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INDUSTRIAL DEVELOPMENT ORGANIZATION



GLOBAL PROGRAMME
GREEN HYDROGEN IN INDUSTRY



CLEAN HYDROGEN SKILLS ASSESSMENT METHODOLOGY



Centre for Sustainable
Structural Transformation
SOAS UNIVERSITY OF LONDON

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The report was led by Petra Schwager, Smeeta Fokeer and Sven Schuppener.

Authors: Prof. Antonio Andreoni, Dr. Keno Haverkamp, and Dr. Abraham Lartey (Centre for Sustainable Structural Transformation, SOAS, University of London). Country assessment conducted by Amal Sdiri and Malek Mejri (Matine Consulting) as well as Adel Taha and Noha El Balky (Federation of Egyptian Industries, ECO-FEI).

UNIDO contributors: Jan Bernd Sievernich, Camila Daoudi, Ahmed Osama Hassan, Juan Pablo Davila, Pablo Navacerrada Busquets.

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The United Nations Industrial Development Organization (UNIDO) supports Member States in their efforts towards inclusive and sustainable industrial development and is committed to taking the lead in promoting an inclusive energy transition. With its long-standing experience in renewable energy projects and the application of clean energy technologies in industry, UNIDO successfully collaborates with a wide range of partners globally, supporting industries in their pathway to net-zero emissions.

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Contents

List of abbreviations.....	8
Executive Summary.....	10
1. Introduction	11
2 Clean Hydrogen, Industrial Transformation and Policy.....	16
2.1 Industrial skills development in emerging markets and developing economies: Challenges and opportunities.....	16
2.2 Clean hydrogen value chain.....	18
2.2.1 Upstream value chain segments	20
2.2.1.1 Green hydrogen.....	20
Upstream renewable energy generation	20
Manufacturing of components for green hydrogen production.....	21
2.2.1.2 Blue hydrogen	22
Blue hydrogen production	22
Manufacturing of components and equipment for blue hydrogen production	24
2.2.2 Midstream value chain segments	23
Hydrogen storage	23
Hydrogen transport.....	24
2.2.3 Downstream value chain segments	24
2.3 Investments, skills and employment: Evidence-based policy design	25
3. Skills Assessment Methodology for Policy Design.....	28
3.1 Analytical framework	28
3.2 Skills demand: Industrial activities and technical jobs.....	31
3.2.1 Integrated methodology for skills demand assessment.....	31
3.2.1.1 Skills transferability: Enhancing workforce agility.....	32
3.2.1.2 Occupation complexity.....	39
3.3 Skills supply: Quantity, quality and demand-supply mismatches	43

4. Methodology Pilots: Applications and Results 46

4.1 Egypt: Overview 46

4.1.2 Egypt: Assessment..... 47

4.1.3 Egypt: Policy recommendations 53

4.2 Tunisia: Overview.....54

4.2.2 Tunisia: Assessment..... 54

4.2.3 Tunisia: Policy recommendations..... 62

5. Systematic Guide: Implementation Strategy of UNIDO’s Methodology 64

Phase 1: Engage key stakeholders 65

Phase 2: Data collection and analysis.....65

 Data collection..... 65

 Data analysis 66

Phase 3: Road-mapping and strategic plan development 66

APPENDIX A 68

APPENDIX B 71

APPENDIX C 72

List of Figures

Figure 1. Different hydrogen types.....	12
Figure 2. Hydrogen production by technology and region.....	13
Figure 3. Hydrogen use by sector and region	14
Figure 4. Map of announced low-carbon hydrogen production projects, 2024	14
Figure 5. Learning-adjusted years of schooling (around 2020) and GDP per capita in sub-Saharan Africa in 2022	17
Figure 6. Hydrogen value chain	19
Figure 7. Hydrogen value chain	20
Figure 8. Pillars of UNIDO's methodology for skills mapping in clean hydrogen value chains.....	29
Figure 9. Clean hydrogen value chain with industrial activities.....	30
Figure 10. Skills demand methodology.....	32
Figure 11. Distribution of surveyed firms by category and size.....	48
Figure 12. Employment by occupation and gender in Egypt's green hydrogen upstream and midstream industries ...	49
Figure 13. Employment by occupation and gender in Egypt's green hydrogen downstream industries.....	50
Figure 14. Employment by occupation and gender in Egypt's green hydrogen support industries	50
Figure 15. Employees by occupation and firm size in Egypt's fertilizer industry.....	51
Figure 16. Gender composition by occupation in Egypt's fertilizer industry.....	52
Figure 17. Enrolment in green hydrogen-related academic programmes in Egypt.....	53
Figure 18. Distribution of surveyed firms by industry category and size in Tunisia.....	55
Figure 19. Employment by occupation and gender in Tunisia's green hydrogen upstream and midstream industries	56
Figure 20. Employment by occupation and gender in Tunisia's green hydrogen downstream industries	57
Figure 21. Employment by occupation and gender in Tunisia's green hydrogen support industries	58
Figure 22. Employees by occupation and firm size in Tunisia's electricity generation, transmission and distribution	59
Figure 23. Gender composition by occupation in electricity generation, transmission and distribution in Tunisia	60
Figure 24. Enrolment in green hydrogen-related fields in Tunisia.....	61
Figure A1.1. Skills mapping procedure	70

List of Tables

Table 1. Skills transferability across the green hydrogen value chain 34

Table 2. List of highly complex occupations.....40

Table A.1. Identified areas of expertise and skills essential for the hydrogen sector 68

Table A.2. Industrial survey response rate in Tunisia 71

Table A.3. Industrial survey response rate in Egypt 71

List of Boxes

Box 1. Workforce composition and firm size in Egypt’s fertilizer industry..... 51

Box 2. Workforce composition and firm dynamics in Tunisia’s electricity industry.....59

Abbreviations and Acronyms

AEM	Anion exchange membrane electrolyzer	MRO	Maintenance, repair and operation
ATR	Autothermal reforming	Mt	Metric ton
BEV	Battery-electric vehicles	Mt CO ₂	Metric tons of carbon dioxide
CAD	Computer-aided design	Mtpa H ₂	Million tons per annum of hydrogen
CBAM	Carbon Border Adjustment Mechanism	NG	Natural gas
CCS	Carbon capture and storage	NLP	Natural Language Processing
CCUS	Carbon capture, utilization and storage	OECD	Organisation for Economic Co-operation and Development
CO ₂	Carbon dioxide	OP	Occupational Profile
CSST	Centre for Sustainable Structural Transformation	PEM	Proton exchange membrane
DRI	Direct reduced iron	POx	Partial oxidation
EAF	Electric arc furnaces	PtX	Power to X
EMDEs	Emerging markets and developing economies	PV	Photovoltaic
ESCO	European Skills, Competencies, and Occupations	QSE	Quality, safety, and environment
FCEV	Fuel cell electric vehicle	R&D	Research and development
GDP	Gross domestic product	RE	Renewable energy
GHG	Greenhouse gas	RES	Renewable energy sources
GW	Gigawatt	SME	Small- and medium-sized enterprise
H ₂	Hydrogen	SMR	Steam methane reforming
ILO	International Labour Organization	SOEC	Solid oxide electrolyzers
ISCO	International Standard Classification of Occupations	TVET	Technical vocational education and training
kg CO ₂ -eq/kg H ₂	Kilograms of carbon dioxide equivalent per kilogram of hydrogen	UNIDO	United Nations Industrial Development Organization
Kt	Kiloton	VAT	Value-added tax
LH ₂	Liquefied hydrogen		
LOHC	Liquid organic hydrogen carrier		
MEP	Mechanical-electrical-plumbing		





Executive Summary

In the global transition to sustainable energy, emerging markets and developing economies (EMDEs) are well-positioned to lead the change in clean hydrogen production. As these countries pursue a shift towards more sustainable energy sources, developing a clean hydrogen industry presents an opportunity for economic growth, technological progress, and environmental stewardship. However, successful implementation of clean hydrogen projects depends on a skilled workforce equipped with the necessary expertise in engineering, chemistry, renewable energy, and related fields.

To advance the hydrogen economy in EMDEs, the United Nations Industrial Development Organization (UNIDO), in collaboration with the Centre for Sustainable Structural Transformation (CSST) at the School of Oriental and African Studies (SOAS), University of London, developed a skills assessment methodology. It can be used to identify the technical, scientific and managerial skills needed to effectively plan, implement and operate clean hydrogen facilities. The methodology also enables the design of targeted education and training programmes to build a skilled workforce that is capable of driving growth in the clean hydrogen sector.

UNIDO's methodology can be used to conduct a comprehensive assessment of skill needs, offering a clear picture of the current educational landscape and technical job profiles required for the development of the hydrogen economy. The skills assessment methodology is built on three interconnected pillars:

1. **Industrial Activities:** Mapping of industrial activities associated with the hydrogen value chain to understand the broader economic and industrial context
2. **Technical Job Profiles:** Defining the specific job profiles needed in the clean hydrogen industry to inform targeted training programmes
3. **Educational Programmes:** Reviewing existing educational programmes to align them with industry needs, with a focus on strengthening university curricula and technical vocational education and training (TVET) systems.

This comprehensive skills assessment methodology serves as a strategic tool to bridge the gap between the industry demands and current educational programmes, enabling resource-rich EMDEs to play a leading role in the global transition to sustainable energy.



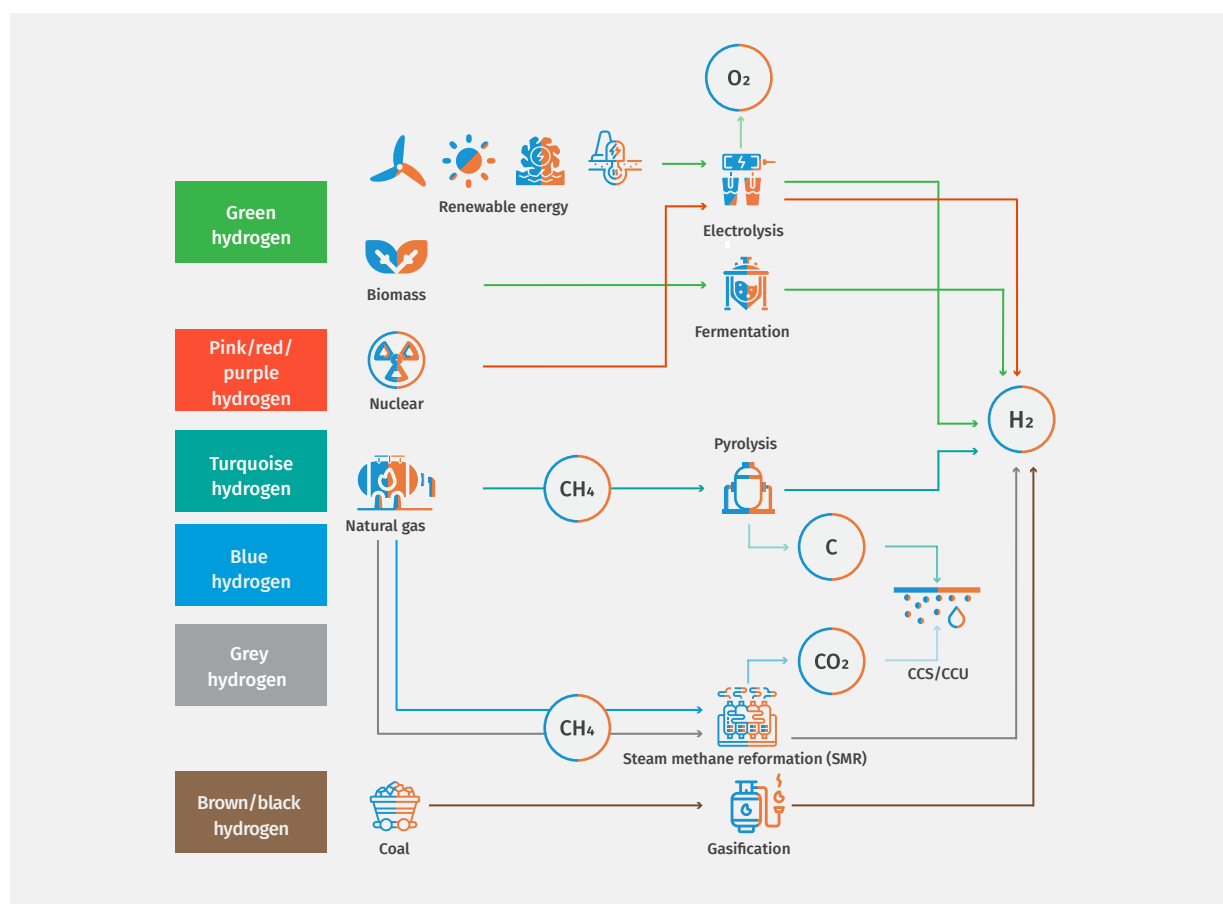
1. Introduction

Hydrogen has become a key element in the policy frameworks of both developed and developing countries, serving as a cornerstone of global decarbonization strategies. Its importance is particularly pronounced in hard-to-abate industries such as steel, iron, chemicals, cement and long-distance transport. Hydrogen can be produced through several methods (see Figure 1). One common approach relies on fossil fuel sources,

producing what is known as “grey hydrogen.” However, this production process is carbon-intensive and contributes substantially to greenhouse gas (GHG) emissions. On the other hand, hydrogen can also be produced using renewable or other low-carbon energy sources, or by applying carbon capture technologies to reduce emissions from fossil fuel-based production.



Figure 1. Different hydrogen types



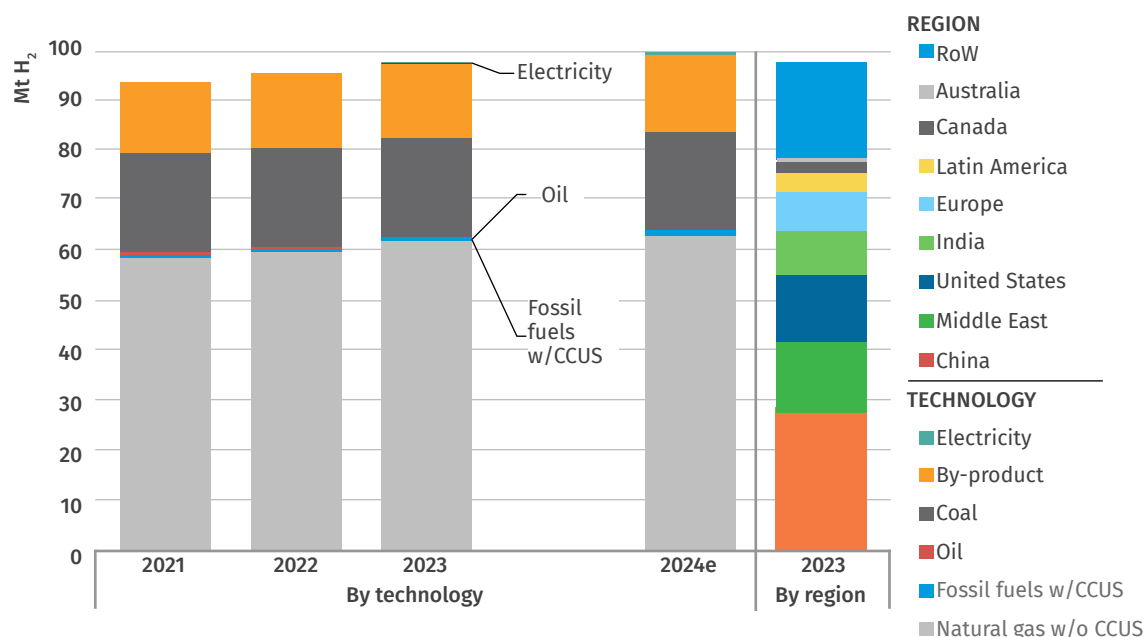
Source: Stamm et al., 2023¹

At present, hydrogen is predominantly produced from fossil fuels. In 2023, global hydrogen production reached around 97 metric ton (Mt), with China accounting for nearly 30 per cent of that total (Figure 2). The United States (U.S.) and the Middle East each accounted for 14 per cent, and India for 9 per cent. Two-thirds of production was derived from natural gas without carbon capture, while unabated coal—largely concentrated in China—made up another 20 per cent.

Low-carbon hydrogen accounted for less than 1 per cent of the total, generated primarily from fossil fuels combined with carbon capture, utilization and storage (CCUS). Hydrogen production through water electrolysis remained minimal (under 100 kiloton (kt)), and was concentrated in China, Europe, and the U.S., which together generated 75 per cent of global electrolytic hydrogen production.

¹ Stamm, A., Altenburg, T., Strohmaier, R., Oyan, E., & Thoms, K. (2023). Green hydrogen: Implications for international cooperation. With special reference to South Africa (IDOS Discussion Paper 9/2023). Bonn: German Institute of Development and Sustainability (IDOS). <https://doi.org/10.23661/idp9.2023>

Figure 2. Hydrogen production by technology and region



IEA. CC BY 4.0

Notes: By-product hydrogen from the chlor-alkali industry is not included. CCUS = carbon capture utilisation and storage; RoW = rest of world; 2024e = estimate for 2024. The estimated value for 2024 is a projection based on trends observed until June 2024.

Source: IEA, 2024²

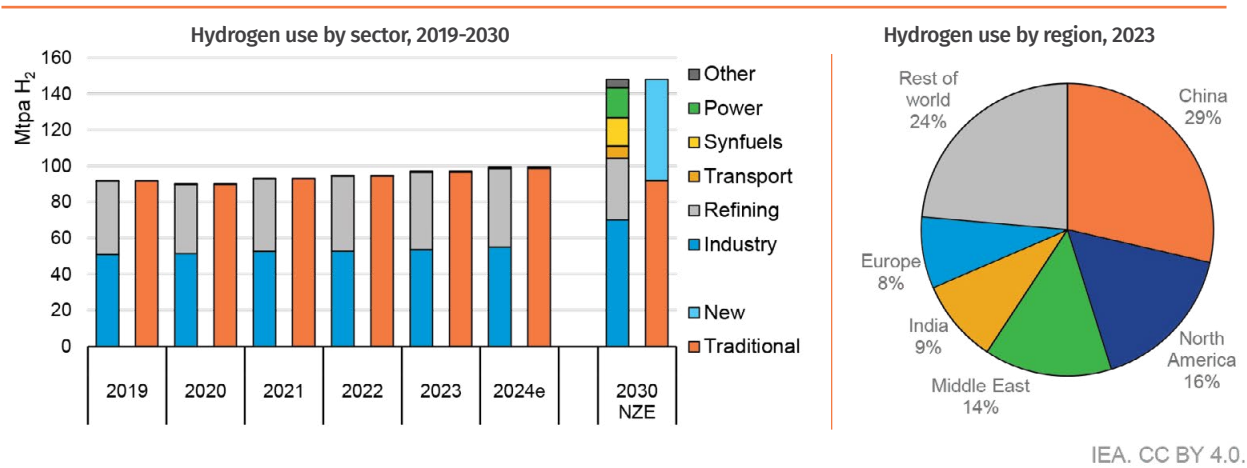
In 2023, global hydrogen production emitted 920 metric tons of carbon dioxide (Mt CO₂), equivalent to the combined annual energy-related emissions of France and Indonesia. Production from unabated natural gas released 10-12 kilograms of carbon dioxide equivalent per kilogram of hydrogen (kg CO₂-eq/kg H₂), while unabated coal emitted 22-26 kg CO₂-eq/kg H₂, with 75 per cent to 95 per cent of emissions occurring at the production site (IEA, 2024).

China is also the largest hydrogen consumer, accounting for nearly 30 per cent of global sup-

ply—more than twice that of the U.S.—driven by strong demand from refineries and the chemical industry. Currently, hydrogen use is concentrated in traditional industries such as refining, chemicals (as feedstock), and steelmaking (as a reducing agent). Emerging applications in heavy industry, transport, hydrogen-based fuels, and energy generation or storage remain limited, at less than 0.1 per cent of global demand. However, global demand is projected to grow by 6 per cent annually, surpassing 150 Mt by 2030, with nearly 40 per cent derived from such new applications (Figure 3).

2 IEA (2024). Global Hydrogen Review 2024, IEA, Paris <https://www.iea.org/reports/global-hydrogen-review-2024>

Figure 3. Hydrogen use by sector and region

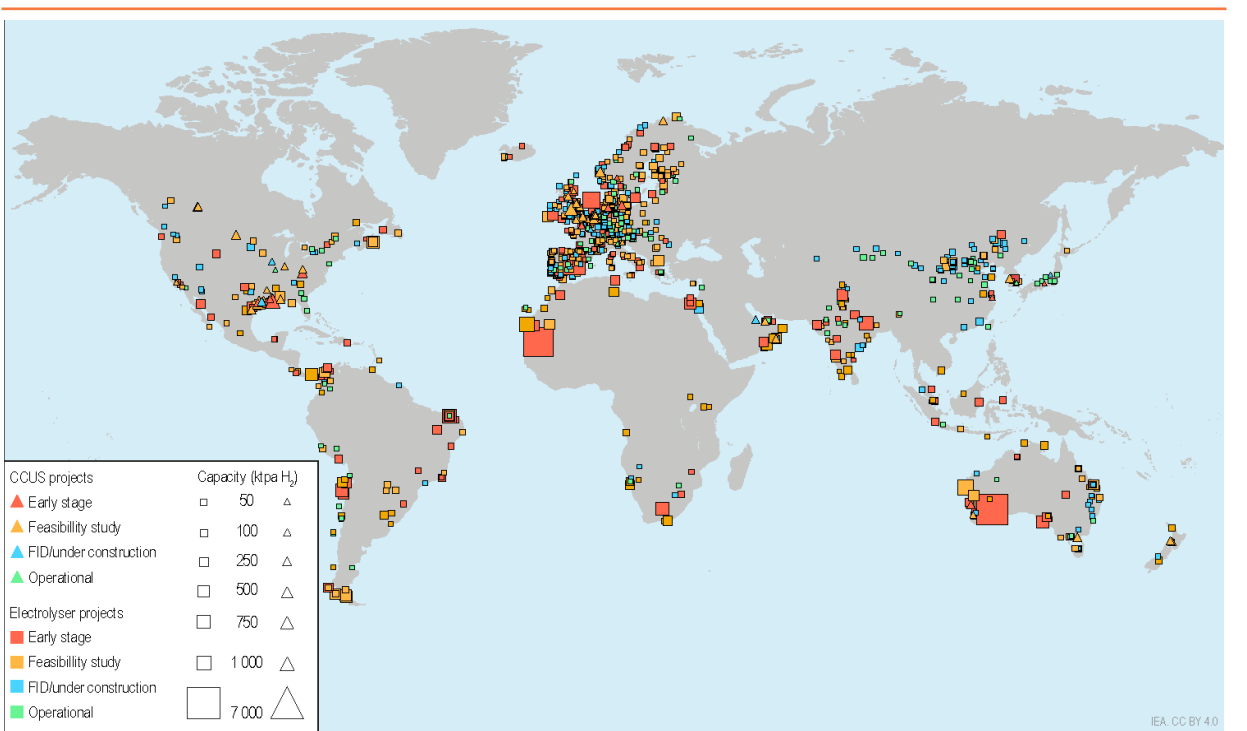


Notes: NZE = Net Zero Emissions by 2050 Scenario. “Other” includes buildings and biofuels upgrading. 2024e = estimate for 2024. The estimated value for 2024 is a projection based on trends observed until June 2024.

