
4. In today's rapidly evolving job market, it's essential for hydrogen related employers to keep up with changing demands from new generations of employees in order to attract and retain skilled professionals. This includes factors such as flexible working arrangements, opportunities for career advancement and training, and an emphasis on work-life balance.
5. Developing training programs or fostering employee development (e.g., in cooperation with postgraduate institutes) and creating a learning culture can help to alleviate the burden of finding new employees with hydrogen-related skills. This could include in-house training programs, workshops, and seminars. Given the existing experience of many stakeholders in energy-related topics, such as natural gas transmission and distribution operators, this would be considered a relatively low-hanging fruit when considering the costs and efforts of retraining existing personnel versus hiring new personnel.
6. While it is recognized that developing a new hydrogen economy inherently carries uncertainties, it is advisable for stakeholders' executive departments to give more attention to planning and strategy to the potential needs for hydrogen-related skills. This proactive approach can help avoid potential shortages of human capital and ensure that the necessary talent is available to support the development and growth of the hydrogen economy. Investing in planning and strategy can also provide external signals of certainty, which may help to attract investment, foster innovation, and accelerate the deployment of hydrogen technologies. By taking a long-term view and investing in the necessary skills and talent, stakeholders can position themselves for success in the emerging hydrogen economy.
7. To avoid a personnel shortage related to hydrogen jobs (and to help solve the current shortage in the Netherlands), stakeholders can support diversity and inclusion encouraging underrepresented groups to pursue careers in the field and/or join their organization. This can involve developing targeted initiatives that promote diversity in education and training programs, as well as outreach programs to connect with underrepresented communities and showcase the benefits of a career in the industry. By promoting diversity and inclusion, stakeholders can access a wider pool of talent and bring new perspectives and ideas to the

table. Furthermore, it can help address systemic issues of inequality in the workforce and create a more equitable and inclusive industry.

8. A focus on safety is paramount in the hydrogen sector in order to prevent accidents and limit the impact of any incidents, which could have serious consequences for people and the environment. In addition, the perception and trust of the public are crucial for the success of a hydrogen economy. If the public perceives hydrogen as unsafe or risky, companies may face challenges in securing funding, partnerships, or customers. Therefore, prioritizing safety skills is essential for companies in the hydrogen sector to build trust with the public and demonstrate their commitment to responsible business practices.

For the government stakeholders

1. Reinforcing basic education related to climate change by incorporating it into the school curriculum can help raise awareness, interest and understanding among students from a young age. This can include educating students on the basics of climate change, its causes and effects, and the importance of transitioning to a low-carbon economy including the potential of hydrogen, to later motivate students to choose a hydrogen-related profession.
2. It is recommended to continue fostering collaboration between hydrogen stakeholders by setting up funding programs that prioritize the development of human capital in the hydrogen economy. Examples of such programs include GroenvermogenNL[16], which includes creating regional clusters that identify the unique characteristics and needs of each region in terms of human capital development.
3. To encourage companies to hire and retain skilled workers in the hydrogen industry, governments can offer financial incentives such as tax credits or grants for developing training programs for their employees. Additionally, creating certification programs and offering subsidies for companies that employ certified workers can further incentivize companies to invest in their employees' training and development. Moreover, subsidies targeted to the general public (such as the STAP[17] budget) can be made more attractive or adapted for those areas of the workforce where specific skills are in higher demand.
4. To provide more clarity and certainty for stakeholders to invest in hydrogen-related projects, it is important for governments to establish transparent and well-defined national objectives strategies, and policy mechanisms to promote a hydrogen economy. This can help signal to potential investors that there is a long-term commitment to the development of the hydrogen industry. Additionally, it can guide industry and educational institutions in developing appropriate training programs to acquire the necessary skills and provide a clear understanding for new students seeking to enter the industry on time.
5. It is important to adapt to the ever-changing hydrogen sector by continuously monitoring the labor/economic market and adjusting policies accordingly, to ensure that there is an adequate supply to support the growth of the industry. By doing so, the government can help prevent skill shortages and ensure the long-term success of the hydrogen economy.