Source: IEA, 2024

According to IEA (2024), announced projects could increase annual low-carbon hydrogen production to 49 million tons per annum of hydrogen (Mtpa H₂) by 2030 (Figure 4). However, over 45 per cent of these projects are currently at the feasibility or early development stage, while only 7 per cent (3.4 Mtpa) are already committed, with 55 per cent based on electrolysis and 45 per cent on fossil fuels with CCUS. Excluding early-stage projects, production could exceed 26 Mtpa annually by 2030 (IEA, 2024). In some developing countries, particularly in Africa, most announced projects—totalling nearly 6 Mtpa of production—remain in early development stages, making full deployment by 2030 uncertain.

Figure 4. Map of announced low-carbon hydrogen production projects, 2024



The transition to sustainable energy is essential for effectively addressing climate change and securing energy access. Global energy consumption is projected to rise by 50 per cent by 2050, with growth in emerging markets and developing economies (EMDEs) reaching up to 70 per cent. Meeting this demand sustainably requires a comprehensive energy transition in which clean hydrogen not only enables effective energy storage but also supports diverse applications, particularly in fuel production. It can be produced through electrolysis, which splits water into oxygen and hydrogen. Clean hydrogen can be produced by deriving it from renewable energy, yielding green hydrogen; when produced from natural gas combined with carbon capture, it results in blue hydrogen, ensuring the process is climate-neutral.

By combining green or blue hydrogen with carbon dioxide, it can be converted into climate-neutral gas or synthetic liquid fuels, a process known as “Power to X” (PtX). PtX technology is a key component of future energy systems that rely entirely on renewable energy sources. For many hard-to-abate industries such as iron, steel, chemicals, cement and heavy transport, green hydrogen is the only viable path to zero emissions, making it indispensable for global net-zero strategies. Projections indicate that by 2050, hydrogen could supply between 4 per cent to 11 per cent of global energy demand, with a larger share expected in Europe than in China.³

While clean hydrogen offers significant potential to decarbonize non-electrifiable applications and strengthen energy security, maximizing the benefits of the clean hydrogen industry requires a highly skilled workforce with expertise in hydrogen technologies and infrastructure. Better-educated and skilled workers have more job opportunities, earn higher wages, and possess greater capacity to adapt. They boost productivity of both colleagues and capital and drive technological innovation which is crucial for economic diversification, productivity growth, and higher living standards (Almeida, 2012).⁴ Developing the necessary skills is essential for fostering innovation, ensuring efficient and safe clean hydrogen production and distribution, and integrating it into sectors such as transportation, industry and power generation.

In response to rising demand for hydrogen, 35 countries have either published or are in the process of developing national hydrogen strategies, with many more countries taking steps in this direction.⁵

3 Riemer, M., Zheng, L., Pieton, N., Eckstein, J., Kunze, R., & Wietschel, M. (2022). Future hydrogen demand: A cross-sectoral, multiregional meta-analysis (HYPAT Working Paper 04/2022). Karlsruhe: Fraunhofer-Institut für System- und Innovationsforschung (ISI).

4 Almeida, Rita, Jere Behrman, and David Robalino, eds. 2012. *The Right Skills for the Job?: Rethinking Training Policies for Workers*. Washington, DC: World Bank. DOI: 10.1596/978-0-8213-8714-6.

5 WEC (World Energy Council – Germany). (2022). International hydrogen partnerships. Retrieved from <https://www.weltenergieat.de/publikationen/studien/international-hydrogen-strategies/>



2. Clean Hydrogen, Industrial Transformation and Policy

2.1 Industrial skills development in emerging markets and developing economies: Challenges and opportunities

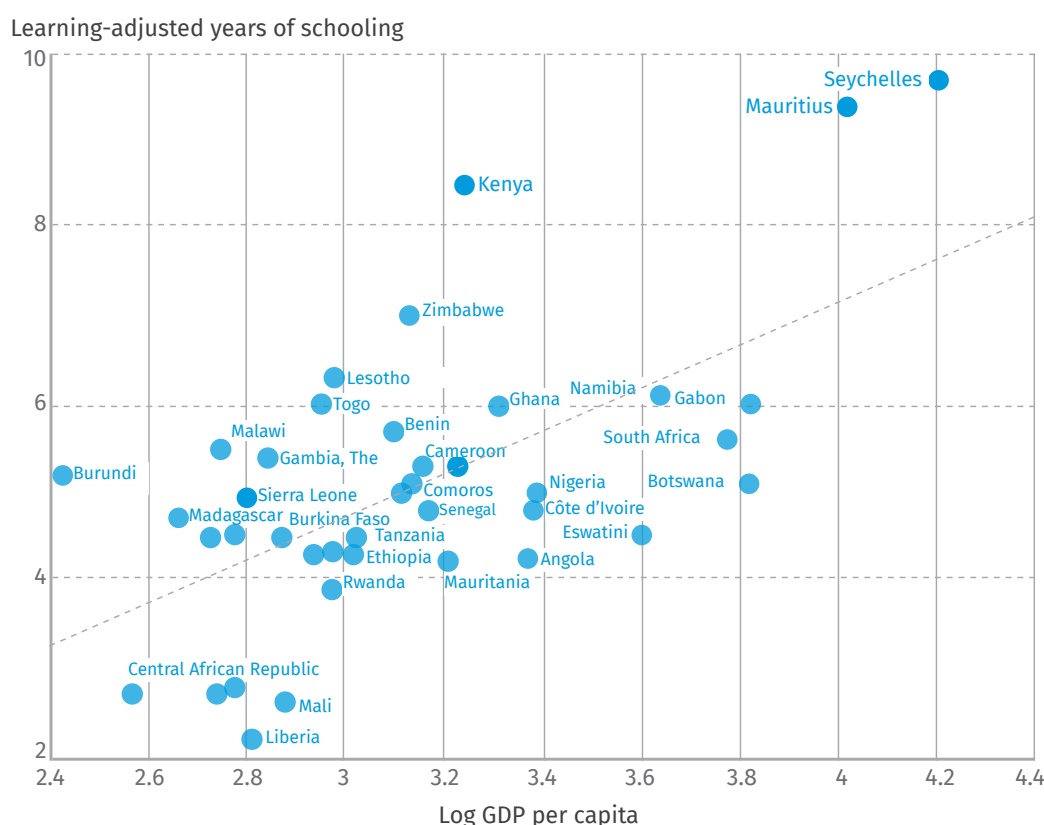
Most EMDEs are experiencing a learning crisis which significantly hampers the inclusive and sustainable industrial development of their economies. Across the globe, one-fifth of the population aged 15 or older without formal education live in extreme poverty, compared to just 3 per cent of those with higher education.⁶ In sub-Saharan Africa, 7 out of 10 children do not attend pre-primary education, and almost 9 in 10 chil-

dren are unable to read and understand a simple text by age 10. About one-third of children drop out of primary school due to economic pressures, early marriage, and poor school facilities (education spending in low-income countries is only USD 54 per student on average). Nearly 60 per cent of the poorest youth are not attending school. One additional year of education in sub-Saharan Africa boosts income by 12.4 per cent (14.5 per cent for women) compared to 10 per cent globally. With Africa's working-age population expected to double by 2050, improving education outcomes and workforce skills could add 11 per cent to 15 per cent to gross domestic product (GDP) by 2030 and lift 40 million to 60 million people out of poverty.⁷

⁶ [Poverty, Prosperity and Planet Report 2024.](#)

⁷ [Transforming Education for Inclusive Growth – Africa's Pulse Report 2024.](#)

Figure 5. Learning-adjusted years of schooling (around 2020) and GDP per capita in sub-Saharan Africa in 2022



Source: World Bank, 2024⁸

Least developed countries, particularly across Africa, require more skills, higher skill levels and different types of skill sets to produce essential goods and services and to transform their economies and societies. Skills development is critical for youth to access quality jobs and for promoting broader social mobility. Weak primary education affects the quality of skills across the entire education chain, with TVET institutions often compensating for gaps in basic education rather than focusing in work-relevant skills. Although the TVET sector has grown significantly in many countries and attracted several private providers, often incentivized by funding from multilaterals and philanthropic organizations, this expansion has not always translated into improved educational outcomes. Financing has often prioritized expanding access over enhancing quality (e.g. re-training of teachers, investment in facilities, etc.). Similarly, the higher-level education landscape faces challenges, including limited links with industry and in developing advanced skills aligned with present and future needs.

While a shortage of skills is evident, and firms often import expertise to fill key gaps, effective demand for skills remains limited. Relatively few firms possess the organizational capabilities to effectively deploy skilled workers and to adequately compensate them for increasing the firm's productivity. Most micro and small enterprises in semi-formal markets struggle to invest in technology or adopt organizational practices that support learning and innovation. Medium and large firms are more likely to operate in the formal economy, but in most EMDEs, there are too few to absorb and train the workforce. They also struggle to find experienced mid-level employees, such as production managers, logistics managers, etc. Consequently, many EMDEs paradoxically export skilled workers who cannot find suitable jobs locally while at the same time importing expensive expertise from abroad (Andreoni et al., 2024).⁹

⁸ World Bank. 2024. Transforming Education for Inclusive Growth. Africa's Pulse, No. 30 (October 2024). World Bank, Washington, DC. doi:10.1596/978-1-4648-2176-9

⁹ Andreoni, A. S. van Huellen, L. Katera & C. Jahari (2024). How to overcome rent seeking in Tanzania's skills sector? Exploring feasible reforms through discrete choice experiments, World Development, Volume 182, 106705

Technological advancements continually redefine industries' skills needs and job profiles. The Fourth Industrial Revolution and the green transition are driving both incremental and radical changes, especially in production technologies, with significant implications for skills development. First, TVET (and most universities) are in a persistent race to catch up; even when training programmes are updated frequently and rapidly, the rate of technological change tends to outpace them (so-called 'Red Queen effect'). Second, many new digital and renewable technologies arise from 'technology fusion', combining innovations from multiple fields of science and engineering (Andreoni et al., 2021).¹⁰ This creates challenges for educational institutions because they need to completely overhaul their training programmes. This pattern is not new, however. In the 1990s, the increasing integration of electronics and mechanical engineering into 'mechatronics' called for new skills training programmes. In many African countries, skills development is still catching up with technologies from the past two decades, while new value chains, such as the green hydrogen value chain, are emerging. Without upskilling, these technological developments may not translate into new job creation.

EMDEs that have identified hydrogen as a key element of their energy strategies must ensure that value chain's technical sustainability. Countries with abundant hydrocarbon and renewable energy resources can leverage these to produce clean hydrogen and its derivatives, opening up numerous opportunities for industrial growth. By capitalizing on their resource endowments, these countries can increase value addition, boost job creation, and strengthen domestic technological expertise. The positive impact on development can be further amplified through strategic investments in industrial forward and backward linkages, fostering stronger connections across industries (Altenburg et al., 2022; Andreoni and Roberts, 2025).¹¹

2.2 Clean hydrogen value chain

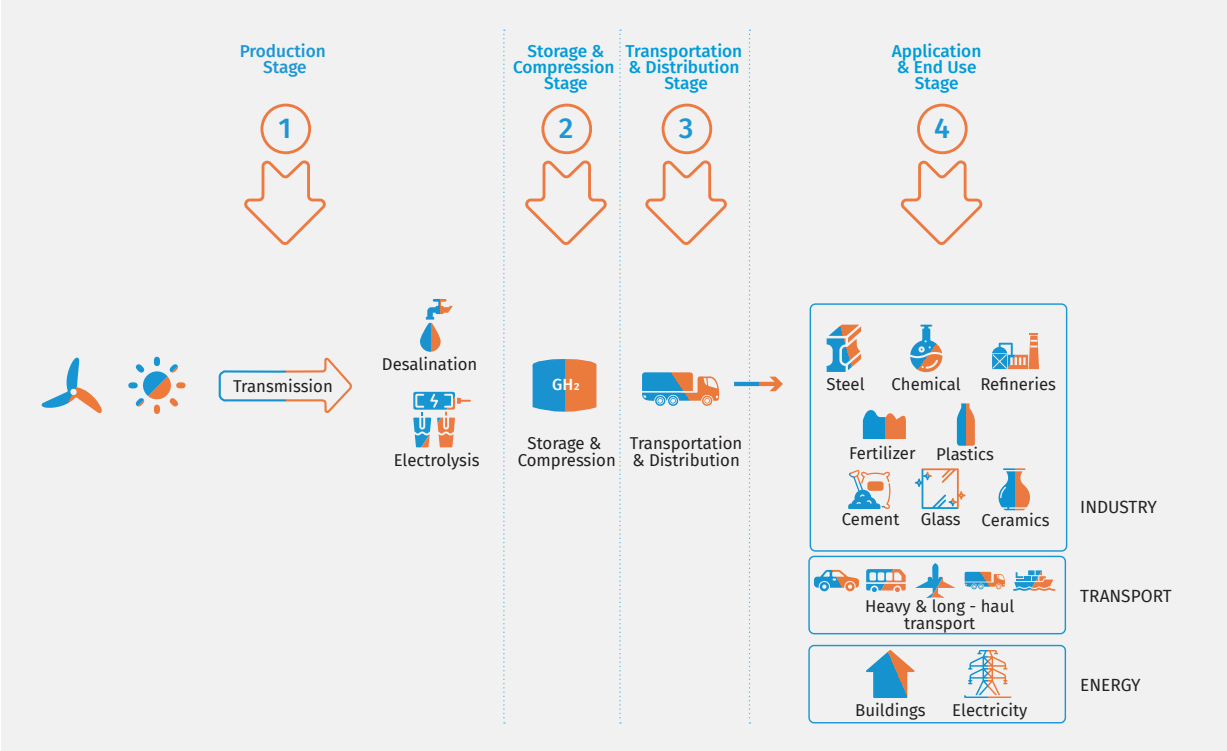
The clean hydrogen value chain includes upstream, midstream and downstream segments, which can be developed individually or simultaneously. By engaging in each segment of the hydrogen value chain, EMDEs can create sustainable jobs, add long-term value, strengthen global competitiveness, and reduce risks associated with international hydrogen trade.

Figure 6 provides an overview of the hydrogen value chain. Upstream segments involve the manufacturing components, materials and equipment for hydrogen production. Electrolysers are the most important production technology for hydrogen production. This segment also includes renewable energy production and the associated development, manufacturing and operational segments of renewable energy projects, such as solar and wind farms. Midstream segments focus on the logistics of storing and transporting hydrogen from production sites to areas of demand, including hydrogen compression, liquification and reconversion. Downstream segments cover the conversion of hydrogen into end products and end-use applications across different sectors. This also includes maintenance, repair and operation (MRO) services.

¹⁰ Andreoni, A., Chang, H.-J. and M. Labrunie (2021) *Natura non facit saltus: Challenges and opportunities for digital industrialisation across developing countries*, *European Journal of Development Research*, 33(2): 330-370, 2021.

¹¹ Altenburg, T., Wenck, N., Fokeer, S., & Albaladejo, M. (2022). *Green hydrogen: Opportunities for industrial development through forward linkages from renewables*. Research Network Sustainable Global Supply Chains. Retrieved from <https://www.sustainable-supplychains.org/green-hydrogen-opportunities-for-industrial-development-through-forward-linkages-from-renewables/>
Andreoni, A. and S. Roberts (2025) *Minerals, Energy-Intensive Industries, and Development*, in: Jayadev, A., Noman, A. and J. Stiglitz (eds.) *The Future of Work in Developing Countries*, Columbia University Press.

Figure 6. Hydrogen value chain



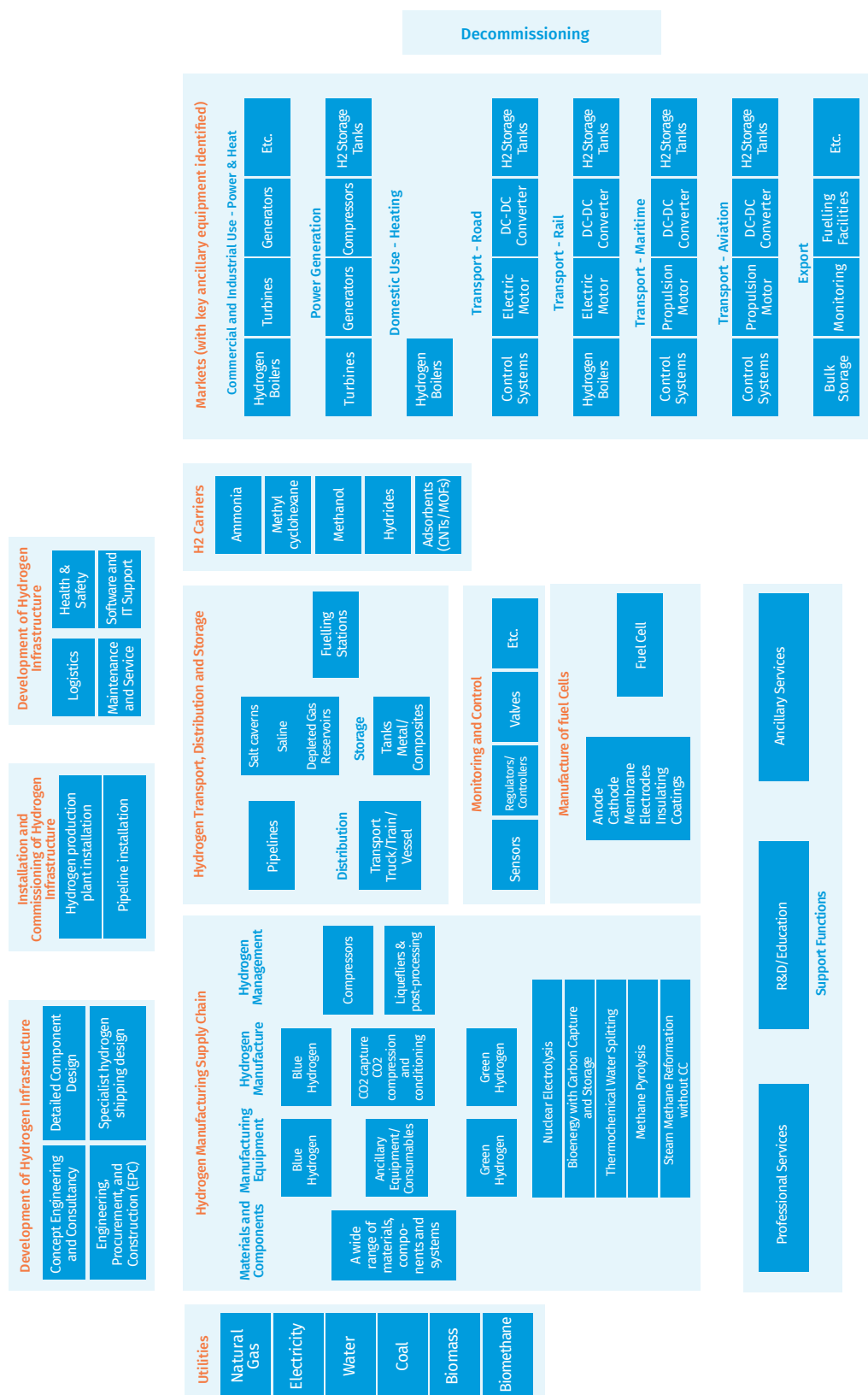
Source: UNIDO

Blue and green hydrogen rely on different production technologies, but both share common components such as compressors, pumps, and electrical equipment (e.g. transformers and rectifiers). These similarities and differences are better captured through more granular value chain schematics (BEIS, 2022). For example,

while green hydrogen production typically uses renewable energy for electrolysis, while blue hydrogen relies on steam methane reforming with carbon capture. Despite the differences in energy source and production method, the overall scale and type of equipment used in both systems is largely similar.



Figure 7. Hydrogen value chain



Source: BEIS, 2022¹²

¹² BEIS (2022). Supply Chains to Support a Hydrogen Economy. Department for Business, Energy & Industrial Strategy. <https://assets.publishing.service.gov.uk/media/62d6f573e90e071e798d11bb/supply-chains-to-support-uk-hydrogen-economy-wood-template.pdf>

2.2.1 Upstream value chain segments

2.2.1.1 Green hydrogen

Upstream renewable energy generation

Green hydrogen is produced using renewable energy sources such as wind or solar photovoltaic (PV), which provide the clean electricity needed to power electrolyzers. Solar and wind are the most scalable and widely available renewable energy sources. Many EMDEs are rich in renewable energy resources, making them well-suited for large-scale green hydrogen production. Regions such as Africa, the Gulf, India and South America have substantial renewable energy potential. For example, Africa's onshore renewable energy capacity is projected to be 1,000 times greater by 2040 than anticipated demand. This abundance positions Africa as a potential net exporter of renewable energy, which could create new green jobs and promote economic value creation.¹³

One of the main objectives is establishing backward linkages with suppliers of clean energy technologies. Renewable energy has value chains that offer opportunities for value creation, both in the generation of renewable energy and in the manufacturing of technology components. For example, solar PV systems require components such as solar cells, modules and steel frames, while wind energy relies on towers, blades, generators and gearboxes. Other important aspects include connecting renewable energy sources to hydrogen production plants via the grid or, in some cases, developing dedicated off-grid systems to directly power electrolysis units.

Employment opportunities and skills in this segment of the green hydrogen value chain are diverse, depending on the extent to which countries move upstream into renewable energy technology and on the extent to which they build up large solar and wind farms, which require operators and maintenance. The upstream segment will require more advanced engineering expertise, given the level of technological complexity of digitally-enabled and cost-effective renewable technologies. In addition, the maintenance and integration of energy systems

with different technology mixes will require more advanced managerial and organizational capabilities to deal with complex operations.

Manufacturing of components for green hydrogen production

The green hydrogen value chain relies on equipment such as fuel cells, stacks, electrolyzers and compressors, which are essential for producing hydrogen before it is stored, transported (including for export) or used.

Four main types of electrolyzers can be used in green hydrogen production, each with distinct advantages, disadvantages, and levels of technological maturity: alkaline electrolyzers, polymer electrolyte membrane (PEM) electrolyzers, anion exchange membranes (AEMs), solid oxide electrolyzers (SOECs). No single electrolyser technology outperforms others across all dimensions. Alkaline and PEM electrolyzers are already commercially available, while AEMs and SOECs remain at the laboratory stage of development. By the end of 2023, installed electrolyser capacity reached 1.4 gigawatt (GW) and was expected to reach 5 GW by 2024, with China leading in terms of committed projects, accounting for around 70 per cent of capacity in 2024. Announced projects indicate capacity could rise to nearly 520 GW by 2030, yet only 4 per cent have secured a final investment decision or are under construction (IEA, 2024). Experience in building large-scale electrolyzers that are needed for significant expansion remains limited. China, which accounts for one-third of global electrolyser production, has set ambitious domestic hydrogen targets to meet its decarbonization objectives.¹⁴ China's electrolyser exports remain limited for now, potentially slowing global green hydrogen growth. On the other hand, this could open opportunities for advanced developing countries to manufacture electrolyzers or supply components and systems to regional markets.

Electrolyzers require materials such as catalyst electrodes, membranes, valves, tubes and power electronics. Supporting infrastructure, including pipelines and storage tanks for transporting water and hydrogen, plays an essential role as well. Desalination plants may need to be

¹³ KfW, GIZ, & IRENA (German Credit Institute for Reconstruction, German Agency for International Cooperation, & International Renewable Energy Agency). (2020). The renewable energy transition in Africa. Powering access, resilience and prosperity. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/March/Renewable_Energy_Transition_Africa_2021.pdf

¹⁴ Li, L., Steinlein, A., Kuneman, E., & Eckardt, J. (2022). Hydrogen factsheet – China. Retrieved from <https://www.adelphi.de/en/publication/hydrogen-factsheet-%E2%80%93-china>

established in water-scarce regions. Countries can capture value in upstream industries by investing in technological capabilities and introducing demand-side incentives, such as local content requirements. Electrolysers also require various mineral resources; while alkaline electrolysers use relatively abundant and cost-effective materials, PEM electrolysers rely heavily on two critical minerals: platinum and iridium. Iridium is scarce, with only around 7 tons produced globally each year, primarily as a by-product of platinum extraction. South Africa is the leading supplier, providing 92 per cent of global platinum and 70 per cent of iridium.¹⁵

Hydrogen compression is essential for gaseous storage, with compressors increasing gas density by raising hydrogen's pressure. The two primary types used are (i) dynamic compressors, which increase the gas's velocity as it flows through without confinement, and (ii) positive displacement compressors, which compress gas by reducing its volume within a confined space.¹⁶ Not all compressor types are suitable for hydrogen, but two frequently cited solutions are diaphragm compressors and hydraulically-driven dry-running reciprocating compressors.¹⁷

Another key technology in the hydrogen value chain are fuel cells, which share similarities with electrolysers. They operate in reverse to electrolysers, converting chemical energy into electricity by reacting hydrogen with oxygen, and producing water and heat. Fuel cells can run on various fuels, including hydrogen, natural gas or methanol, but only hydrogen achieves conversion without producing greenhouse gas emissions. Fuel cells are particularly valuable for generating electricity from hydrogen, making them an essential component of seasonal energy storage from renewable sources.

Developing local expertise in these areas is crucial for reducing reliance on foreign technologies and investment. Building a skilled workforce capable of designing, installing and maintaining renewable energy technologies allows countries to capture more value domestically while creating long-term sustainable employment opportunities. The production of compo-

nents for hydrogen technologies - particularly electrolysers - involves technologically complex tasks and relies on advanced engineering skills, alongside research, development and innovation capabilities. The cost of electrolysers varies significantly, while their long-term reliability under continuous operation is uncertain. This presents an opportunity for EMDEs investing in hydrogen to build advanced engineering capabilities, although the direct employment potential in this regard remains relatively limited.¹⁸

2.2.1.2 Blue hydrogen

The upstream component of blue hydrogen primarily entails the production of hydrogen through steam methane reforming (SMR) or other fossil fuel-based methods, combined with CCUS technologies. The skills required in this segment of the hydrogen value chain closely align with those in the gas industry, i.e. 'skills relatedness' can play an important role for countries seeking to kick-start investments in the blue hydrogen sector (see the case of Egypt below, for example).

Blue hydrogen production

EMDEs with abundant natural gas resources can leverage these to produce blue hydrogen, a key transitional energy source in the short to medium term. As green hydrogen becomes more competitive in the medium term, the cost of blue hydrogen could drop significantly by 2030 as a result of access to low-cost natural gas and advances in CCUS technologies. Natural gas reformation is commonly used for hydrogen production, and relies on three main technologies:

(i) SMR, (ii) auto thermal reforming (ATR), and (iii) partial oxidation (POx). All hydrogen processes involve the conversion of natural gas into syngas, followed by a shift reaction, carbon dioxide (CO₂) removal and hydrogen purification. The key difference lies in how natural gas is converted into syngas: SMR uses steam while ATR and POx require pure oxygen, which is supplied by air separation units (BEIS, 2022).

¹⁵ Minke, C., Suermann, M., Bensmann, B., & Hanke-Rauschenbach, R. (2021). Is iridium demand a potential bottleneck in the realization of large-scale PEM water electrolysis? *International Journal of Hydrogen Energy*, 46(46), 23581-23590. <https://doi.org/10.1016/j.ijhydene.2021.04.174>

¹⁶ Machado H, Ferreira AC, Teixeira SF, Teixeira JC. (2024): Green Hydrogen Value Chain: Modelling of a PV Power Plant Integrated with H2 Production for Industry Application. *Energies*, 17(6):1414. <https://doi.org/10.3390/en17061414>

¹⁷ Escamilla, A.; Sánchez, D.; García-Rodríguez, L. (2022): Assessment of Power-to-Power Renewable Energy Storage Based on the Smart Integration of Hydrogen and Micro Gas Turbine Technologies. *Int. J. Hydrogen Energy*, 47, 17505-17525.

¹⁸ Andreoni A, Roberts, S. (2024): Minerals, Energy Intensive Industries and Development: Green Transition and Employment in Southern Africa. CSST Working paper 003. London: SOAS Centre for Sustainable Structural Transformation

In SMR, 60 per cent of CO₂ emissions come from hydrogen production in the reformer, while the remaining 40 per cent result from natural gas combustion in the furnace. Currently, 60 per cent of CO₂ is captured from the syngas produced in reformer processes, but capturing the remaining 40 per cent from the diluted furnace flue gas is still costly. ATR enables higher CO₂ capture rates by generating a single, concentrated CO₂ stream (IEA, 2024).

Manufacturing of components and equipment for blue hydrogen production

The production of blue hydrogen requires specialized equipment and infrastructure, including reformers, pumps, compressors, heat exchangers and separation units. Natural gas and steam react in reformers at high temperatures (700 °C –1,000 °C) to produce hydrogen, making reformers a key component of the hydrogen production process. Heat exchangers are used for energy recovery, enhancing the process's overall efficiency.

Carbon capture and storage (CCS) infrastructure, which includes compression, transport and storage equipment, is essential for capturing CO₂ from the reformer process. Compression units are used to increase the pressure of CO₂, enabling transport via pipelines or injection into deep geological formations for long-term storage. The development of specialized CCS technologies is critical for reducing emissions from blue hydrogen production.

Although the equipment and components used across the three main technologies are similar, ATR and POx require larger components, resulting in greater costs and added complexity. SMR, on the other hand, is often considered the standard for blue hydrogen production due to its lower cost compared to ATR and POx (BEIS, 2022).

2.2.2 Midstream value chain segments

Hydrogen storage

The next stage in the value chain is storage and compression. Compression increases hydrogen's energy density for efficient storage and transport. Hydrogen can be stored using various methods, each with distinct advantages and shortcomings, depending on its intended application and the available infrastructure.¹⁹ Compressed hydrogen is the simplest and most common storage method, relying on high-pressure tanks. While this method is widely used, compressed hydrogen has relatively low density, requiring large storage volumes and high pressure. It presents certain challenges such as the risk of leakage and material degradation over time.

Hydrogen can be liquefied, which increases its density compared to compressed gas and makes it a more efficient option for long-range transport and specific industrial applications. However, the process of liquefying hydrogen requires extremely low temperatures, resulting in substantial energy consumption. Liquid hydrogen storage is best suited for short-term use due to energy loss from boil-off during storage.

Solid-state systems can be used to store hydrogen by either adsorbing it onto surfaces (physisorption) or chemically bonding it to materials (chemisorption). These methods offer improved safety and in some cases higher density, but are still being developed. While some materials can store considerable amounts of hydrogen, the processes to release it are often complex and less energy efficient, requiring further refinement before widespread adoption.

¹⁹ Aziz, Muhammad, Agung Tri Wijayanta, and Asep Bayu Dani Nandiyanto. 2020. «Ammonia as Effective Hydrogen Storage: A Review on Production, Storage and Utilization» *Energies* 13, no. 12: 3062. <https://doi.org/10.3390/en13123062>

Methanol, which is often associated with surplus electricity production, can also be used for hydrogen storage. It offers a convenient method for storing and releasing hydrogen, but produces CO₂ during use, undermining the goal of a carbon-free energy system. Additionally, methanol production involves energy-intensive CO₂ separation methods, limiting its suitability for fully sustainable applications. Ammonia is a promising option for hydrogen storage due to its high hydrogen density and the already well-established infrastructure for its production and transport. It is particularly useful for long-term storage and hydrogen export. Ammonia can be used to either release hydrogen or be directly used as a fuel. However, when used as an energy source, it still faces challenges related to conversion and potential environmental impacts.²⁰

Hydrogen storage requires either extremely high pressure or very low temperatures, making it a costly endeavour. To address this problem, hydrogen is often converted into derivatives such as ammonia or synthetic fuels, which are easier to store and transport. The choice of derivative depends on its specific end use (e.g. ammonia for fertilizer production or e-kerosene for aviation fuel). Producing such derivatives facilitates transport and links the energy and agricultural sectors, creating opportunities for job creation as well as for the development of local capacities and skills.

Hydrogen transport

Hydrogen can be transported and distributed through pipelines or by truck or ship to reach its end-use locations. Hydrogen transport technologies are essential for building clean hydrogen supply chains, particularly in terms of unlocking the low-cost potential of remote regions. Four means of transport stand out: (i) pipelines for gaseous hydrogen, (ii) ammonia, (iii) liquefied hydrogen (LH₂), and (iv) liquid organic hydrogen carriers (LOHCs).²¹ Each has distinct advantages and limitations, depending on scale, geography and logistics.

Pipelines are a well-established means for transporting gaseous hydrogen, similar to natural gas systems. Hydrogen is compressed to the pipelines' operating pressure and transported through networks equipped with control valves, gates and

metering stations. This is a low-cost and highly efficient solution for delivering large volumes of hydrogen along fixed routes. However, fixed infrastructure limits flexibility by leaving some areas of demand unserved. While pipelines will play an important role in hydrogen distribution, they cannot serve all regions where hydrogen is needed.

Ammonia is another option for hydrogen transport. Hydrogen is synthesized into ammonia (a well-established process) and transported in refrigerated tanks. At its destination, it is "cracked" back into hydrogen and nitrogen (the latter being released into the atmosphere). Ammonia transport is already in use today, primarily for agricultural and industrial applications. Its main advantage lies in the widespread availability of infrastructure for ammonia production and transport, but the reconversion of ammonia into hydrogen adds complexity and raises energy costs.

LH₂ is produced by cooling hydrogen to extremely low temperatures (-253 °C), increasing its storage density. It is transported in specially insulated, double-hulled tanks that minimize heat transfer and reduce evaporation losses. While LH₂ is already being transported by trucks today, the main drawback is the high energy required for cooling and maintaining low temperatures during transport. Despite being a promising option, LH₂ is energy-intensive and prone to boil-off during long-term storage and transport.

LOHCs are chemical compounds that store hydrogen through a hydrogenation process, enabling transport at atmospheric pressure. At its destination, the hydrogen is released through a dehydrogenation process. The carrier liquid can then be reused and transported back to the source. LOHCs offer a flexible and safe method for hydrogen transport since it can be treated much like conventional fuels. However, the energy required for both the hydrogenation and dehydrogenation processes adds complexity and reduces LOHCs' overall energy efficiency.

The production of components for hydrogen storage and transport—similar to electrolyzers—requires technologically complex processes and advanced engineering skills, alongside research, development and innovation capabilities. This presents an opportunity for EMDEs investing in hydrogen to build such capabilities, although

²⁰ Aziz, Muhammad, Agung Tri Wijayanta, and Asep Bayu Dani Nandiyanto. 2020. «Ammonia as Effective Hydrogen Storage: A Review on Production, Storage and Utilization» *Energies* 13, no. 12: 3062. <https://doi.org/10.3390/en13123062>.

²¹ Roland Berger (2021): Hydrogen Transportation | The key to unlocking the clean hydrogen economy.

the potential for job creation remains relatively limited. Given the safety risks associated with hydrogen storage and transport, this segment of the value chain is bound to be subject to stringent international regulations and standards. Consequently, EMDEs will need to enhance their engineering expertise and strengthen regulatory capacity in this regard.

2.2.3 Downstream value chain segments

Finally, the hydrogen value chain results in a wide range of potential end uses. Downstream activities in the hydrogen value chain comprise the application and end use of clean hydrogen, a stage marked by complexity and high costs. Hydrogen is already being used in several industrial processes, notably as a key component of ammonia production, hydrocracking and desulfurization in refineries, and methanol synthesis. In 2023, global industrial hydrogen demand totalled 54 Mt, with 60 per cent used for ammonia production, 30 per cent for methanol, and 10 per cent for direct reduction in iron and steel. While these applications currently rely on grey hydrogen, it is expected to be gradually replaced by green hydrogen.

Steel industry: Hydrogen can be integrated into steel production through the direct reduction of iron (DRI) process, replacing carbon-based reactants. Green hydrogen can be applied in both blast furnaces which use iron ore, and electric arc furnaces (EAFs) which rely on steel scrap or DRI. Hydrogen-based DRI is the most advanced non-carbon technology currently used in the steel industry, but requires costly plant retrofits and could raise steel prices by around one-third.²²

Cement industry: The carbon footprint of cement production is largely attributed to the use of clinker, which emits CO₂ from both fuel combustion and limestone decomposition. Hydrogen can replace fossil fuels, reducing direct emissions by around 35 per cent.²³ However, process emissions are more difficult to eliminate and require the use of materials such as gypsum or slag to reduce clinker content together with CCS technologies for full decarbonization.

Chemical industry: The chemical industry is the largest industrial consumer of fossil fuels, with ammonia production being a major source of CO₂ emissions. Hydrogen plays a central role in ammonia production, which is used in fertilizers, plastics and other products. Currently, ammonia production relies on carbon-intensive grey hydrogen, but transitioning to green hydrogen could decarbonize this process.²⁴ Methanol, another important chemical, can be produced using green hydrogen (e-methanol), offering a promising low-carbon fuel option for industries such as shipping.

Transport industry: Hydrogen plays a central role in decarbonizing the transport industry, particularly long-distance rail, heavy freight, shipping and aviation. If powered by green hydrogen, fuel-cell electric vehicles (FCEVs) could compete with battery-electric vehicles (BEVs) in long-haul transport. In maritime shipping and aviation, hydrogen-based fuels such as ammonia, methanol and e-kerosene offer viable options for reducing GHG emissions. Hydrogen is expected to become a key player in these industries' future decarbonization efforts.

Potential new hydrogen applications include the use of hydrogen as a reducing agent in 100 per cent hydrogen DRI, long-distance transport, hydrogen-based fuels (such as ammonia or synthetic hydrocarbons), biofuels upgrading (e.g. hydrogenation of fats and oils), high-temperature industrial heating, and electricity storage and generation (IEA, 2024).

The majority of new jobs and skill requirements is expected to emerge in the downstream segments of the hydrogen value chain. Given the broad range of hydrogen applications, skill needs will be highly diverse in terms of both scope and complexity. Capturing both direct green jobs along the value chain and generating indirect green jobs across the economy through linkages requires deliberate efforts to drive incremental and sustainable structural transformation. From this perspective, green jobs arise through a dynamic process of employment growth and the development of local production linkages across different sectors, each with varying degrees of "brown" and "green" (Andreoni and Roberts, 2025).²⁵

²² Kurrer, C. M. (2020). The potential of hydrogen for decarbonising steel production. Retrieved from [https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/641552/EPRS_BRI\(2020\)641552_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/641552/EPRS_BRI(2020)641552_EN.pdf)

²³ SRU (German Advisory Council on the Environment). (2021). Wasserstoff im Klimaschutz: Klasse statt Masse: Stellungnahme Juni 2021. Retrieved from https://www.umweltrat.de/SharedDocs/Downloads/DE/04_Stellungnahmen/2020_2024/2021_06_stellungnahme_wasserstoff_im_klimaschutz.pdf;jsessionid=9CF689B04E5CD9A2BFB70D2D7CAEF7BB.intranet212?__blob=publicationFile&v=4

²⁴ Miller, D., Armstrong, K., & Styring, P. (2022). Assessing methods for the production of renewable benzene. *Sustainable Production and Consumption*, 32, 184-197. <https://doi.org/10.1016/j.spc.2022.04.019>

²⁵ Andreoni and Roberts (2025).

2.3 Investments, skills and employment: Evidence-based policy design

The clean hydrogen value chain is a complex ecosystem. Its development hinges on interdependent investments across the upstream, midstream and downstream segments. The required investments are typically large in scale and involve long investment cycles. Hydrogen production systems can be configured in different ways, for example, reliance on in-grid or off-grid energy supply. Operating below optimal efficiency or using electrolyzers below full capacity risks undermining the overall viability of investments, given that the price of hydrogen and its derivatives, e.g. green ammonia, must remain competitive for off-takers. Without an off-taker agreement in place with downstream industries, investment is not financially viable due to the high risk of producing hydrogen without a guaranteed buyer.

The ‘first order problem’ most countries face when seeking to develop a hydrogen ecosystem is managing the interlinked technical, financial and system-level investments. Addressing this challenge has proven particularly difficult in countries that have introduced a green hydrogen programme, with many failing to move beyond scoping studies and translating them into actual investments. The cases of Brazil, Namibia, Morocco and China, however, demonstrate that these challenges can be overcome: they are investing in these technologies to gain a green competitive advantage ahead of 2030 and 2040, when market access will be increasingly impacted by carbon adjustment mechanisms.

In countries that have already addressed the ‘first order problem’, skills development emerges as a critical ‘second order problem’. Without local skills development and domestic hydrogen off-take to supply key hard-to-abate industries, hydrogen production will remain an enclave industry. Investing in local education and training programmes that focus on clean hydrogen technologies can build a workforce that is capable of driving the hydrogen ecosystem’s domestic development. Moreover, local industries that plan to integrate clean hydrogen into their operations—such as the chemical, iron and steel, cement, aviation, maritime and heavy cargo transport industries—will need to develop new skills and processes to effectively manage

and use hydrogen. This does not only include technical expertise but also an understanding of evolving global standards and regulations, such as the EU’s Carbon Border Adjustment Mechanism (CBAM), which is increasingly influencing international trade dynamics.

Strong human capital is a fundamental pillar of any successful industry. The hydrogen industry’s success will depend on a high level of expertise to ensure safety, cost efficiency, regulatory compliance, and strict adherence to standards and codes. It will require a highly skilled workforce, ranging from managers to engineers, technicians and operators, responsible for driving innovation, promoting sustainability, and fostering collaboration, all essential elements for the hydrogen industry’s growth and success.

The hydrogen industry has the potential of creating 25 million jobs globally by 2050,²⁶ with the majority of these jobs requiring technical skills. A diverse range of occupational profiles across the value chain will need upskilling and reskilling, from technicians and assemblers to engineers and supporting services, such as maintenance specialists and certifiers. Careful planning will be crucial to fully reap the benefits of the hydrogen ecosystem.

Given the long investment cycles in green hydrogen, skills development policies must account for the time lag between training and the uptake of skills in the hydrogen ecosystem and related industries. In other words, building the required skills takes time and a wide range of skills of different complexity level must be developed. Therefore, evidence to inform skills development policies should not be static; they need to be grounded in an understanding of the skills required in a fully mature hydrogen ecosystem, given the range of diverse technical job profiles across the hydrogen value chain’s upstream, midstream and downstream segments. The policies should also be informed by an understanding of which skills can be built during the hydrogen ecosystem’s transition towards maturity, taking into account which skills are transferable across industries and which ones require more time to develop.