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[16] https://groenvermogennl.org/

[17] The STAP budget is a budget offered by the Dutch Education Service (DUO, Dienst Uitvoering Onderwijs in Dutch) for people to continue their education after entering the workforce or being unemployed. The STAP budget in its current form will end in 2024, and the government is looking at different ways to continue stimulating education for professionals and people in working age. For more information, the reader is encouraged to visit https://www.rijksoverheid.nl/onderwerpen/leven-lang-ontwikkelen/leven-lang-ontwikkelen-financiele-regelingen/stap-budget

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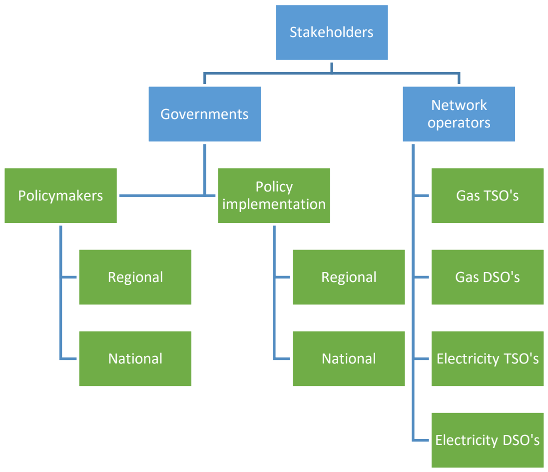
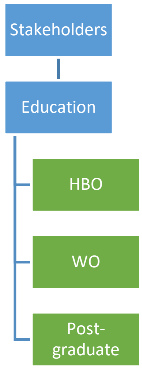
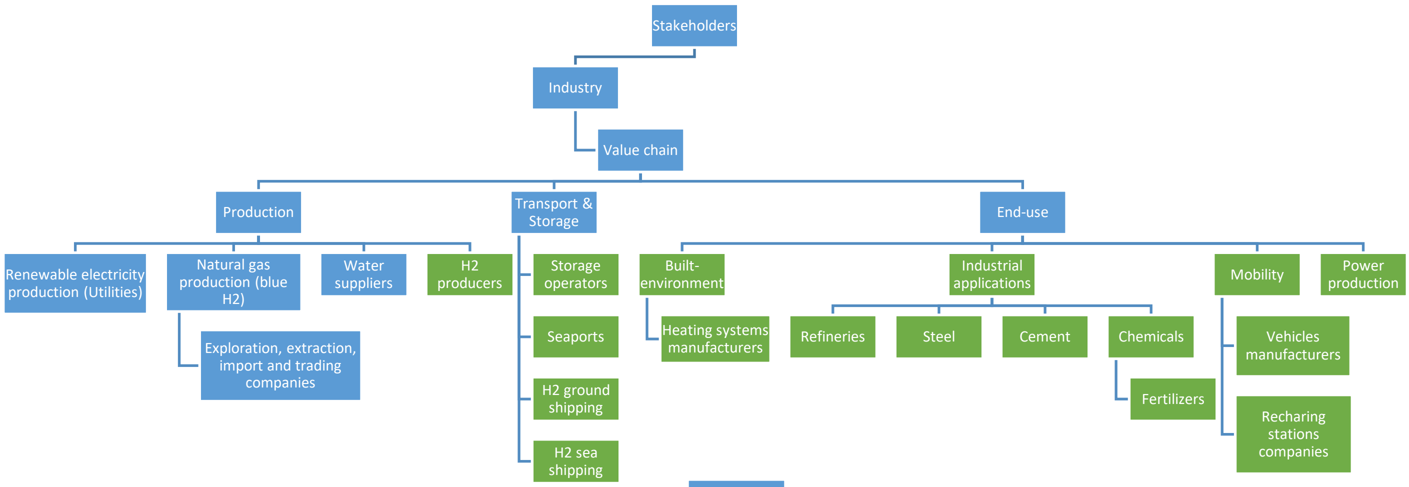
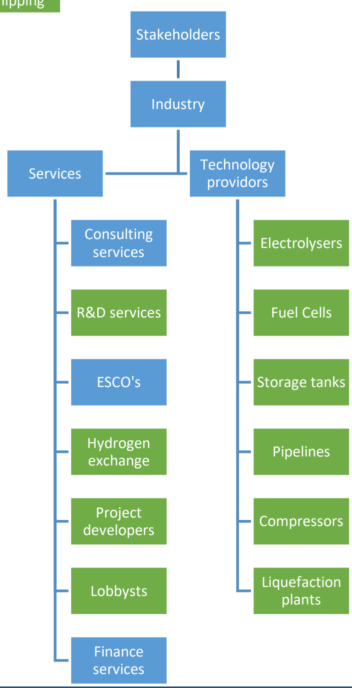
Appendix A: Stakeholder map