²⁶ <https://hydrogencouncil.com/wp-content/uploads/2024/05/Emerging-trade-corridors-for-hydrogen-and-its-derivatives.pdf>





3. Skills Assessment Methodology for Policy Design

3.1 Analytical framework

The primary objective of this skills assessment methodology is to provide EMDEs that have identified hydrogen as a key component of their energy strategy with a strategic framework that not only bridges current sectoral gaps but also anticipates the hydrogen market's future development. Skills development is a critical dimension of hydrogen's future growth, and potential challenges such as skills mismatches must be addressed early on. Mismatches can manifest as skills gaps, deficits or surpluses, and carry significant costs: lacking necessary skills reduces productivity, while unused skills result in forgone earnings. In most EMDEs, skills gaps in the clean hydrogen industry will have an impact on both domestic employment generation and firms' growth prospects.

UNIDO's methodology to assess the skills requirements for developing a country's clean hydrogen industry provides a systematic guide for evaluating and addressing skills shortages across the hydrogen value chain. The methodology follows a phased approach tailored to the needs of EMDEs that are well-positioned to become clean hydrogen production and export

hubs, but face potential skill shortages that could undermine the feasibility of their clean hydrogen strategy. This targeted approach ensures that the resulting strategies are practical, impactful, and closely aligned with existing national priorities.

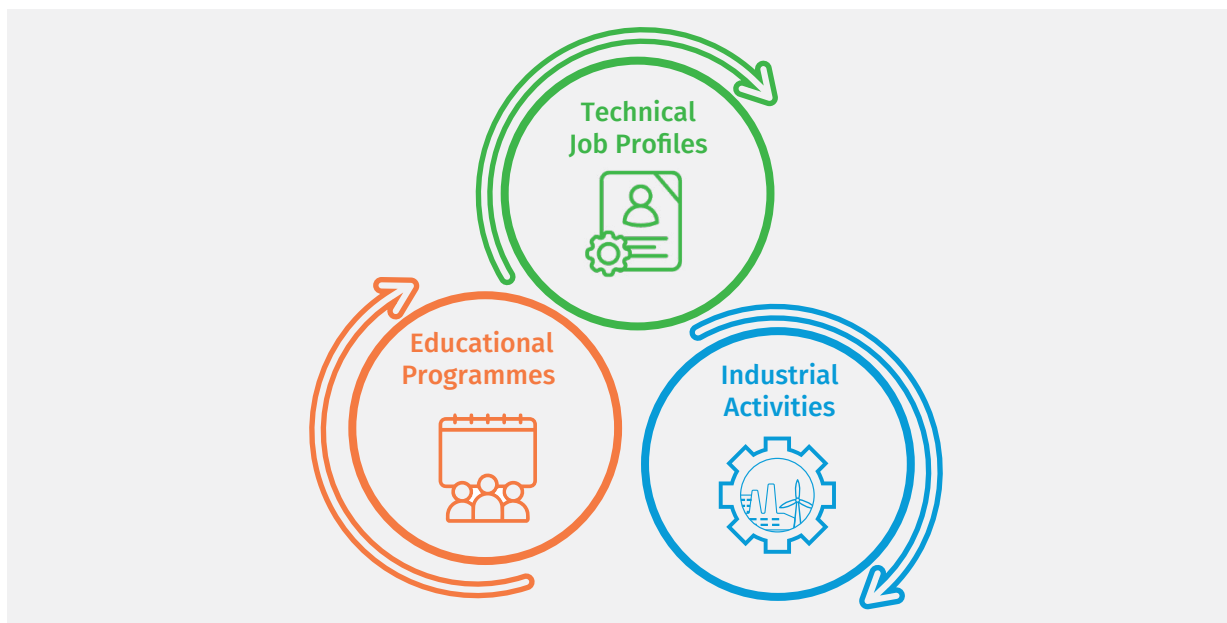
UNIDO's methodology identifies the skills required for developing EMDEs' clean hydrogen industry by addressing the following questions:

1. Which segments of the hydrogen value chain does the country's national hydrogen strategy target (if applicable)?
2. Which skills are crucial for operating the respective hydrogen value chain segments?
3. What skills are already available within the country's hydrogen value chain?
4. What essential skills and competencies are currently lacking in the country that are critical to advancing sustainable development and growth within the hydrogen value chain?

UNIDO's skills assessment methodology provides a structured framework to address these core questions by mapping existing skill levels, identifying gaps, and guiding the design of targeted educational programmes that align with industry needs. Understanding what skills are required at each stage of the hydrogen value chain is essential for building a robust workforce. The methodology draws on a comprehensive review of global best practices and litera-

ture, including studies from the European Union, Canada and Australia. It can be tailored to the specific needs of EMDEs and other countries and is organized around three interconnected pillars (Figure 8), namely skills associated with: (i) Industrial Activities, (ii) Technical Job Profiles, and (iii) Educational Programmes. The objective is to ensure that the approach to these fundamental questions remains both systematic and adaptable across different contexts.

Figure 8. Pillars of UNIDO's methodology for skills mapping in clean hydrogen value chains



Source: Authors' elaboration

Industrial Activities cover all segments of the clean hydrogen value chain, including renewable energy production; the upstream manufacturing of materials, components and equipment; clean hydrogen production, storage, transport and distribution; as well as end-use applications. Cross-cutting and enabling activities support and connect all stages of the value chain.

This pillar identifies hydrogen-related skill needs within industries already engaged in, or preparing to adopt, clean hydrogen. To support this, a comprehensive analysis was carried out using UNIDO's Industrial Statistics database, which found over 30 industrial activities closely connected to the hydrogen value chain. These activities were carefully selected and mapped using ISIC codes, incorporating countries' statistical data on public and private firms as well as on employing firms within these industries (see Appendix). Mapping these industrial activities

serves as a first step in assessing existing workforce profiles and identifying critical skill gaps, as well as the future roles needed to support hydrogen adoption. The approach also highlights key industrial sectors such as steel, chemicals, transport and energy.

Each segment of the clean hydrogen value chain can be further disaggregated into specific activities. Within the upstream segment, for example, the renewable energy industries for wind and solar PV comprise four major supply chain segments:

- Equipment and component manufacturing
- Project development
- Construction and installation
- Operations and maintenance.

Figure 9. Clean hydrogen value chain with industrial activities

RE Production for Green Hydrogen			Upstream Manufacturing		H2 Production		H2 Storage		H2 Transportation	Downstream end-use		
Solar PV	Wind	Geothermal	Components and Materials	Equipment	Blue H2	Green H2	H2 Carriers	H2 Storage		Industry	Mobility & Transport	Energy
			Catalyst electrodes	Fuel cells	Thermochemical water splitting	Water desalination	Compressed H2	Tanks				
Generators	Panels / Modules	Generators							Pipelines	Steel	Shipping	Heating
Blades	Steel frames	Turbines	Membranes	Alkaline electrolyzers	Methane pyrolysis	Electrolysis	Liquefied H2	Metal / composites	Trucks	Cement	Trucks	
Towers	Battery storage	Pumps	Valves	PEM electrolyzers	Carbon Capture & Storage		Methanol	Saline	Ships	Chemicals	Aviation	
Gearboxes	Inverters		Tubes	Anion exchange membranes			Ammonia			Petrochemicals	Railway	
			Power electronics	Solid oxide electrolyzers			Synthetic fuels			Ceramics		
			Insulating Coatings	Compressors			Absorbents			Glass		
			Sensors									
			Regulators / Controllers									
Cross cutting services; Maintenance, repair, and operation (MRO)												
Professional Services												
R&D												
Ancillary Services												

Source: Authors' elaboration based on Stamm et al. (2023) and BEIS (2022)

Technical Job Profiles focus on the occupational profiles associated with each industrial activity. H2 Europe has identified current and emerging job profiles as well as the urgent skills required in the industry. These are based on desk research of the 10 largest European hydrogen industries.²⁷ Occupational profiles (jobs), along with skills, competencies and qualifications needed across the hydrogen value chain, were summarized using the European Skills, Competencies, and Occupations (ESCO) classification.

- **Occupational Profiles (OP):** Jobs within the European labour market. This framework lists 3,008 distinct occupations, each mapped to a single ISCO-08 code, and serving as a hierarchical structure for the 'Technical Job Profiles' pillar.
- **Skills:** The ability to apply knowledge and know-how to complete tasks and solve problems.
- **Competence:** Proven ability to apply knowledge, skills and personal, social and/or methodological capabilities in both professional and personal contexts.

UNIDO's methodology identifies over 60 essential technical job profiles across the hydrogen value chain, standardized according to ISCO-08 codes (see Appendix). These profiles, including technicians, engineers, managers and other technical support roles, are critical across different segments of the value chain, ensuring the efficient development and operation of the clean hydrogen industry.

Educational Programmes refer to the country's existing educational programmes providing training for workers to acquire the skills and competencies required for each 'Technical Job Profile' (Pillar 1). Qualifications are formal outcomes of an assessment and validation process, awarded by a competent body when an individual has demonstrated achievement of specific learning outcomes according to established standards. This may include long-term programmes such as university degrees or vocational training schemes, as well as short-term courses delivered through TVET systems.

This pillar assesses the alignment between existing educational and training programmes and the skills required by the hydrogen industry. UNIDO's skills assessment methodology examines the competencies developed through the formal academic sector. Using this approach, 72 distinct skills essential to the hydrogen industry were identified, and include competencies such as renewable energy integration, electrochemistry, process optimization, material suitability for hydrogen applications, and rigorous quality assurance standards (see Appendix A). The objective is to determine whether educational programmes equip graduates with the necessary qualifications, skills and competencies to meet industry demands.

UNIDO has developed two questionnaires—one demand-side and one supply-side questionnaire—to identify, analyse and summarize existing literature on industrial activities, technical jobs and educational programmes. The Organization's methodology builds on H2 Europe's work in identifying skills development needs for hydrogen and the International Labour Organization's (ILO) research on skills and occupational requirements in renewable energy.²⁸

3.2 Skills demand: Industrial activities and technical jobs

3.2.1 Integrated methodology for skills demand assessment

To effectively map the skills required across the hydrogen value chain, specific skills are aligned with the tasks performed within each occupation profile. This approach draws on detailed insights into the green hydrogen value chain, relevant skill sets, and the International Standard Classification of Occupations (ISCO) framework, which defines occupational tasks. One key challenge, however, is that skills are not always explicitly linked to occupations within the value chain. Occupations are typically described as bundles of tasks – the performance of these tasks requires diverse types of skills. The relationship between skills and tasks is usually defined in engineering terms, i.e. the performance of task X requires a specific set of skills S (S1, S2, ..., Sn).

²⁷ H2 Europe (2023): European Hydrogen Skills Analysis. <https://greenskillsforhydrogen.eu/public-deliverables/eu-hydrogen-skills-strategy/>

²⁸ ILO (2011): Skills and Occupational Needs in Renewable Energy. https://www.ilo.org/sites/default/files/wcmsp5/groups/public/@ed_emp/@ifp_skills/documents/publication/wcms_166823.pdf

This relationship is often described with a high degree of precision in technical terms in international classifications.

To bridge the gap between occupation and skills in the methodology, advanced Natural Language Processing (NLP) techniques are used to align tasks with the required skills (see Appendix

B for details). Specifically, semantic similarity methods are applied, which allows the matching of tasks with the most relevant skills by analysing the underlying meaning of textual descriptions (Figure 10 – see Excel file for a detailed list of occupations-skills matching for each stage of the clean hydrogen value chain).

Figure 10. Skills demand methodology

Clean Hydrogen Value Chain	Renewable energy production				Upstream Manufacturing				Hydrogen Production				Downstream end-use				
	Solar PV	Wind	LNG Production & CC		Equipment	System integrators		Components & Materials	Production	Distribution		Storage & Transport	Industry	Mobility & Transport		Energy	
Skills	S ₁	S ₂	...	S _n	S ₁	S ₂	...	S _n	S ₁	S ₂	...	S _n	S ₁	S ₂	...	S _n	110
Occupations (ISCOs)																	
ISCO 1																	
ISCO 2					NLP-based matching between skills and occupations												
...									Matrix 173 X 110								
ISCO n																	
173																	Tot

Source: Authors’ elaborations

The semantic similarity approach involves identifying and comparing the meaning and context of different textual elements, such as documents, sentences or phrases. In this case, “task” refers to a textual description of an activity or responsibility, while “skills” corresponds to a set of competencies or qualifications described in textual form. Using semantic similarity, the system searches for skills that exhibit a high degree of conceptual or contextual overlap with the given task. The resulting analysis provides crucial insights into two key aspects of the hydrogen value chain’s workforce: skills transferability and occupation complexity.

3.2.1.1 Skills transferability: Enhancing workforce agility

Skills transferability refers to the degree of overlap between different occupations, allowing workers to effectively transition from one role to another. This concept is central to workforce development, as many skills extend beyond specific roles and industries. Workers who possess transferable skills have the ability to perform a wide range of tasks, either because of the presence of similarities between tasks across different occupations or the versatility of certain skill sets that enable adaptation to new contexts (Nedelkoska & Neffke, 2019).²⁹

²⁹ Nedelkoska, L., & Neffke, F. (2019). Skill mismatch and skill transferability: review of concepts and measurements. Papers in Evolutionary Economic Geography, 19-21.

Understanding and leveraging skills transferability is indispensable in today's dynamic job market. For workers, it increases career flexibility and employability, allowing them to pursue new opportunities or transition into other industries, including those beyond hydrogen. For employers, it helps identify talent that can adapt to evolving business needs, ultimately fostering a more resilient and versatile workforce.

Table 1 presents a mapping of skills transferability across the green hydrogen value chain. It is measured by the number of occupations that require a given skill. Based on this measure, skills are grouped into three categories (terciles):

- **High transferability (1st tercile, shaded green):** Skills relevant to a wide range of occupations.
- **Medium transferability (2nd tercile, shaded yellow):** Skills relevant to a moderate range of occupations.
- **Low transferability (3rd tercile, shaded red):** Skills relevant to only few occupations, given their high level of specialization in specific tasks, often within science/engineering fields.

Production and operation

Skills with high and medium transferability in the production and operation segments of the hydrogen value chain primarily include process engineering, petrochemical facility management, safety management, and operational oversight of energy projects. Professionals with expertise in renewable energy project development, chemical engineering, CCUS technology integration, and high-pressure systems are well-positioned for seamless transitions due to significant overlap in operational practices. Additionally, skills in regulatory compliance, permitting, and international stakeholder management offer medium-to-high adaptability across industries.

Electrolysers, electrolysis and fuel cells

Within electrolysis and fuel cell systems, highly transferable skills include electromechanical equipment design, assembly and maintenance, and in-depth knowledge of fuel cell and electrolyser technologies. Professionals with experience in electrical systems, computer-aided design (CAD) software, materials engineering for electrodes, and process safety exhibit particularly high transferability potential. Skills with

medium-level transferability include retrofitting automotive applications, power electronics, and the integration of renewable systems, enabling effective crossover from related industrial and manufacturing industries.

Hydrogen systems

Skills with high and medium transferability within hydrogen systems primarily include interdisciplinary engineering roles. High-transferability skills entail expertise in integrating renewable electrolysis systems, quality management and hydrogen energy system optimization. Medium-transferability skills involve in-depth knowledge of thermodynamics, industrial processes, power electronics, and energy system modelling. Professionals with experience in oil and gas, renewable integration, and mechanical-electrical-plumbing (MEP) systems are well-positioned to transition because their competencies closely align with the skills required in hydrogen systems.

Storage

The storage segment of the hydrogen value chain involves high-to-medium transferable skills related to gas infrastructure, chemical process management and safety protocols. Highly transferable expertise includes managing high-pressure systems, petrochemical production facilities, hazard modelling (explosion and fire safety) and process automation. Medium-level transferable skills cover in-depth knowledge of electrolyser and liquefaction technologies, port infrastructure operations, and metal structure design, enabling professionals with a background in petrochemical, marine and energy to effectively transition into hydrogen storage roles.

Transport and refuelling

High-transferability skills in the transport and refuelling segment of the hydrogen value chain entail safety management, operational maintenance of refuelling stations, and managing high-pressure hydrogen infrastructure. Expertise in explosion hazard modelling, chemical handling, and retrofitting automotive systems significantly facilitates mobility between industries such as automotive, maritime and petrochemical logistics. Medium-transferable competencies include design and engineering related to fuel cells for mobility, electrolysis-based ammonia production, and renewable energy integration, expanding job opportunities in hydrogen transport.

Table 1. Skills transferability across the green hydrogen value chain

VALUE CHAIN	SKILLS
Production & Operation	Investment analysis, economics, and legal aspects of renewable energy (RE) project development, process engineering, petrochemical industrial production
	Operation, monitoring and maintenance of production, transport, and storage refinery's facilities
	RE project development, process engineering, petrochemical industrial production
	Health, safety and risk of chemical facilities construction and operation
	Hazards and safety of hydrogen (H ₂) production, distribution, storage and refuelling
	CCUS technology engineering, integration, operation and maintenance
	Operation and maintenance of chemical production facilities
	Public relations and engagement, international networks, extensive experience, commercial delegates,, navigating the complexities of hydrogen (offering foundational insights into H ₂ production, economies, risks, technology, RE and scaling)
	Management of energy production projects, environmental and social impact analysis, regulations, permitting
	Electrolysis technologies, operation and maintenance
	H ₂ production, electrolysis, blending with natural gas (NG), plant management
	Permitting and certification of chemical production facilities
	Process quality, gas production facilities, operation and maintenance
Production & Operation	H ₂ and its derivatives, production processes in fertilizers, steel, chemicals, etc.
	Operation, maintenance and monitoring of gas infrastructure
	Port infrastructure, operation, bunkering, storage and support logistics
	Technical background in mining and subsurface operation
	Health and safety of gas production, storage and operation
	Life cycle operation and routine maintenance
	Petrochemical production facilities, refuelling, gas storage facilities and transport
	H ₂ production and consumption in refineries and fertilizers
	Vessels' operation, H ₂ and ammonia production facilities, electrical facilities
	Operational and maintenance of fuel cell systems and powertrains
	Optimization and operation of energy production facilities, efficient and economic arbitration between energies
	H ₂ production, transport, storage and refuelling stations

VALUE CHAIN	SKILLS
Production & Operation	High pressure processes, chemical production facilities, monitoring
	Operation of H ₂ production facilities, high compression, explosion, firefighting, automation
	Electric system integration, operation and maintenance
	High pressure equipment, handling, operation and maintenance
	Chemical production, processing, electrode, catalysts
	Refuelling stations operation and H ₂ in mobility application
	H ₂ process design, production, storage and transport
	Gas facilities operations and maintenance
	Risk and hazards of H ₂ production and transport facilities
	Development, construction and operation of H ₂ production facilities
	Operation of valves, pipes and wells
	Sailing, flight deck operations
	Production of green e-fuels
Electrolysers, Electrolysis and Fuel Cells	Design/building an integrated renewable energy sources (RES) electrolyser system, refuelling stations construction, maintenance and service, H ₂ for grid balancing, H ₂ safety
	Knowledge of port machines and tools, including their design, use, repair and maintenance, knowledge of fuel cells
	Assemble, install or repair wiring, electrical or electronic components, pipe systems, plumbing, machinery, knowledge of fuel cells
	Design, test, operate and maintain electromechanical equipment, CAD software experience, knowledge of fuel cells
	Materials engineering, knowledge of materials used in electrolyser electrodes: appropriate mechanical properties and high corrosion resistance
	H ₂ details – understanding the H ₂ value chain, technical – integration of fuel cells and basic knowledge of storage and electrolyses
	Piping, electrolysers, storage, liquification, safety and security
	H ₂ production, electrolysis, blending with NG, plant management
Electrolysers, Electrolysis and Fuel Cells	Knowledge of hydrogen production machines and tools, including their design, use, repair and maintenance, knowledge of electrolysers
	Electrolysers and fuel cell design and operation, and maintenance
	Retrofitting of automotives (transport, refuelling and fuel cells)
	Regulation standards - minimum insight into ASME/API, high temperature electrolysis (SOEC) for steam, CO ₂ and co-electrolysis
	Fuel cell manufacturing, testing, power systems, retrofitting and back-up energy generation
	Industrial experience, high temperature electrolysis (SOEC) for steam, CO ₂ and co-electrolysis
	Electrochemical engineering, understanding of electrodes, membranes and electrolysis processes

VALUE CHAIN	SKILLS
Electrolysers, Electrolysis and Fuel Cells	Electrolysers, H ₂ storage facility and refuelling stations
	Electrolysis, ammonia production, storage and transport
	Operation and maintenance of fuel cell systems and powertrains
	Supercapacitors , fuel cells, electrolysis
	CCUS, synthetic fuels, biogas, electrolysis, fuel cells, renewables
	Fuel cells in mobility applications, refuelling stations
	Power electronics, high and low voltage, fuel cell systems
	Electrolysers, fuel cell technologies and H ₂ mobility applications
Hydrogen Systems	Understanding of equipment and systems, knowledge of mechanical, electrical, plumbing and heating systems, working under pressure, ensuring equipment maintenance
	Design/building an integrated RES electrolyser system, refuelling stations, construction, maintenance and service, H ₂ for grid balancing, H ₂ safety
	Industrial engineering, quality management system, good understanding of product specifications
	Design/building an integrated RES electrolyser system for technical office team
	Oil and gas, quality of gases, H ₂ economy, systems and projects, subsurface science including geology, drillings, microbiology for the subsurface, and fluid flow in porose media
	Intermittent power profiles, optimization of energy systems, CO ₂ prices, etc, certificate trading, H ₂ pricing, modelling of energy scenarios
Hydrogen Systems	Fuel cells manufacturing, testing, power systems, retrofit and back up energy generation
	Chemical engineering, thermodynamics, industrial process, understanding of hydrogen as an energy gas and mechanical boundaries of gas systems
	Energy systems integration and infrastructure repurposing
	Electric system integration, operation and maintenance
	Refuelling stations, storage, transport, fuel cells, H ₂ propulsion systems
	Renewables, system coupling, innovative technologies
	Management of hydrogen systems manufacturing, installation and commissioning

VALUE CHAIN	SKILLS
Hydrogen Systems	Renewable energy, electrolyser systems, automation, high voltage
	Energy systems integration experience
	Power electronics, high and low voltage, fuel cell systems
	Control systems and intelligence (linear, time variant)
	Integration, management system, water management
	High voltage and renewable energy systems, synergies experience
Storage	Explosion, jet fire, modelling, testing, test facility management, in-depth knowledge of H ₂ hazards, risk profiles of H ₂ , H ₂ transport fuel, bunkering, storage
	Piping, electrolyzers, storage, liquification, safety and security
	Risk, hazards and safety procedures of H ₂ production, storage and transport
	Port infrastructure operation, bunkering, storage and support logistics
	Chemical process design, refinery, gas handling, storage and transport
Storage	Petrochemical production facilities, refuelling, gas storage, facilities and transport
	Compressors, change of state, gasification, pipelines and storage tanks
	Design and construction of gas production and storage facilities
	H ₂ production, transport, storage and refuelling stations
Storage	Electrolyser, H ₂ storage facility and tanking station
	Installation, operation and maintenance of gas and liquid H ₂ storage and transport facilities
	Process automation, energy storage
	Marine and energy production, storage and transport construction
	Design, production of metal structures related to the production, storage and transport of hydrogen

VALUE CHAIN	SKILLS
Transport and Refuelling	Design/building an integrated RES electrolyser system, refuelling stations, construction, maintenance and service, H ₂ for grid balancing, H ₂ safety
	Operation, maintenance and safety of refuelling stations
	Explosion, jet fire, modelling, testing, test facility management, in-depth knowledge of H ₂ hazards, risk profiles of H ₂ , H ₂ transport fuel, bunkering, storage
	Hazards and safety of H ₂ production, distribution, storage and refuelling
	Operation, maintenance and safety of electrolysers
	Safety standard and risk of H ₂ production, transport and fuelling facilities
Transport and Refuelling	Knowledge of hydrogen safety procedures, such as refuelling a tugboat
	Refuelling stations, safety, H ₂ production technologies
	Chemical process design, refinery, gas handling, storage and transport
	Retrofitting of automotives (transport, refuelling and fuel cells)
	Petrochemical production facilities, refuelling, gas storage facilities and transport
	Electrolysis, ammonia production, storage and transport
	Engineering, planning, grid design, material science, transporting gas
Transport and Refuelling	H ₂ production, transport and storage and refuelling stations
	Refuelling stations, storage, transport, fuel cells, H ₂ propulsion systems
	Automotives and marine H ₂ refuelling, storage and transport
	H ₂ process design, production, storage and transport
	Electrical, mechanical, compression, wind, solar PV, refuelling, gas storage facilities and transport
	Fuel cells in mobility application, refuelling stations
	H ₂ storage, transport and high-pressure equipment
	Installation of metal structures related to the production, storage and transport of hydrogen
	Production, transport and storage of green H ₂

3.2.1.2 Occupation complexity

Occupation complexity refers to the knowledge intensity of activities, reflecting the extent to which they depend on specialized skills and expertise (Balland et al., 2020).³⁰ These activities are economically valuable, as they generate high rents (Rigby et al., 2019)³¹ and embody tacit knowledge that can offer a competitive advantage (Andreoni, 2018).³² Local labour markets that create jobs in more complex occupations tend to outperform those with less complex ones (Hane-Weijman et al., 2022).³³ complex jobs generate stronger multiplier effects (Morretti, 2013)³⁴ and are less geographically mobile (Balland & Rigby, 2017),³⁵ embedding them more strongly in local economies and enhancing the potential for regional competitive advantage.

Understanding both skills transferability and occupational complexity is key to successful workforce development in the hydrogen value chain and beyond. These insights foster the growth of a flexible, adaptable labour force while strengthening local economies through innovation and long-term competitive advantage. Occupational complexity is measured by the number of distinct skills required for the performance of a given job. To analyse this in more detail, occupations are divided into three categories (i.e. terciles) based on their respective skill requirements. For example, high-complexity occupations (1st tercile, shaded green) require a broad and diverse set of skills, reflecting a high degree of functional versatility and adaptability.

Table 2 presents highly complex occupations essential for advancing the green hydrogen value chain. These roles extend across highly specialized areas of engineering, such as electrical, mechanical, chemical and environmental engineers, as well as complex operational positions including power plant operators, chemical processing controllers and petroleum refining operators. The inclusion of managerial and strategic occupations, such as mining, manufacturing, and research and development managers, highlights the critical role leadership plays in navigating technical and operational complexities. Additionally, technicians and specialized experts, e.g. electrical and chemical engineering technicians as well as welders, reflect the wide spectrum of skills required in the hydrogen industry, reinforcing the multidisciplinary nature and extensive knowledge integration needed to drive innovation and growth in the green hydrogen economy.

³⁰ Balland, P. A., Jara-Figueroa, C., Petralia, S. G., Steijn, M. P., Rigby, D. L., & Hidalgo, C. A. (2020). Complex economic activities concentrate in large cities. *Nature human behaviour*, 4(3), 248-254.

³¹ Rigby, D. L., Roesler, C., Kogler, D., Boschma, R., & Balland, P. A. (2019). Do EU regions benefit from smart specialization. *Utrecht University Papers in Evolutionary Economic Geography*, 19.

³² Andreoni, A. (2018) The architecture and dynamics of industrial ecosystems, *Cambridge Journal of Economics*, 42(6):1613-1648.

³³ Hane-Weijman, E., Eriksson, R. H., & Rigby, D. (2022). How do occupational relatedness and complexity condition employment dynamics in periods of growth and recession? *Regional Studies*, 56(7), 1176-1189.

³⁴ Moretti, E. (2012). *The New Geography of Jobs*. Houghton Mifflin Harcourt Publishing Company.

³⁵ Balland, P. A., & Rigby, D. (2017). The geography of complex knowledge. *Economic geography*, 93(1), 1-23.

Table 2. List of highly complex occupations

Electrical engineers
Ships' engineers
Power production plant operators
Chemical products plant and machine operators
Chemical processing plant controllers
Petroleum and natural gas refining plant operators
Chemical engineers
Incinerator and water treatment plant operators
Insulation workers
Chemical engineering technicians
Air conditioning and refrigeration mechanics
Metal finishing, plating and coating machine operators
Packing, bottling and labelling machine operators
Electrical and electronic equipment assemblers
Steam engine and boiler operators
Mining managers
Mechanical engineers
Chemical and physical science technicians
Manufacturing managers
Physical and engineering science technicians not elsewhere classified
Production clerks
Mechanical machinery assemblers
Metal processing plant operators
Industrial and production engineers
Electrical mechanics and fitters
Electronics engineers
Electrical engineering technicians
Professional services managers not elsewhere classified
Agricultural and industrial machinery mechanics and repairers
Assemblers not elsewhere classified
Mechanical engineering technicians
Metal production process controllers
Welders and flame cutters
Environmental engineers
Plumbers and pipe fitters

Engineering professionals not elsewhere classified
Civil engineering technicians
Electronics engineering technicians
Mining and metallurgical technicians
Manufacturing labourers not elsewhere classified
Computer network professionals
Mining engineers, metallurgists and related professionals
Systems administrators
Environmental and occupational health inspectors and associates
Lifting truck operators
Blacksmiths, hammersmiths and forging press workers
Retail and wholesale trade managers
Life science technicians (excluding medical)
Pulp and papermaking plant operators
Precision-instrument makers and repairers
Environmental protection professionals
Software and applications developers and analysts not elsewhere classified
Chemists
Environmental and occupational health and hygiene professionals
Computer network and systems technicians
Valuers and loss assessors
Human resource managers
Database designers and administrators
Printers
Building and related electricians
Electronics mechanics and servicers
Glass and ceramics plant operators
Civil engineers
Stock clerks
Freight handlers
Medical and pathology laboratory technicians
Miners and quarriers
Motor vehicle mechanics and repairers
Metal working machine tool setters and operators
Clearing and forwarding agents
Supply, distribution and related managers

Sheet metal workers
Telecommunications engineers
Managing directors and chief executives
Insurance representatives
Systems analysts
Mineral and stone processing plant operators
Social welfare managers
Information and communications technology operations technicians
Information and communications technology service managers
Mining supervisors
Commercial sales representatives
Construction supervisors
Business services and administration managers not elsewhere classified
Policy administration professionals
Health service managers
Building structure cleaners
Electrical line installers and repairers
Finance managers
Senior officials of special-interest organizations
Construction managers
Data entry clerks
Information and communications technology installers and servicers
Government regulatory associate professionals not elsewhere classified
Information and communications technology sales professionals
Product and garment designers
Rubber products machine operators
Web technicians
Manufacturing supervisors
Management and organization analysts
Draughtspersons
Toolmakers and related workers
Town and traffic planners
Glass makers, cutters, grinders and finishers
Ships' deck officers and pilots
Research and development managers

Source: Authors' elaboration

3.3 Skills supply: Quantity, quality and demand-supply mismatches

To effectively engage with the hydrogen value chain, countries must develop more skills, higher-level competencies and different types of abilities. Multiple institutions are mandated to provide such capabilities, each offering programmes that cover both general and specialized knowledge. Most of the skills identified by the demand-side methodology, especially the most complex skills, are provided by tertiary education institutions, alongside technical and vocational establishments and dedicated training centres.³⁶

Four main types of institutions should be considered when reviewing a country's skills training programmes.

- **Universities:** Public and private institutions offering a broad range of undergraduate and postgraduate programmes, including foundational science disciplines.
- **Technological universities:** Specialized institutions focusing on engineering and applied sciences, providing long-term, advanced training, including industry-driven programmes.
- **Intermediate institutes:** Vocational schools bridging secondary and higher education, providing medium-term training to develop technical and practical skills for specific careers.

- **Training centres:** Short-term programmes targeting specific skills, often tailored to market demand and focused on vocational training and certification.

For each of these institutions, information on their specific programmes aligned with the skills demand identified above should be collected. A list of programme types includes:

- Long-term postgraduate programmes (3 to 5 years) in basic sciences
- Long-term postgraduate programmes (3 to 5 years) in applied sciences and engineering
- Medium-term undergraduate programmes (3 years) in specialized engineering fields
- Medium-term undergraduate programmes (3 years) in specialized management fields
- Short- and medium-term vocational programmes (1 to 3 years).

The assessment of skills training programmes' quantity and quality cannot be entirely separated from labour market demand; it is therefore an inherently relative assessment. Nonetheless, several **parameters of both quality and quantity of supply** must be considered when assessing a country's skills training programmes.

These parameters are presented in the following score card:

	SCORE CARD: Assessment parameters	Score
1	Type, scale and reliability of financing of skills supply	1 to 5
2	Accreditation of the training programme to national and international standards	1 to 5
3	Appropriate length of the programme given the degree of skills complexity	1 to 5
4	Students/teacher ratio in the delivery of the programme	1 to 5
	Appropriate incentives and schemes to ensure trainers continuously update their skills	
5	Access to training pathways linking secondary and higher education	1 to 5
6	Access to training facilities including pilot lines and demonstration projects	1 to 5
7	Participation of industry in the design of programme curricula	1 to 5
8	Participation of industry in the delivery of the programme (on-the-job training)	1 to 5
9	Provision of matching services to improve labour market access	1 to 5
10	Offering schemes to promote skills transferability and retraining	1 to 5
	Total score	

³⁶ World Bank (2000). Higher Education in Developing Countries: Peril and Promise. <https://documents1.worldbank.org/curated/en/345111467989458740/pdf/multi-page.pdf>
 Altbach, P. G., & Knight, J. (2007). The internationalization of higher education: Motivations and realities. *Journal of studies in international education*, 11(3-4), 290-305.
 Banga, K, and te Velde, D.W. (2019) Preparing developing countries for the future of work: understanding skills-ecosystem in a digital era. Pathways for Prosperity Commission Background Paper Series; no. 29. Oxford, United Kingdom.

Effective training systems are shaped by the unique characteristics of each country's institutions and the broader ecosystem within which they operate. A robust skills development system anticipates future skill needs, involves employers and workers in training decisions, ensures quality and relevance, provides accessible and targeted training programmes, supports equitable financing, and monitors economic and social outcomes.³⁷

This is often not the case in EMDEs, where higher education and vocational institutions frequently fail to meet market needs, resulting in labour market mismatches. In Egypt, for example, many graduates lack essential competencies, skills, behaviours and knowledge.³⁸ These systems often struggle to meet growing demand, provide insufficient support to learners, and weak incentives for teachers and training providers, thereby jeopardizing overall skills development and the transferability of acquired skills.³⁹

A skills mismatch occurs when individuals' skills do not align with the requirements of their current job or available vacancies, resulting in unemployment or underemployment.⁴⁰ This typically occurs when education and training systems fail to meet labour market demands, or when the economy lacks jobs that match individuals' skills.⁴¹ Skills mismatches are more pronounced in EMDEs, with firms reporting that their workers' level of education and skills are inadequate (reported by 25 per cent of employers in Organisation for Economic Co-operation and Development (OECD) countries, 40 per cent in sub-Saharan Africa, and 50 per cent in East Asia and the Pacific).⁴²

Skills mismatches manifest in various forms, such as skills gaps, deficits and surpluses. Such mismatches are costly: a lack of required skills reduces productivity, while unused skills may result in forgone earnings. At the individual level, overqualification can lead to wage penalties, negatively impacting workers' job and life satisfaction. Even in EMDEs with limited training opportunities, many struggle to find jobs that match their skills, reducing productivity and limiting their career prospects. Skills mismatches harm firms' productivity, competitiveness and innovation, and increase staff turnover and inefficiency. Ultimately, these mismatches lead to lost profits and missed market opportunities.

Skills gaps arise when an employee's abilities fall short of or do not match job requirements, while skills deficits refers to employers' inability to find workers who have the skills they need. Such gaps have a negative impact on workers, firms and economies: low-skilled workers earn less, dynamic firms face constraints, and future economic development is curtailed (Koettl et al., 2016).⁴³

³⁷ ILO (2010) A Skilled Workforce for Strong, Sustainable and Balanced Growth. International Labour Organization. <https://www.ilo.org/publications/skilled-workforce-strong-sustainable-and-balanced-growth-0>

³⁸ El Baradei, L., & Kadry, M. (2022). Bridging the employability skills gap in higher education.

³⁹ World Bank, UNESCO and ILO (2023). Building Better Formal TVET Systems: Principles and Practice in Low- and Middle-Income Countries. Washington D.C., Paris, Geneva: The World Bank, UNESCO, and ILO.

⁴⁰ Lyon, S., Ranzani, M., & Rosati, F. (2012). Skill deficit in developing countries: a review of empirical evidence from enterprise surveys. Paper commissioned for the Education for All Global Monitoring Report.

⁴¹ ILO (2020). What is skills mismatch and why should we care? International Labour Organization <https://www.ilo.org/resource/article/what-skills-mismatch-and-why-should-we-care>

⁴² Almeida, Rita, Jere Behrman, and David Robalino, eds. 2012. The Right Skills for the Job?: Rethinking Training Policies for Workers. Washington, DC: World Bank. DOI: 10.1596/978-0-8213-8714-6. License: Creative Commons Attribution CC BY 3.0.

⁴³ Koettl, J., Johansson de Silva, S., Kupets, O., Olefir, A., & Safir, A. (2015). Skills Gaps and the Path to Successful Skills Development: Emerging Findings from Skills Measurement Surveys in Armenia, Georgia, FYR Macedonia, and Ukraine, Report no. ACS14318. Washington, DC: World Bank.





4. Methodology Pilots: Applications and Results

UNIDO's methodology was piloted in two countries – Egypt and Tunisia (see country reports). The hydrogen industry in both countries is in a nascent stage, limiting the sample of actors from which data could be collected. In some cases, firms are not yet fully aware of the importance of future skills development or of the complex range and depth of new occupations and skills that might emerge in the industry. The following section analyses the main findings in each country, with a focus on industries demonstrating the greatest potential.

4.1 Egypt: Overview

Egypt, as one of the largest and most industrially diversified economies in North Africa, plays a leading role in regional efforts to reduce GHG emissions. Several key industries of Egypt's economy—particularly heavy industries—are major emitters, highlighting the urgency of

sustainable transitions. The fertilizer industry stands out as a major consumer of hydrogen, traditionally produced using Egypt's abundant natural gas reserves.

The fertilizer industry alone accounts for approximately 46 per cent of natural gas consumption in Egypt's industrial sector.⁴⁴ This heavy reliance on natural gas-based hydrogen significantly contributes to national GHG emissions, but also presents a strategic opportunity: transitioning to green hydrogen could decarbonize critical industries, lower Egypt's carbon footprint, and strengthen its emerging leadership in the global clean energy transition.

Recognizing the need to decarbonize energy-intensive industries and leverage its abundant renewable resources, Egypt has launched an ambitious green hydrogen strategy. The National Low-Carbon Hydrogen Strategy, which outlines a phased approach to position Egypt as a regional leader in green hydrogen production and export,

⁴⁴ https://www.oecd.org/content/dam/oecd/en/events/2024/5/cefim-egypt-2nd-stakeholder-workshop-29-may/ECO%20Presentation_Egypt%20LCH%20workshop.pdf

is a cornerstone of this initiative.⁴⁵ The strategy targets the production of 1.5 million tons of green hydrogen annually by 2030, scaling up to 5.8 million tons by 2040.

To facilitate this transition, Egypt has implemented a comprehensive policy and regulatory framework. In January 2024, the government enacted the Green Hydrogen Incentives Law (Law No. 2 of 2024), offering a range of fiscal and non-fiscal incentives to attract investment in green hydrogen projects.⁴⁶ These incentives include:

- **Tax rebates:** Cash investment incentives ranging from 33 per cent to 55 per cent of the taxes paid on income derived from green hydrogen activities.
- **Value added tax (VAT) exemptions:** Exemption from VAT on imports of equipment and materials essential for green hydrogen projects, as well as a 0 per cent VAT rate on exports of green hydrogen products.
- **Customs and land use benefits:** Reductions in port fees, land use rights, and the establishment of dedicated customs ports to streamline the import and export processes for green hydrogen firms.
- **Regulatory streamlining:** Provision of a single license covering all stages of project development, from establishment to operation, to simplify bureaucratic procedures.

Achieving these strategic ambitions will require a workforce transformation aligned with Egypt's hydrogen vision. The National Low-Carbon Hydrogen Strategy explicitly recognizes that the envisioned scale-up by 2040 will necessitate a deep pool of skilled labour across engineering, process operations, and safety management. Egypt's established fertilizer and heavy indus-

trians and engineers, but their reorientation toward hydrogen-based processes will demand retraining, upskilling, and cross-sectoral knowledge transfer. Incentive frameworks such as the Green Hydrogen Incentives Law are therefore not only investment tools but also mechanisms to stimulate job creation and technical training partnerships. This workforce dimension links directly to Egypt's broader development goals: reducing unemployment among young graduates, increasing women's participation in STEM roles, and positioning the domestic labour force as a competitive advantage in attracting hydrogen investment. By embedding skills and workforce development into the green hydrogen strategy, Egypt can ensure that industrial decarbonization simultaneously advances inclusive growth and human capital development.