Note: the stakeholders considered as direct stakeholders for this study (meaning that they have a direct interest in this study) have been highlighted in green.









Appendix B: Interviewed organisations

Organisation interviewed	Type of organisation
Air Liquide	Gas company
Brunel	Job subcontractor
Enexis	Network operator
Fluvius	Network operator
Gasunie	Network operator
Gemeente Groningen	Government
Hanzehogeschool Groningen	Research & education institution
New Energy Business School	Research & education institution
Resato	Original Equipment Manufacturer
Rotterdam Seaports	Port manager
RVO	Government
RWE	Energy company
Saxion Hogeschool	Research & education institution
Stedin	Network operator
TNO	Research & education institution
University of Twente	Research & education institution

Notes:

1. The table above shows the parties that were interviewed and whose transcripts were used in the analysis shown in this document.
2. There were more interviews with other parties that are not named in the table above. It could be that not all parties interviewed had a meeting note done, therefore those interviews were not added to the analysis we did; therefore, we did not add their names to the table above.
3. Besides companies, we also interviewed a number of students, some of whom participated in the Post-HBO Waterstof course, offered by Brunel in cooperation with the New Energy Business School.

Appendix C: Interview template

1.	**Welcome and introduction** • Recording • Introduce yourself participants • Introduction Adrian & NEC (Adrian) • Introduction Mariska • Introduction WP. 11 and aim (Mariska)	Mariska & Adrian
2.	**Interview Questions** Internal perspective **What type of jobs has the hydrogen economy brought to your company in the previous years?** **What type of skills do those jobs entail?** **Have you retrained your own personnel? Developers** **What is the current situation in terms of match between the company's demand of human capital and the offer? Are there any risks associated?** **Do you have any internal scenarios related to employment and a hydrogen economy?** External perspective **What expectations for other jobs do you see outside your company? What do you think are the main jobs and skills needed for this hydrogen economy?** Recommendations **What are the recommendations originating from an industry perspective?**	Adrian & Mariska
3	**Closing**	Adrian & Mariska

Appendix D: Mentioned hard skills in the hydrogen-related job openings analysed

Skill(s)	Number of times mentioned
Knowledge/experience in the hydrogen sector	19
Experience/knowledge with modelling/programming software	5
Knowledge/experience of safety regulations and requirements	5
Knowledge/experience with fuel cell systems	4
Experience in consultancy	3
Experience in project development	3
Experience in the refinery industry	3
Experience in the renewable energy sector	3
Experience with industrial gases	3
Experience in power distribution systems	2
Experience in the energy sector	2
Experience in the oil and gas industry	2
Experience with design software	2
Experience with Microsoft Excel	2
Affinity with combustion engines and fuel injection equipment	1
Cryogenics knowledge	1
Experience in carbon capture, utilization and storage	1
Experience in corporate finance advisory and /or project finance	1
Experience in energy systems	1
Experience in municipalities and regional public organizations	1
Experience in product development	1
Experience in strategy	1
Experience in systems engineering	1
Experience in tendering sales process	1
Experience in the chemical industry	1
Experience in the field of finite element methods	1
Experience materials development	1
Experience with composite manufacturing	1
Experience with electric codes	1
Experience with electron beam-induced grafting	1
Experience with testing electric hardware	1
Experience in energy/sustainability consultancy	1
Knowledge of economic principles	1
Knowledge of energy markets	1
Knowledge of environmental regulation and policy	1
Knowledge of fiber optics	1
Knowledge of high voltage equipment	1
Knowledge of permitting for chemical and industrial gases	1
Knowledge of scientific principles	1
Knowledge of sustainability	1
Knowledge of sustainable mobility	1
Knowledge of system engineering/integration	1
Knowledge of the energy transition	1
Knowledge/experience of energy regulation	1
Knowledge/experience of industrial regulations	1
Laboratory experience	1
Proven scientific track record	1