4.1.2 Egypt: Assessment

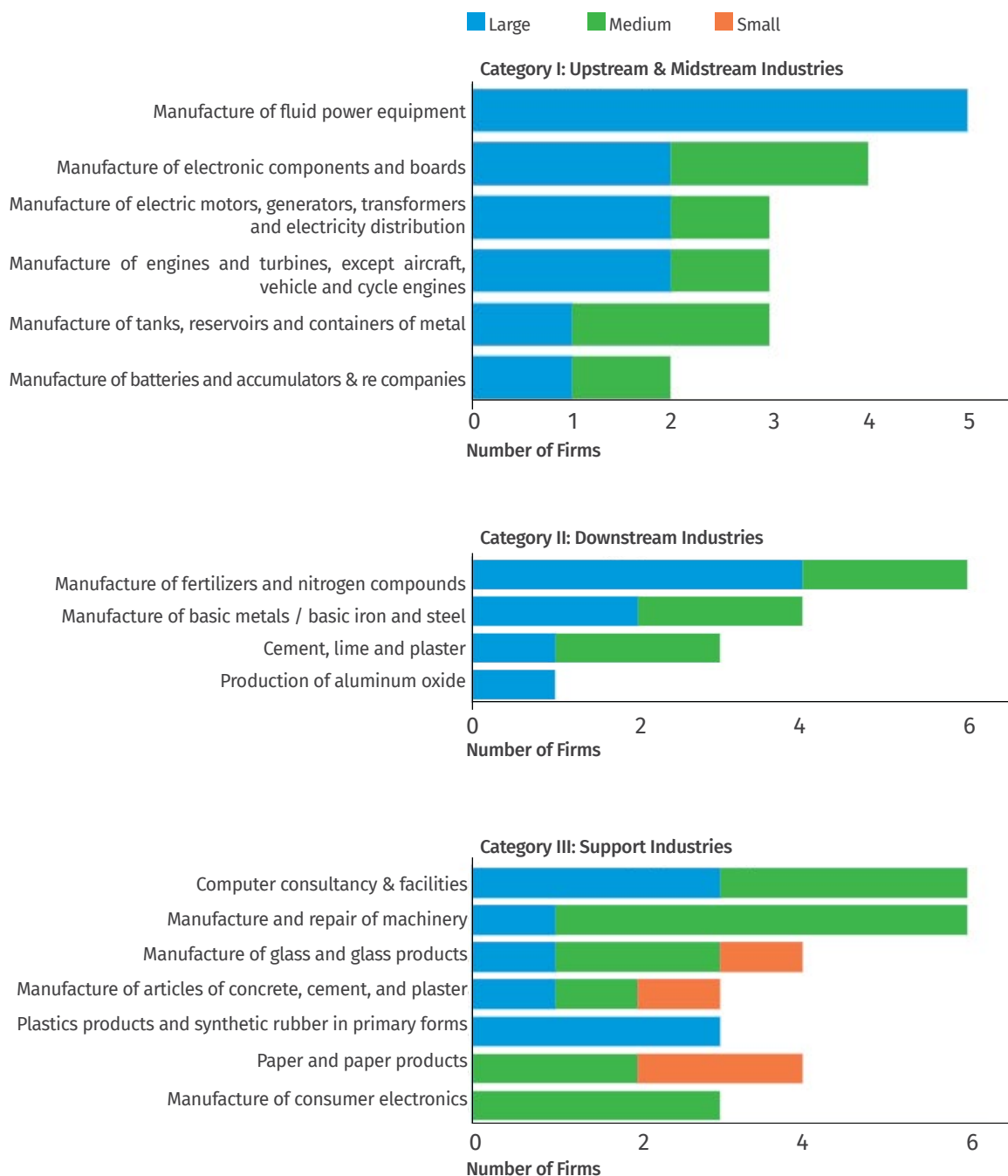
Figure 11 presents the distribution of surveyed firms in Egypt's manufacturing sector, grouped into three categories: (I) upstream and mid-stream industries; (II) downstream industries, and (III) support industries, disaggregated by firm size (large, medium and small). Large firms dominate activities in Category I, such as the manufacturing of engines, turbines and electric motors, with minimal participation from small firms. Category II shows a more balanced distribution, particularly in fertilizer and basic metals production, where both large and medium firms are represented. In Category III, support industries have the widest variation in terms of firm size, with small and medium enterprises more visible in subsectors such as consumer electronics, paper products and glass manufacturing. These findings should be interpreted with caution, as the limited sample size due to the low response rate may restrict the data's generalizability across the industry.

tries already employ large numbers of tech-

⁴⁵ <https://beta.sis.gov.eg/en/media-center/strategies/national-strategy-for-low-carbon-hydrogen/>

⁴⁶ https://www.oecd.org/content/dam/oecd/en/about/programmes/cefm/green-hydrogen/2024-case-studies/Green-hydrogen-incentives-law-case-study-2024.pdf/_jcr_content/renditions/original/Green-hydrogen-incentives-law-case-study-2024.pdf

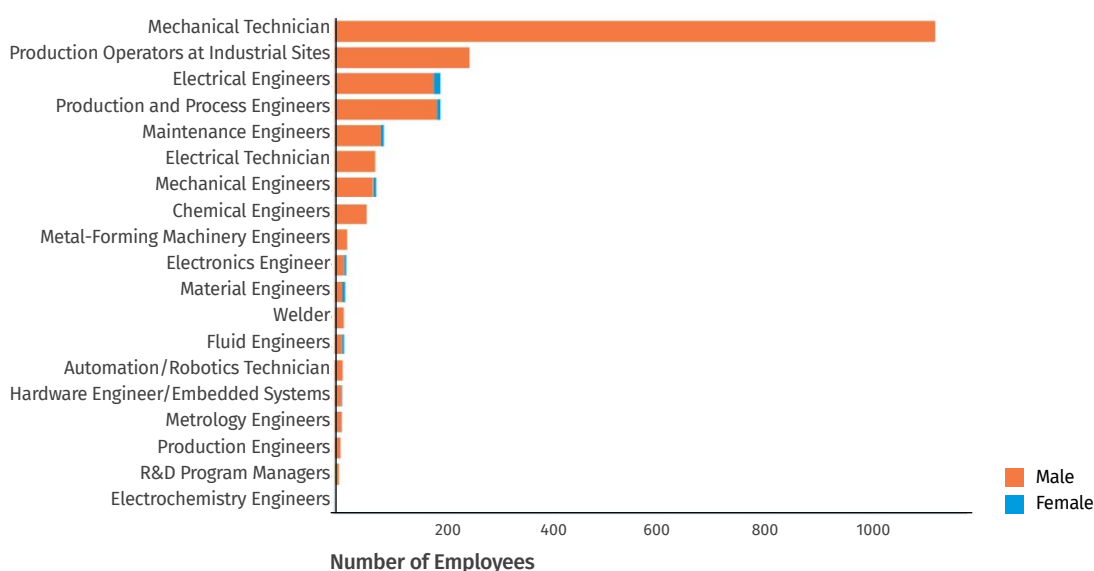
Figure 11. Distribution of surveyed firms by category and size



Distribution of occupations in Egypt's green hydrogen upstream and midstream industries

- Mechanical technicians are the most common occupation by a wide margin, followed by production operators at industrial sites, electrical engineers, and production and process engineers (Figure 12).
- A few complex occupations—such as maintenance engineers, electrical technicians and mechanical engineers—also employ notable numbers, whereas many specialized positions have relatively low representation.
- The workforce is overwhelmingly male across all roles, with women represented in only a few occupations and in significantly smaller numbers.
- Female representation also remains minimal in higher employment categories, such as electrical engineers and production engineers.
- These patterns indicate both a concentration of employment in specific roles and a substantial gender gap, highlighting the need for targeted inclusion efforts in technical education and hiring practices.

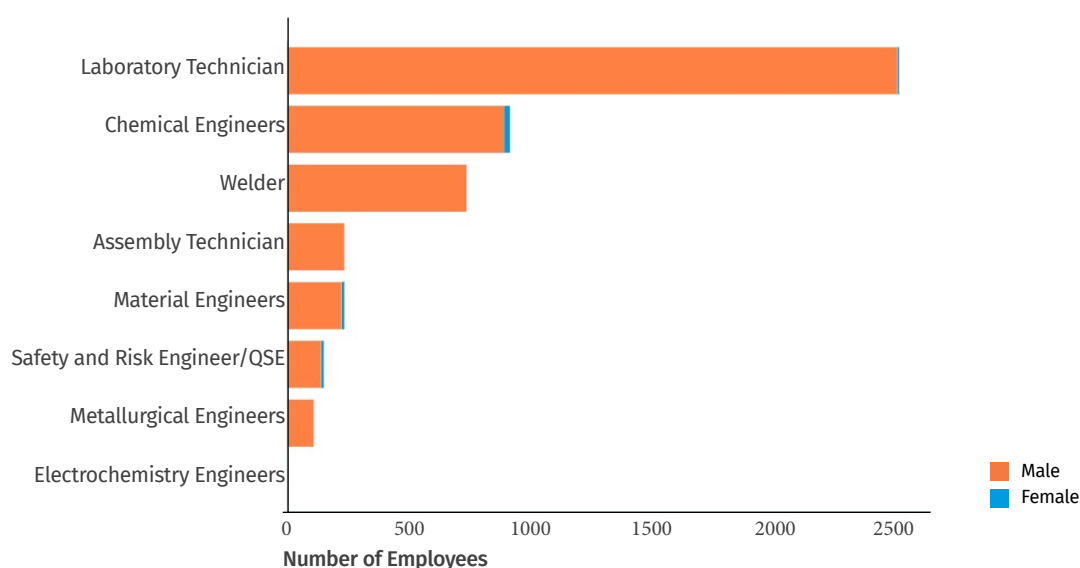
Figure 12. Employment by occupation and gender in Egypt's green hydrogen upstream and midstream industries



Occupation distribution in Egypt's green hydrogen downstream industries

- Laboratory technicians represent the largest occupational group with over 2,000 employees, far exceeding all other groups in this industrial category. This high number is mainly attributable to the fertilizer industry (Figure 13).
- Chemical engineers and welders also have relatively high employment levels, while other roles, such as assembly technicians, material engineers, and safety and risk engineers account for a smaller workforce size.
- The share of electrochemistry engineers is very low; this group is the most underrepresented occupation in this industrial category.
- Gender distribution remains heavily skewed towards male workers across all roles, with female participation limited to a few occupations such as chemical engineers, material engineers, and safety and risk engineers. However, the number of female employees remains very low even in those occupations.
- These data reinforce earlier observations of occupational clustering and gender imbalance in Egypt's upstream and midstream industries, highlighting the persistent challenges to achieving gender inclusivity within the country's technical and engineering workforce.

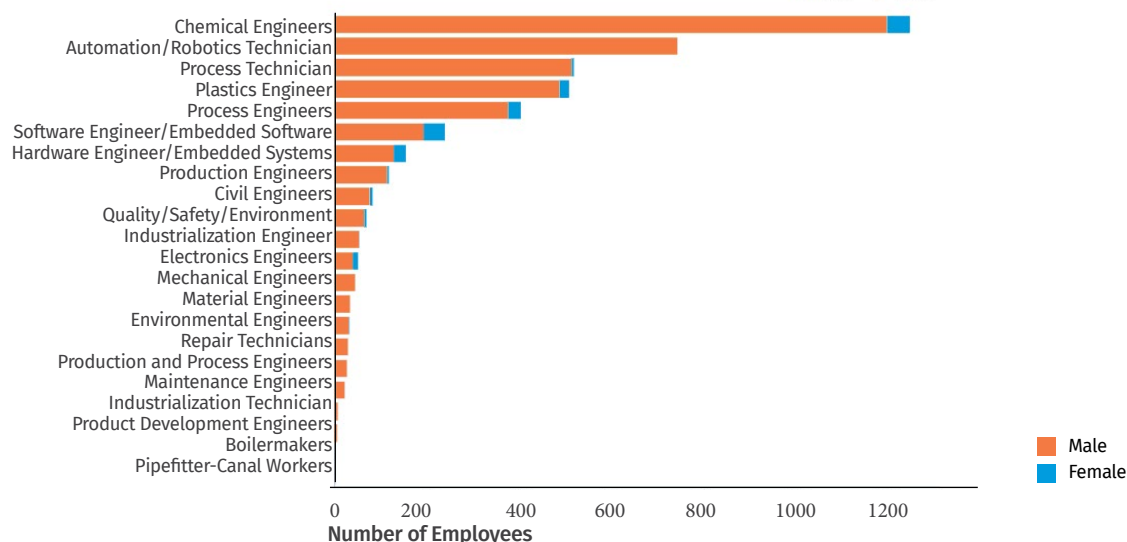
Figure 13. Employment by occupation and gender in Egypt's green hydrogen downstream industries



Occupation distribution in Egypt's green hydrogen support industries

- Chemical engineers account for the largest share of the workforce in this industrial category, followed by automation/robotics technicians, process technicians and plastics engineers (Figure 14).
- Other occupations, such as process engineers, software engineers and hardware engineers, make up a significant share of the workforce in green hydrogen support industries, with a concentration of workers in automation and systems-related occupations.
- In contrast, occupations such as boilermakers, pipefitters/canal workers and product development engineers show very low levels of employment.
- The number of female employees is higher in this industrial category than in others, particularly in occupations such as chemical engineers, software engineers and process technicians, though they remain a minority of total workers across all occupations.
- These findings highlight a concentration of occupations in modern technical roles and modest improvements in gender representation, and point to areas that require targeted inclusion initiatives.

Figure 14. Employment by occupation and gender in Egypt's green hydrogen support industries

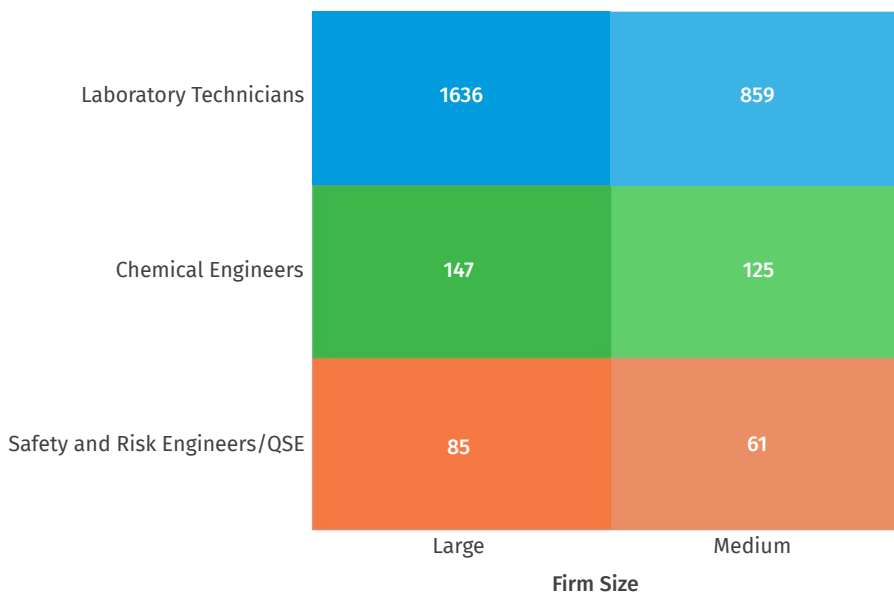


Box 1: Workforce composition and firm size in Egypt's fertilizer industry

The analysis focuses on the manufacturing of fertilizers and nitrogen compounds, given the low overall response rate and small sample size in many industrial categories. This industry is critical to Egypt's decarbonization strategy due to its heavy reliance on fossil fuels. It also garnered the highest survey response rate (66 per cent), with a more balanced representation of both large- and medium-sized firms. Focusing on this industry allows for more robust insights and targeted policy recommendations based on a representative data subset.

- All occupations identified by UNIDO as being essential for the manufacturing of fertilizers and nitrogen compounds are represented within Egypt's fertilizer industry, reflecting the country's position as a leading global producer of nitrogen fertilizers.
- Laboratory technicians make up the largest occupation group (Figure 13), followed by chemical engineers and safety and risk engineers, highlighting a strong foundation of technical workers.
- Large firms (by turnover) employ significantly more workers than medium-sized firms, and cover a broader range of occupations, indicating greater operational complexity and deeper specialization.

Figure 15. Employees by occupation and firm size in Egypt's fertilizer industry



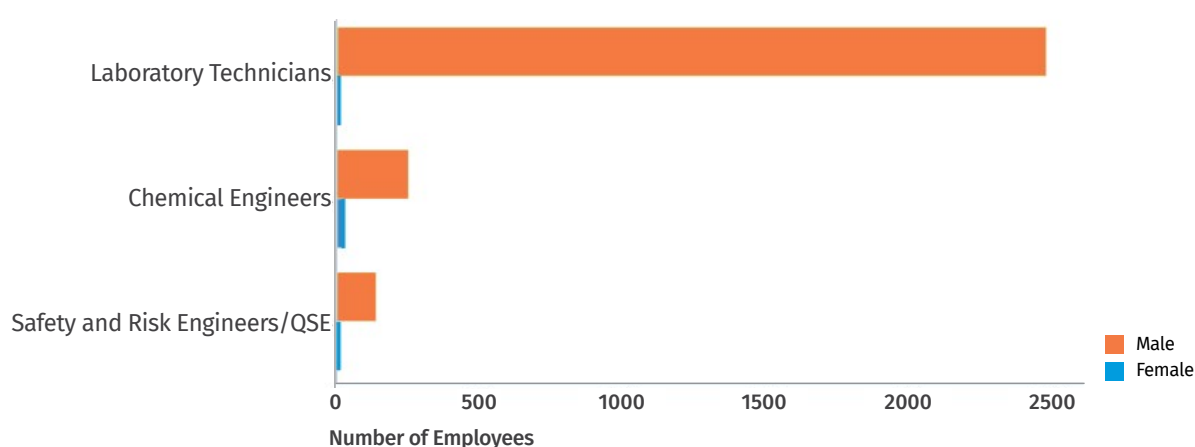
These findings underscore Egypt's strong occupational alignment with international industry standards and the strategic importance of workforce development in high-demand technical roles. To maintain global competitiveness and meet evolving technological demands, policies should prioritize skills diversification, strengthen technical education pathways, and support medium-sized firms in expanding both workforce size and specialization.

Gender representation across occupations in Egypt's fertilizer industry

- Male workers dominate laboratory technician roles, exhibiting the highest level of gender imbalance in one of the industry's most prevalent occupations (Figure 16).
- The group of chemical engineers and safety and risk engineers is also dominated by male workers, reinforcing the broader trend of limited female participation across technical and specialized roles in Egypt's fertilizer industry.

The persistent underrepresentation of women in key technical occupations highlights a structural challenge to building a more inclusive industrial workforce. Addressing gender imbalances, particularly in specialized engineering and laboratory roles, will be crucial for expanding the industry's talent pool and supporting national and international commitments to gender equality in industry.

Figure 16. Gender composition by occupation in Egypt's fertilizer industry



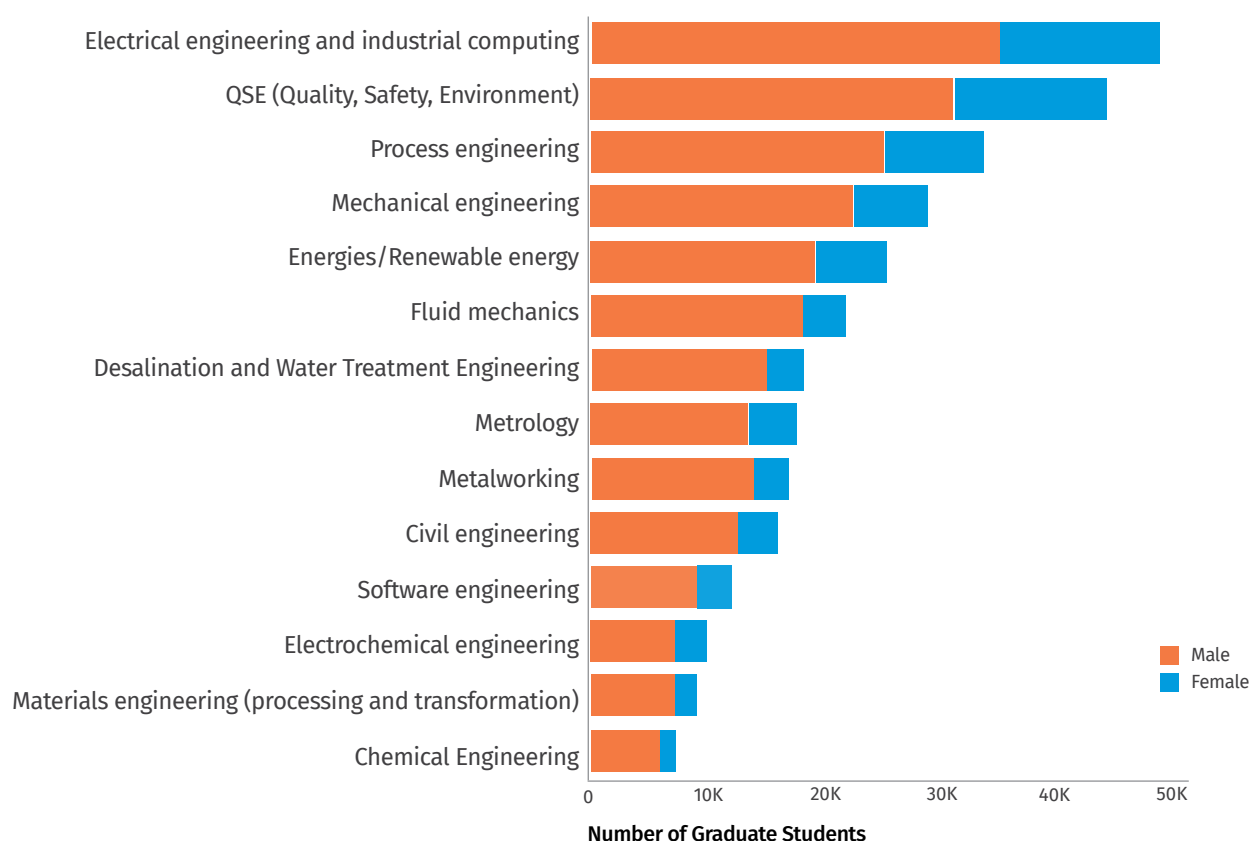
Academic training programmes in green hydrogen-related fields in Egypt

- Electrical Engineering and Industrial Computing have the highest number of graduate enrolments, followed by Quality, Safety, and Environment (QSE) and Process Engineering. These three fields account for over 30,000 graduates, indicating strong academic output aligned with key industrial needs (Figure 17).
- Enrolment in mid-tier disciplines - such as Mechanical Engineering, Energies/Renewable Energy and Fluid Mechanics - is also substantial, while fields such as Chemical Engineering, Materials Engineering and Electrochemical Engineering have comparatively lower enrolment rates.
- A clear gender disparity is evident across all fields. While female participation is present in most disciplines, male students consistently

outnumber females, often by a wide margin. The gap is narrower in fields such as QSE, Desalination and Water Treatment, and Energies/Renewable Energy, suggesting these fields may be more accessible or attractive to female students.

- The gender imbalance in academic training programmes reflects the trends observed in the industrial workforce, where the majority of technical and engineering jobs are held by males. Fields with a low number of female graduates—such as Mechanical, Chemical, and Electrochemical Engineering—generally align with occupations in which women are underrepresented in the labour market.
- These findings highlight the need for gender-sensitive strategies across both education and employment pipelines, ensuring that growth in the industrial sector is supported by a more inclusive and diverse talent pool.

Figure 17. Enrolment in green hydrogen-related academic programmes in Egypt



4.1.3 Egypt: Policy recommendations

1. Strengthen technical education and skills diversification

- Expand partnerships between industry and vocational training institutions to align curricula with the fertilizer industry's evolving technical needs. The fertilizer industry is critical for downstream value chain development, particularly in the agro-food industry, from both a domestic and regional perspective.
- Introduce specialized training modules in emerging fields such as smart grid development, control systems and safety engineering.

2. Support workforce scaling in medium-sized firms

- Provide financial incentives and capacity development programmes aimed at supporting medium-sized firms in diversifying their occupational base.
- Support the growth of medium-sized firms as a key player in the domestic production ecosystem, especially in linking small and large enterprises.

- Facilitate access to technology and infrastructure to help medium-sized firms expand their operations and create more employment opportunities.

3. Promote gender equality in technical roles

- Launch targeted scholarships, internships and mentorship programmes for women pursuing studies and careers in chemical engineering, laboratory sciences and safety engineering.
- Encourage firms to implement internal gender diversity targets and publicly report progress as part of their corporate sustainability initiatives.

4. Establish recognition and visibility programmes

- Establish national awards or certifications recognizing firms that excel in workforce diversity and technical innovation
- Showcase successful female professionals in technical fields through media campaigns and industry events to inspire future talent.

- Develop national guidelines to encourage gender-sensitive workplace policies, including flexible work arrangements, parental leave and career development support.
- Implement gender diversity training within firms to foster more inclusive and supportive professional environments.

4.2 Tunisia: Overview

In September 2023, Tunisia launched its National Strategy for the Development of Green Hydrogen and Derivatives, outlining an ambitious vision to position the country as a leading player in the global green hydrogen market.⁴⁷ The strategy targets an annual production of 8.3 million tons of green hydrogen by 2050, with 6 million tons intended for export to Europe. By 2030, Tunisia aims to export 300,000 tons of green hydrogen per year, supported by infrastructure projects such as the proposed Southern Hydrogen Corridor pipeline, which will link North Africa to European energy markets.

To meet these objectives, Tunisia plans substantial investments in renewable energy infrastructure, including the development of 100 GW of renewable power capacity and 86.8 GW of electrolyser capacity by 2050. The strategy also prioritizes the construction of desalination plants to secure the water resources needed for hydrogen production, helping to address the country's persistent water scarcity challenges.

One of the strategy's key objectives is the decarbonization of Tunisia's electricity industry, which heavily relies on fossil fuels. Transitioning to a clean energy system is expected to reduce energy costs, making it more affordable for households and firms. Furthermore, it will bolster Tunisia's ambition of becoming a regional hub for clean energy trade between Africa and Europe (World Bank Group, 2023).

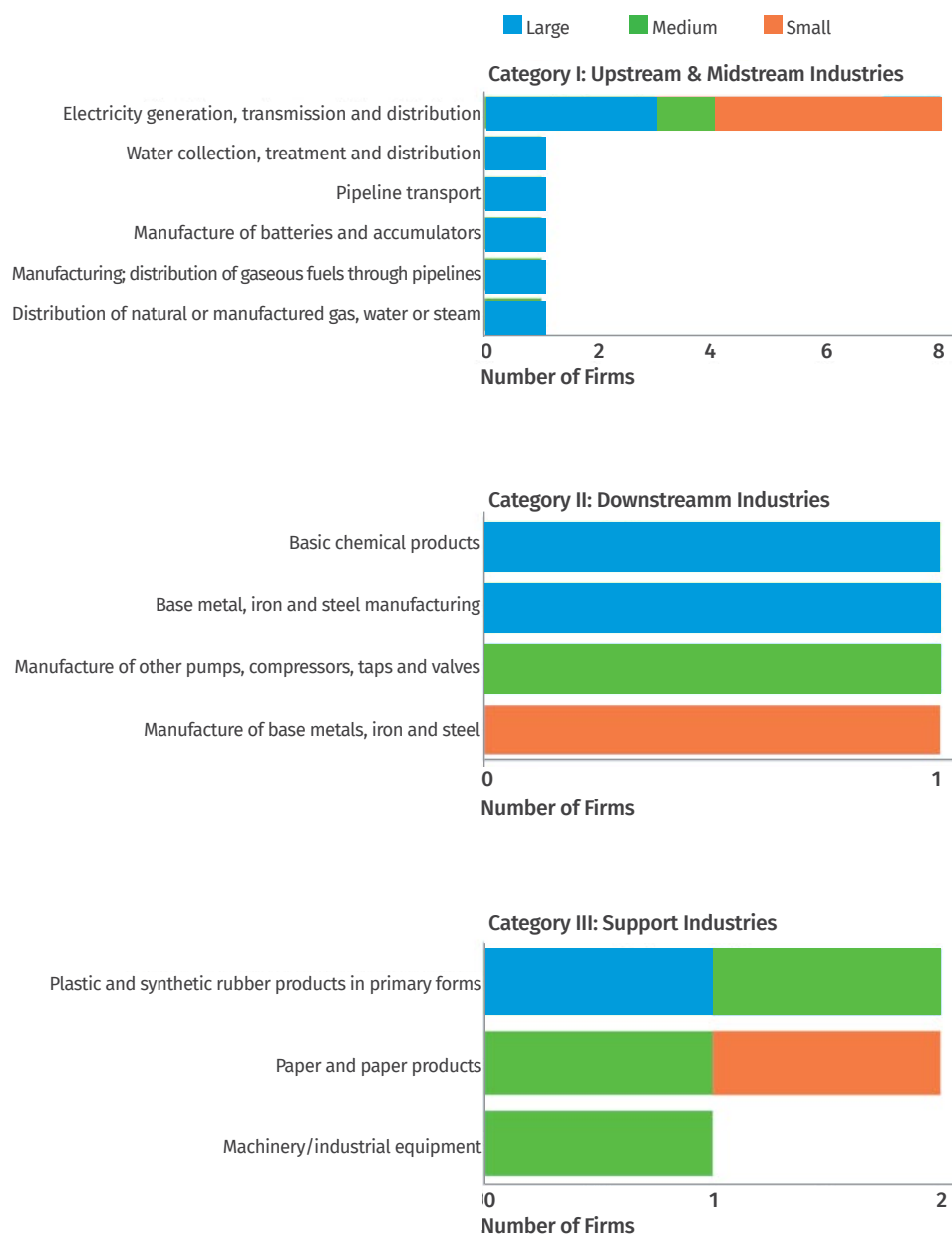
Tunisia's hydrogen vision is inseparable from workforce development. Reaching its renewable energy and electrolyser capacity goals will require tens of thousands of engineers, technicians, and operators with specialized expertise in renewable integration, smart grid management, and hydrogen safety standards. The Southern Hydrogen Corridor initiative underscores the need for internationally recognized qualifications and training standards, allowing Tunisia's labour force to operate across transnational energy systems. Equally, the strategy's emphasis on water desalination for hydrogen production points to new occupational profiles in water management and environmental engineering. For Tunisia, therefore, the green hydrogen transition is not only an export-oriented industrial policy but also a workforce modernization agenda: it provides opportunities to strengthen technical education, align university curricula with hydrogen value chains, and create inclusive employment pathways. Embedding these skills priorities will enable Tunisia to position itself as both a clean energy hub and a regional centre of human capital development in the hydrogen economy.

4.2.2 Tunisia: Assessment

Figure 18 presents the distribution of surveyed firms based on turnover (large, medium and small) across three industrial categories: (I) upstream industries, (II) downstream industries, and (III) support industries. It shows that large firms are concentrated in upstream industries, particularly in electricity and water distribution, while downstream and support industries show a more balanced mix in terms of firm size. Small and medium-sized enterprises (SMEs) play a significant role in certain downstream activities such as base metal manufacturing and the production of pumps and compressors. However, the limited sample size within each industrial category restricts the finding's generalizability, meaning they should be interpreted with caution as they may not fully capture the country's broader industrial structure.

⁴⁷ https://www.energiemines.gov.tn/fileadmin/docs-u1/Re%CC%81sume%CC%81_strate%CC%81gie_nationale_MIME_Anglais.pdf

Figure 18. Distribution of surveyed firms by industry category and size in Tunisia

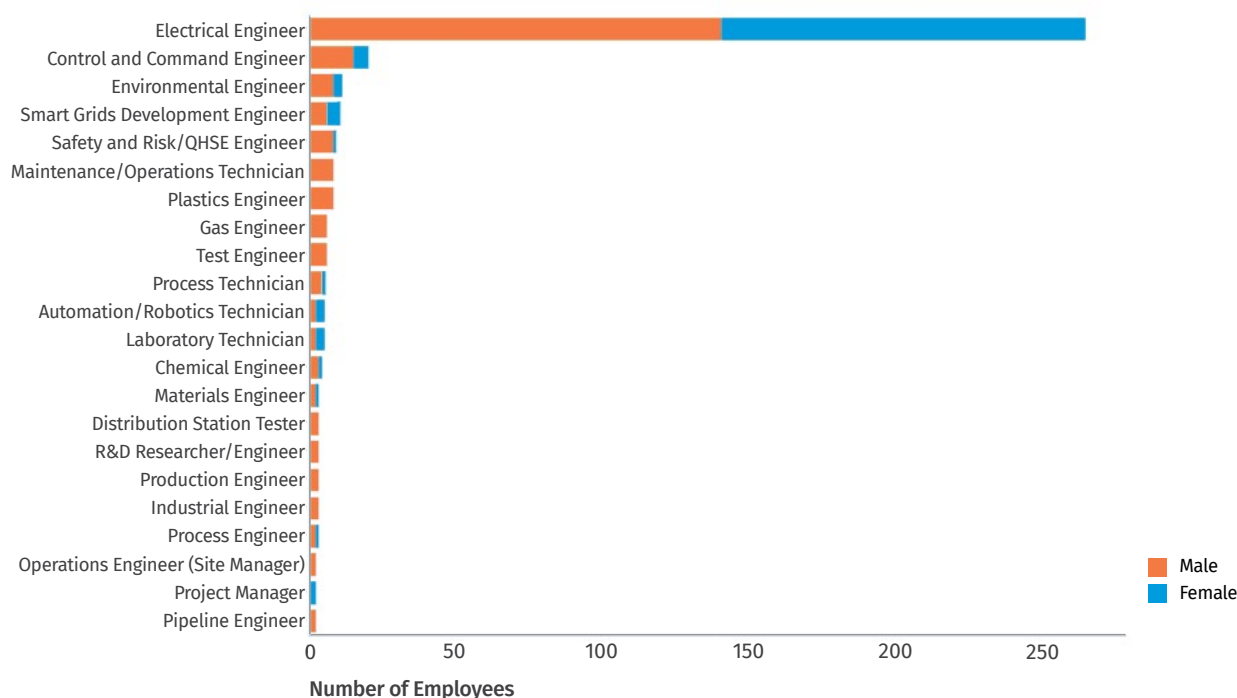


Occupation distribution in Tunisia's green hydrogen upstream and midstream industries

- Electrical engineers account for the largest share of Tunisia's workforce in upstream industries, far exceeding all other occupations. They also show a relatively balanced gender distribution, though males still slightly outnumber women in this occupation group (Figure 19).
- Employment across all other occupations is much lower, with male workers making up the clear majority in nearly all roles.
- Occupations such as control and command engineers, environmental engineers and smart grid development engineers show a visible female presence, although male workers still represent the majority.
- By contrast, technical roles such as maintenance/operations technicians, process technicians and automation/robotics technicians show very limited female participation, suggesting that technical operational roles generally remain male-dominated.

- More specialized roles, such as research and development (R&D) analysts/engineers, industrial engineers and process engineers, are underrepresented in the hydrogen industry's overall workforce, with male employees accounting for the majority of employees.
- The number of female workers in occupations such as pipeline engineers and operations engineers (site managers) is especially low.

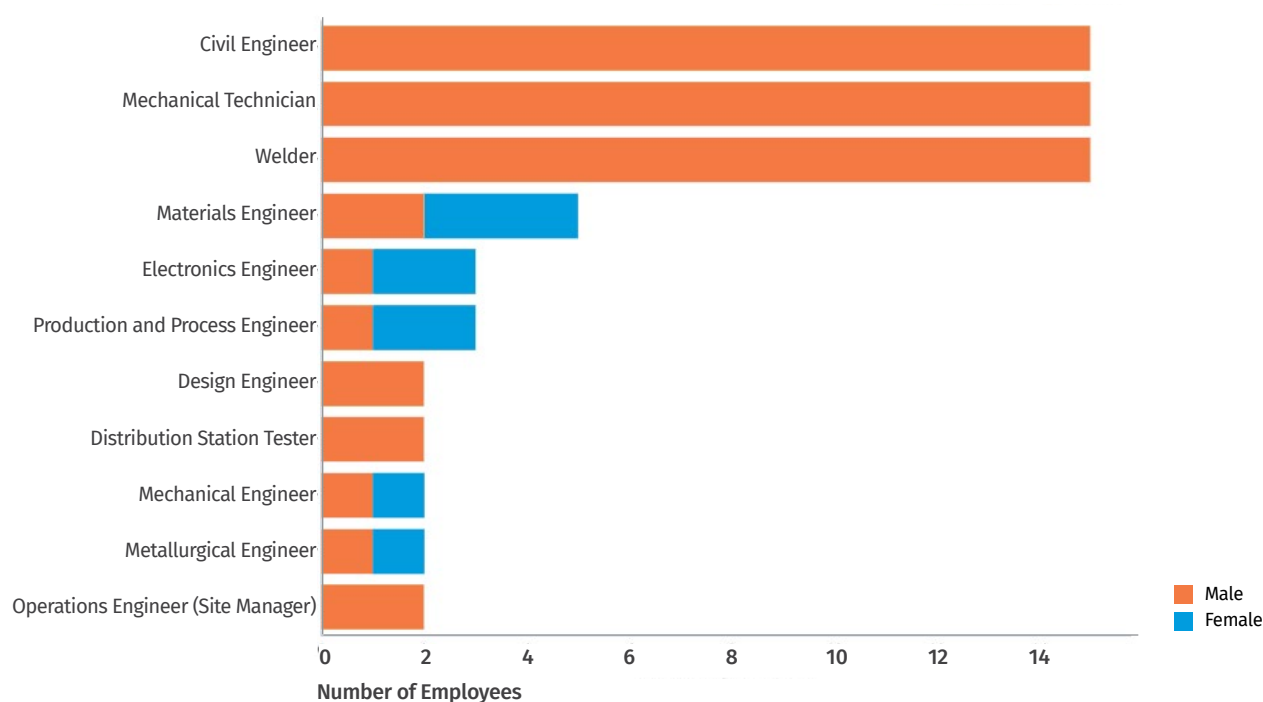
Figure 19. Employment by occupation and gender in Tunisia's green hydrogen upstream and midstream industries



Occupation distribution in Tunisia's green hydrogen downstream industries

- Civil engineers, mechanical technicians and welders account for the highest share of employees in downstream industries. These workers are exclusively male (Figure 20).
- There is a clear male majority across nearly all technical occupations, highlighting a considerable gender disparity in this industrial category.
- A higher level of female participation is found in materials engineering, electronics, and production and process engineering, although their numbers remain relatively low overall.
- There are only very few employees in highly specialized roles (e.g. metallurgical engineers, design engineers). They are predominantly male, suggesting limited opportunities for women or lower representation.

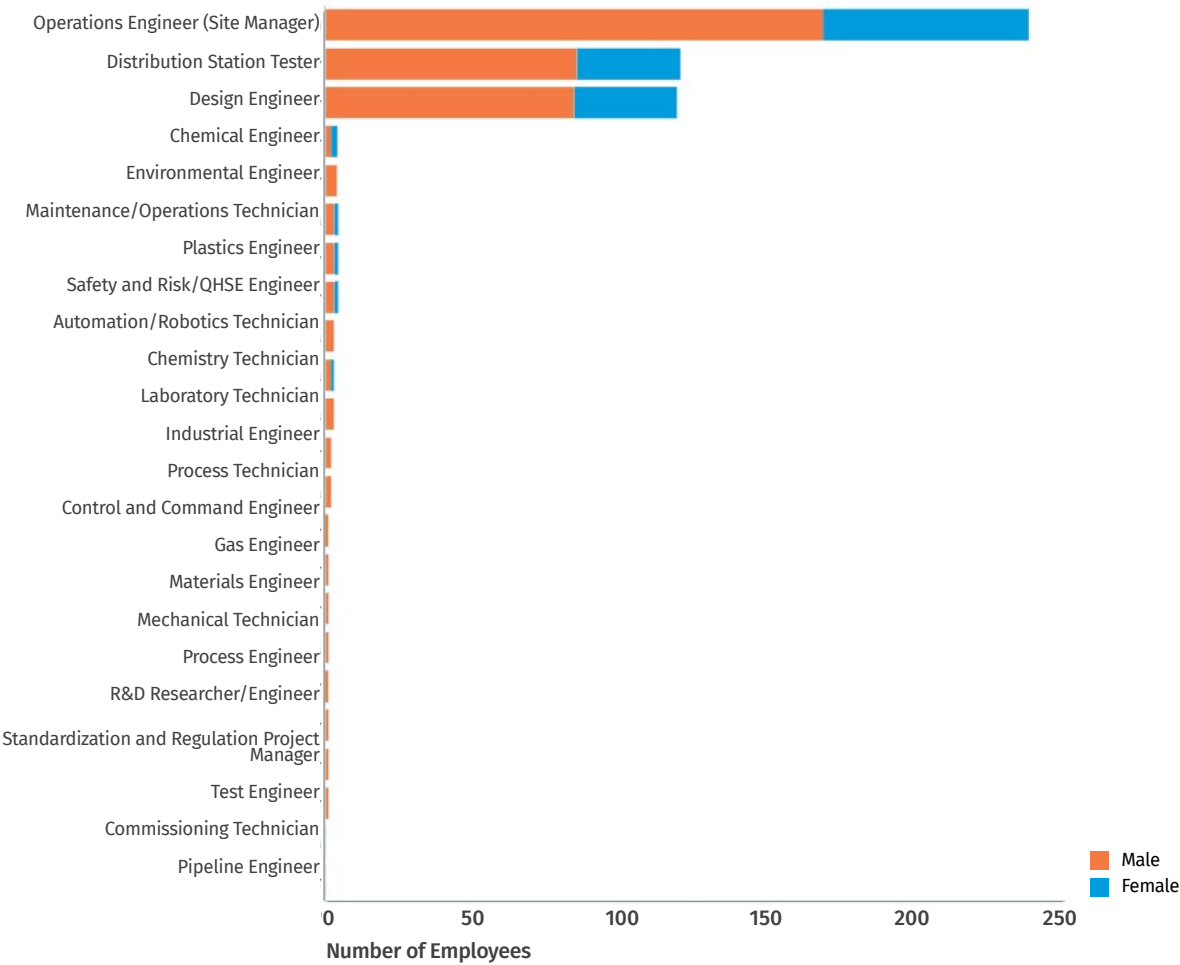
Figure 20. Employment by occupation and gender in Tunisia's green hydrogen downstream industries



Occupation distribution in Tunisia's green hydrogen support industries

- Operations engineers (site managers), distribution station testers, and design engineers represent the largest share of employment in this industrial category (Figure 21). These occupations also show the highest female participation, although women account for a lower share among operations engineers.
- The remaining occupations have very low overall employment, with most roles showing minimal or no female participation.
- Although a few key roles exhibit higher gender balance, the majority of technical and engineering roles remain heavily male-dominated and small in workforce size.

Figure 21. Employment by occupation and gender in Tunisia’s green hydrogen support industries



Box 2: Workforce composition and firm dynamics in Tunisia's electricity industry

Given the low response rate and small sample size across many occupational categories, the analysis focuses on the electricity generation, transmission and distribution industry. This industry stands out with a comparatively higher number of surveyed firms and representation across all three firm sizes—small, medium and large. Focusing on this industry allows for more meaningful insights and the development of targeted policy recommendations based on a robust and representative data subset.

- Large firms (by turnover) employ a broader range of occupations, reflecting operational complexity and specialization (Figure 22).
- In contrast, small and medium firms (by turnover) show occupational concentration, primarily in electrical engineering roles.
- The number of electrical engineers in these firms remains significantly lower than in large firms.

These findings underscore the need for targeted workforce development strategies that address both the depth and breadth of occupational skills across firm sizes. Without deliberate policy interventions, SMEs risk falling behind in building the technical capacity required for green hydrogen innovation and scale-up. Supporting diversified occupational growth and strengthening technical expertise—particularly within SMEs—will be crucial to developing an inclusive, resilient and future-ready hydrogen economy.

Figure 22. Employees by occupation and firm size in Tunisia's electricity generation, transmission and distribution

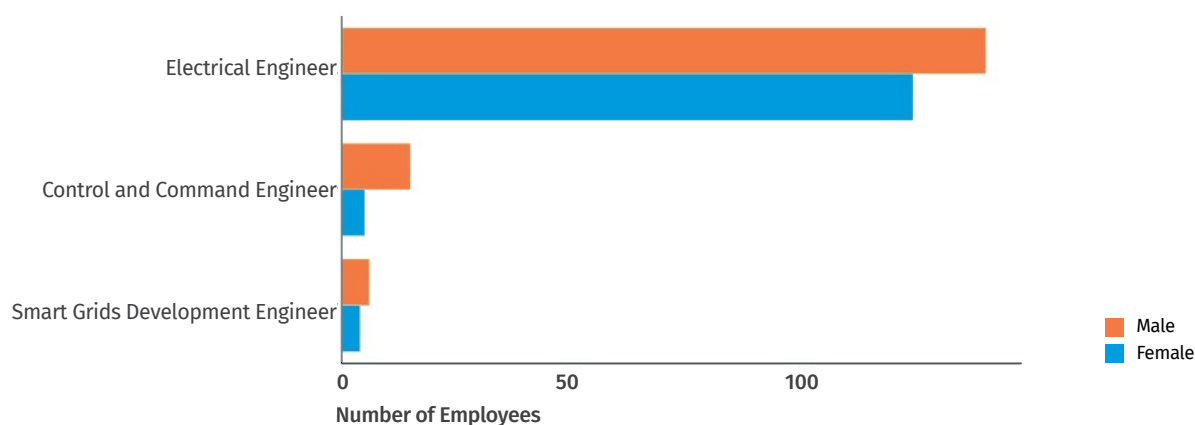
	Large	Medium	Small
Electrical Engineer	260	1	5
Control and Command Engineer	20	0	0
Smart Grids Development Engineer	10	0	0

Gender representation across occupations in Tunisia's electricity industry

- Gender disparities persist across all three industrial categories in Tunisia, though relatively greater gender parity is observed in more complex roles such as electrical engineering.
- Female representation remains particularly low in other specialized technical occupations, including control and command engineering and smart grid development engineering, raising concerns for long-term talent sustainability and the electricity industry's innovative capacity.