Appendix E: Mentioned soft skills in the hydrogen-related job openings analysed

Skill(s)	Number of times mentioned
Communication skills	27
English proficiency	20
Team work skills	18
Project management skills	15
Stakeholders management skills	13
Dutch proficiency	12
Ability to work independently	10
Self-motivated	10
Commercial skills	8
Analytical skills	7
Hands-on mentality	7
Proactive	7
Results oriented	7
Ability to work in a multicultural environments	6
Ability to work in a multidisciplinary environments	6
Creative skills	6
Problem solving skills	6
Negotiation skills	5
Customer oriented	4
Leadership skills	4
Learning skills	4
Thinking out-of-the-box skills/innovative	4
Flexible	3
Anticipation skills	2
Entrepreneurial skills	2
Networking skills	2
Persistent	2
Solutions oriented	2
Ability to work in a fast paced environment	1
Adaptable	1
Assertive	1
Attention to detail	1
Awareness skills	1
Focus on details	1
French proficiency	1
German proficiency	1
Goals oriented	1
Good listener	1
Multitasking skills	1
Open-minded	1
Personal initiative	1
Spanish proficiency	1
Strong in conceptual development and selection	1

Appendix F: Overview of hydrogen related education in the Netherlands at HBO, WO and postgraduate levels

Institute name	Education level	Study programme
Brunel	Post-hbo	Waterstof Specialist
Delft University of Technology	Master	MSc Energy and Process Technology, Hydrogen Track
Dutch Hydrogen Platform	Network	A network of companies, organizations, and government agencies focused on promoting hydrogen as a sustainable energy source
Dutch Institute for Fundamental Energy Research (DIFFER)	Post-Graduate	Hydrogen-related research on materials science and electrochemistry
Energy Research Centre of the Netherlands (ECN)	Post-Graduate	Hydrogen Research Program
HAN University of Applied Sciences	Course	Cursus Waterstof
HAN University of Applied Sciences	Bachelor	Chemical Engineering, Hydrogen Specialization
HanzePro	Course	Hydrogen | Energy Law and Safety regulations
HanzePro	Course	Hydrogen | Introduction into analysing and reducing safety risks associated with designing Hydrogen installations
HanzePro	In-Company	Hydrogen| Introduction to application and safety
Hydrogenious	Knowledge Platform	Educational platform for hydrogen technology and its applications in the Netherlands
Hydromotive (ACE)	Applied University/Vocational	ACE mobility ACE Hydrogen Test Facility
Hydromotive (ACE)	Applied University/Vocational	ACE Academy: Waterstof en Alternatieve brandstoffen werkgroep
Hydromotive (ACE)	Applied University/Vocational	H2 Mobility Lab
New Energy Academy	Extracurricular	Global Hydrogen course
New Energy Business School	Post-Graduate	Hydrogen’s Role in the Energy Transition
New Energy Business School	Post-Graduate	Intensive Course Hydrogen
New Energy Business School	Post-Graduate	Masterclass Hydrogen
PHOE (PostHBO Opleidingen in Energie	PostHBO	Hydrogen Course [in development]
Rijksdienst voor Ondernemend Nederland (RVO)	Knowledge platform	A Knowledge platform for hydrogen education and research in the Netherlands
Rijksdienst voor Ondernemend Nederland (RVO)	Funding & support	Funding and support for Hydrogen research and development projects
TVVL	Course	Hydrogen in the built environment
University of Groningen	Master	Energy and Environmental Sciences, Hydrogen Track
University of Twente	Master	Sustainable Energy Technology, Hydrogen Track
Nederlandse Waterstof en Brandstof Associatie (NWBA)	Knowledge platform	The NWBA promotes the collection and generation of relevant knowledge, the provision of information, education and training