These patterns highlight the urgent need for gender-responsive workforce policies that move beyond broad occupational categories to address disparities in specialized technical fields. Expanding pathways for women into critical engineering roles will be essential not only for fostering a more inclusive workforce, but also for ensuring the technical expertise necessary to sustain the growth of Tunisia's green hydrogen industry.

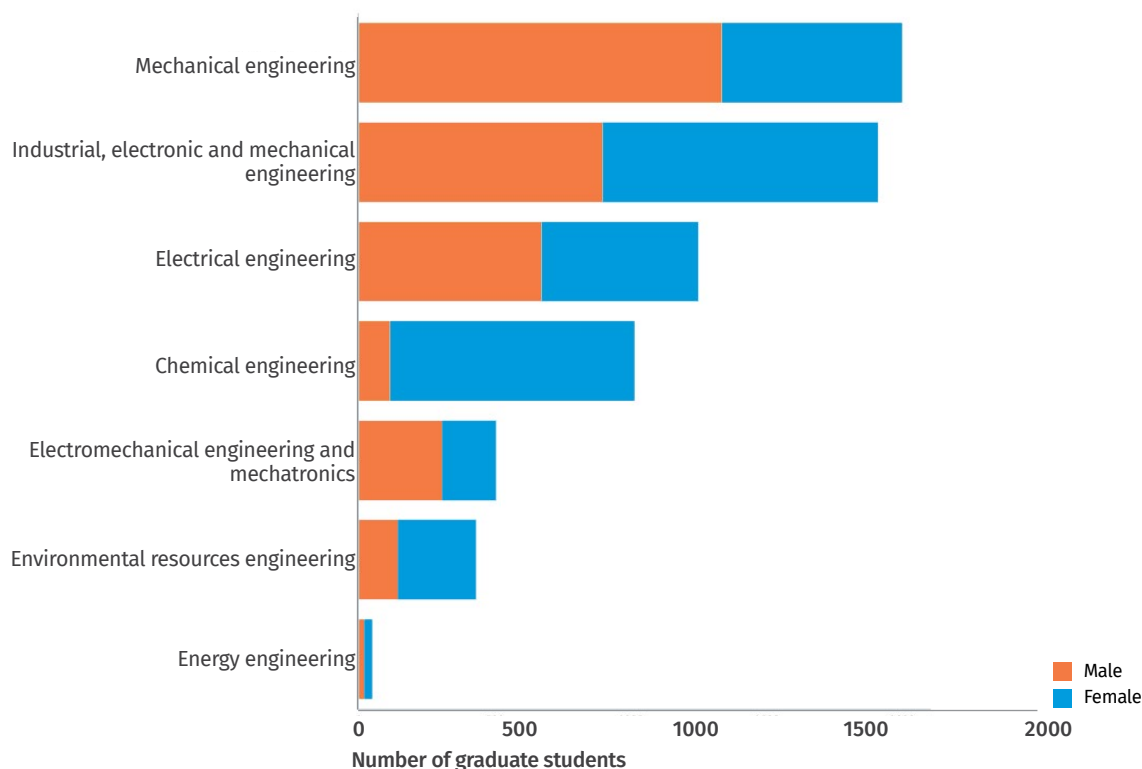
Figure 23. Gender composition by occupation in electricity generation, transmission and distribution in Tunisia



Academic training programmes in green hydrogen-related fields in Tunisia

- Chemical Engineering and Industrial, Electronic and Mechanical Engineering show a strong female majority (Figure 24). These programmes account for the largest share of female engineering graduates overall.
- Mechanical Engineering and Electrical Engineering present more balanced enrolment, though males still outnumber females, particularly in Mechanical Engineering.
- There are relatively low graduate numbers in fields such as Energy Engineering, Environmental Resources Engineering, and Electromechanical Engineering and Mechatronics, with female students slightly outnumbering males in some cases.
- These academic gender patterns closely reflect those in the electricity industry, where women remain underrepresented in key technical and operational roles.
- Fields with higher numbers of female graduates tend to align with industry roles where women have more representation, such as chemical and industrial engineering. However, traditionally male-dominated disciplines such as mechanical and electrical engineering continue to supply talent to the most gender-imbalanced roles in the industry.
- Gender gaps in academic specialization directly influence the composition of Tunisia's technical workforce in electricity generation, transmission and distribution.
- Targeted academic outreach and industry incentives will be critical to narrowing these disparities and fostering more balanced gender representation in key engineering roles.

Figure 24. Enrolment in green hydrogen-related fields in Tunisia



4.2.3 Tunisia: Policy recommendations

1. Promote gender-responsive talent pipelines

- Partner with universities, technical institutes and professional associations to establish mentorship and internship programmes that connect female students with employers in the electricity and green hydrogen industries.
- Launch public awareness campaigns targeting secondary and early university students to promote careers in specialized technical fields for young women.

2. Strengthen workforce development in SMEs

- Provide targeted financial incentives (e.g. grants, tax credits) to SMEs that invest in workforce upskilling in emerging green hydrogen and smart grid technologies.
- Establish SME-focused technical assistance programmes that provide consulting and capacity development to diversify occupational profiles beyond basic electrical engineering roles.
- Promote industry cluster initiatives enabling SMEs to share resources for workforce development, innovation and specialized skills training.

3. Build specialized technical expertise across the industry

- Establish national certification and continuous professional development programmes in critical emerging fields, including green hydrogen technologies, smart grid management, and advanced energy systems engineering.

- Promote partnerships between industry, academia and government to develop modular training curricula aligned with the electricity and distribution industry's evolving needs.

- Incentivize firms to participate in apprenticeship and dual-education models, integrating on-the-job training with formal educational pathways.

4. Embed gender equality and workforce diversification into national energy policies

- Require firms involved in national green hydrogen and electricity projects to report on gender diversity metrics.
- Incorporate workforce diversity and capacity development indicators as key criteria in public procurement and infrastructure investment projects.
- Establish a national monitoring framework to regularly track and report progress on gender equality and workforce diversification progress in the industry.

5. Foster innovation and entrepreneurship in green hydrogen technologies

- Launch innovation hubs and incubators dedicated to green hydrogen, prioritizing support for startups and SMEs led by women and underrepresented groups.
- Provide targeted R&D funding for projects that showcase inclusive teams and interdisciplinary technical expertise.





5. Systematic Guide: Implementation Strategy of UNIDO's Methodology

To effectively develop a skilled workforce for the hydrogen industry, UNIDO's skills assessment methodology employs a structured, step-by-step approach. This systematic process enables governments in partnership with relevant stakeholders to collect insights, identify skill gaps, and design targeted strategies that align educational and training programmes with industry requirements.

This approach is grounded in key questions designed to clearly identify and address national skills gaps within the hydrogen value chain:

1. How can skills gaps in the hydrogen value chain be systematically evaluated and addressed?

2. Which skills, already acquired by graduates, are currently present in the hydrogen value chain?

3. Which occupations are most prevalent in the country?

4. Which industrial activities are related to the hydrogen value chain?

To address these questions, UNIDO's methodology is structured around three key phases:



Phase 1: Engage key stakeholders

The initial phase consists of organizing workshops that introduce the skills assessment methodology and foster collaboration among government bodies, educational institutions, industry leaders and other relevant stakeholders. The objective is to ensure alignment and engagement from the outset, establishing a strong foundation for the subsequent phases. Governments should play a leading role by convening relevant stakeholders around the national hydrogen strategy and raise awareness of the importance of future skills development for both the industry and country.

Phase 2: Data collection and analysis

In the second phase, detailed data are collected from both the demand side (industry) and the supply side (education). The data are then methodically analysed to assess current skills and educational and training programmes, identifying gaps between the skills the educational system provides and those the hydrogen industry needs. This analysis serves as the foundation for developing targeted strategies to bridge these gaps.

Data collection requires a coordinated effort led by government in partnership with industry stakeholders, business associations, and public and private employment agencies. Relevant ministries should assign their labour and skills departments or TVET authorities to lead the process. These stakeholders are essential for facilitating public-private dialogue and providing access to existing firm registries. From an operational perspective, online survey tools such as SurveyMonkey can be used to collect firm data, with universities supporting data analysis to provide robust, evidence-based insights to inform policymaking.

Data collection

The data collection process is structured around two key components: an assessment of industry and of educational and training programmes.

a) Industry assessment: Evaluating the demand side

The first step in the skills assessment focuses on understanding the current and future needs of the hydrogen industry. In this step, the demand side is examined by analysing industrial activities within the hydrogen value chain and evaluating existing workforce profiles. This includes:

- **Mapping current activities:** Identifying industrial activities that are either already part of or have the potential to transition into the hydrogen value chain, such as steel, chemicals, transport and energy.
- **Existing workforce profiles:** Collecting data on the current technical and operational roles within these industries, including:
 - Engineers (chemical, electrical, mechanical, environmental)
 - Technicians (process operation, maintenance, safety)
- **Identifying skills gaps and future needs:** Assessing the alignment between the hydrogen industry's current workforce skills and future needs, particularly the adoption of clean hydrogen technologies.
- **Development of industry questionnaire:** Designing and distributing a targeted questionnaire to relevant stakeholders to collect data on:
 - Current workforce capabilities: Assessing the skills and competencies currently available within the industry.
 - Anticipated future needs: Identifying the skills and roles that will be essential as the hydrogen industry evolves.
 - Workforce development: Gauging existing initiatives in the industry for workforce training and skill development, highlighting gaps that require targeted interventions.

UNIDO will collaborate with industry stakeholders, public and private employment agencies, and the ministries of labour and education to ensure comprehensive data collection.

b) Educational and training programmes: Assessing the supply side

Given that the hydrogen industry is still in a nascent stage, it is essential to assess current educational and training programmes, recognizing that many institutions do not yet fully embed hydrogen-specific skills into their curricula. The assessment focuses on:

- **Mapping existing competencies:** Evaluating the extent to which current educational and training programmes incorporate relevant skills, even if indirectly, including:
 - Renewable energy integration: Assessing programmes that focus on renewable energy technologies relevant to hydrogen applications.
 - Electrochemistry and materials science: Identifying courses and research programmes that cover fundamental principles that are essential for hydrogen production and storage technologies.
 - Process engineering and optimization: Reviewing chemical and process engineering curricula to assess their adaptability to hydrogen-specific applications.
 - Safety and quality standards: Analysing how existing safety and quality protocols in engineering and technical programmes can be expanded to address hydrogen safety standards.
- **Development of educational institutions questionnaire:** A targeted questionnaire will be distributed to collect detailed data from educational and vocational training institutions, focusing on:
 - Current and planned educational and training programmes: Collecting data on existing and planned courses related to hydrogen technologies.
 - Graduate output: Collecting detailed data on the number of graduates in key skill areas relevant to the hydrogen industry, including:

- Proficiency and expertise levels: Measuring the proficiency of graduates based on the duration and intensity of their training programmes.
- Educational attainment levels: Recording qualifications from technician diplomas (Bac+2/+3) to PhDs, ensuring alignment with industry requirements and standards.

Data analysis

The final step in this phase involves comparing and analysing the collected data to identify and address gaps between supply and demand. This includes:

- **Identification of skills surplus:** Identifying areas where educational output exceeds industry demand, indicating the need for curriculum adjustments or new pathways for graduates.
- **Identification of skills shortage:** Highlighting critical gaps where industry demand outpaces the supply of qualified professionals, guiding targeted training and education initiatives to address these deficiencies.

Phase 3: Road-mapping and strategic plan development

Development of a strategic plan: Formulating actionable recommendations for educational institutions, policymakers and industry stakeholders to address identified skills gaps, ensuring a balanced, future-ready workforce for the hydrogen sector.

This phase should be led by government and potentially hosted within government-business councils to ensure alignment between public strategies and industry priorities.



APPENDIX A

Table A 1. Identified areas of expertise and skills essential for the hydrogen sector

Areas of expertise	Skill
Energies/renewable energy	Eco-design of renewable energy technologies
	Energy markets/trading
	Grid integration and smart grids
	Eco-design of energy storage
	Sustainability and environmental impact assessment
	Renewable energy policy
Desalination and water treatment engineering	Desalination technologies
	Water treatment
	Energy management
	Membrane technology
	Water chemistry
	Water resource management
	Process optimization
Electrochemical engineering	Electrochemistry fundamentals
	Electrochemical instrumentation
	Eco design of electrolysis technologies
	Battery and fuel cell technology
	Electrode and catalyst development
	Process modelling and simulation
	Environmental and corrosion control
Process engineering	Chemistry
	Electrochemistry
	Thermochemistry
	Thermodynamics and heat transfer
	Process design and optimization
	Process simulation software
	Process integration
	Scale-up and commercialization

Areas of expertise	Skill
Chemical engineering	Chemical process design
	Catalysis
	Thermodynamics and kinetics
	Plant layout and design
Materials engineering (processing and transformation)	Composites
	Metallurgy
	Plastics engineering
	Glassmaking processes
Electrical engineering and industrial computing	Automation
	Controls and command systems
	Electricity
	Electronics
	Power electronics
	Electrotechnics
Mechanical engineering	Electromechanics
	Mechanics and structural integrity
	Mechanical design
	Manufacturing processes
	CAD and modelling for system optimization
Fluid mechanics	Fluid dynamics
	Aerodynamics
	Hydraulic system design
	Fluid simulation
Software engineering	Cybersecurity for industrial systems
	Programming and software development
Metrology	Physical measurements (characteristics, leaks)
	Instrumentation and metering systems
Civil engineering	Structural analysis for safety
	Infrastructure construction and project management
	Design tools/reading plans

Areas of expertise	Skill
Metalworking	Bodywork and enclosure fabrication
	Sheet metal work
	Plumbing
	Welding techniques
	Pipefitting
QSE (Quality, Safety, Environment)	Risk management and analysis
	Safety protocols
	Finished product control
	Regulatory compliance
	Certification and standardization
	Environmental impact assessment
	Sustainability integration
	Regulatory compliance
	Quality control
	Industry standards

APPENDIX B

PROCEDURE FOR MATCHING TASKS TO HYDROGEN VALUE CHAIN SKILLS

To identify how occupational tasks align with the skills required in the emerging green hydrogen industry, two key data sources are combined:

- **ISCO Framework:** This dataset covers a wide range of occupations, detailing the specific tasks performed within each role.
- **Hydrogen Europe Green Hydrogen Skills:** This dataset includes various occupations across the green hydrogen value chain and information on the essential skills associated with each value chain segment.

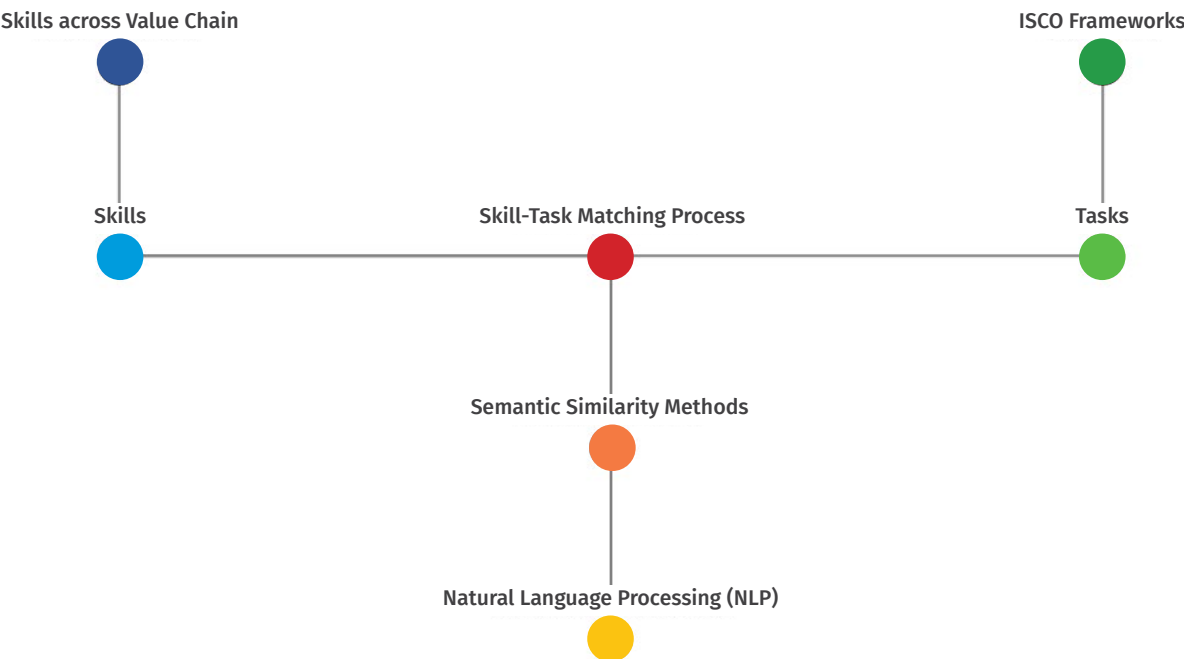
To effectively match tasks from the ISCO Framework with the skills identified by Hydrogen Europe, the following approach is employed:

- **Data cleaning:** The task descriptions were cleaned by removing prefixes, numbering and alphabetical enumerations (such as (a), (b), etc.) to focus exclusively on the content
- **Text preparation:** The language was simplified

by breaking down the text into individual words (tokenization), removing common, less informative words such as “and” or “the” (stopword removal), and converting words to their basic forms, for example, changing “running” to “run” (lemmatization). This was performed for both task and skill descriptions.

- **Semantic word embedding:** Simplified words were transformed into numerical formats known as ‘embeddings’. These embeddings represent words as numeric vectors, where words with similar meanings have similar numeric patterns. This technique enables an accurate measurement of similarities between tasks and skills.
- **Matching tasks and skills:** Each task’s numerical embedding was compared with every skill embedding using a measure called cosine similarity, which quantifies how closely related they are. Tasks and skills with a similarity score of 60 per cent or higher were considered closely aligned, indicating relevant connections between occupations and the required skills.

Figure B 1. Skills mapping procedure



APPENDIX C

FIELD DATA COLLECTION

In line with UNIDO's Skills Methodology Framework, the surveyed firms were grouped into three main industrial categories based on their level of engagement in the green hydrogen value chain:

- **Category I – Core Green Hydrogen-related Industries:** Firms directly engaged in the upstream and midstream segments of the green hydrogen value chain, including production, storage and distribution.
- **Category II – High Energy-use Industries:** These firms operate in energy-intensive industries with strong potential for decarbonization through the adoption of green hydrogen technologies.
- **Category III – Support Service Industries:** Firms providing essential services—such as engineering, logistics or maintenance—that support the activities of industries in both the upstream, midstream and downstream segments.

Table C 1. Industrial survey response rate in Tunisia

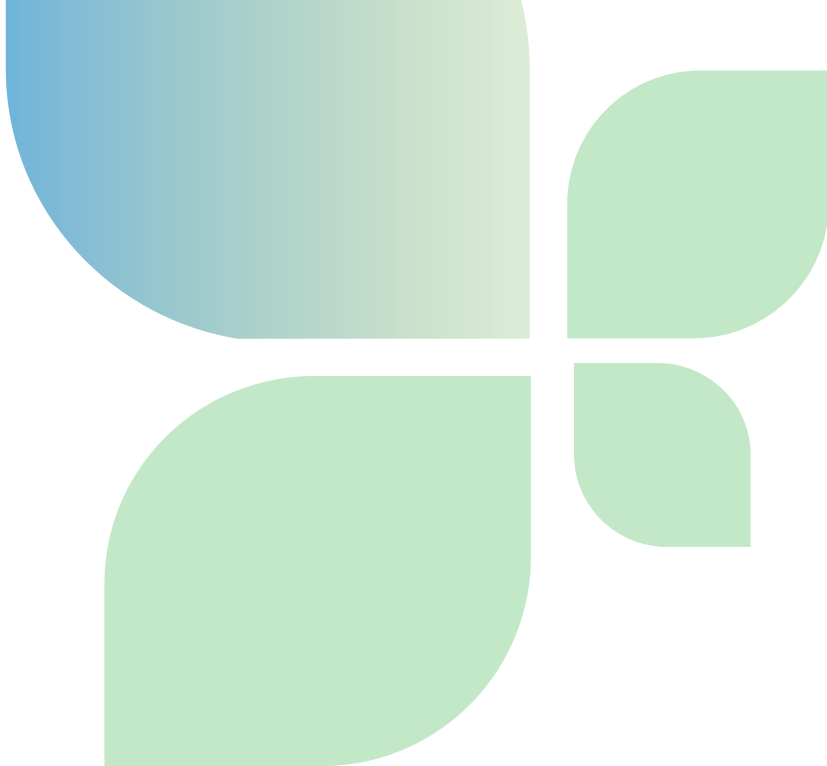
Category	Firms contacted	Firms responded to survey	Response rate (%)
I	50	14	28
II	230	4	1.74
III	630	6	1

Table C 2. Industrial survey response rate in Egypt

Category	Industry	Firms contacted	Firms responded to survey	Response rate (%)
I	Manufacture of electronic components and boards	38	4	10.5
I	Manufacture of electric motors, generators, transformers and electricity distribution	53	3	5.7
I	Manufacture of batteries and accumulators & RE companies	19	2	10.5
I	Manufacture of fluid power equipment	51	5	9.8
I	Manufacture of tanks, reservoirs and containers of metal	35	3	8.6
I	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines	15	3	20
II	Manufacture of fertilizers and nitrogen compounds	9	6	66.7
II	Cement, lime and plaster	26	3	11.5
II	Manufacture of basic metals/ basic iron and steel	17	4	23.5
II	Production of aluminium oxide	1	1	100

III	Computer consultancy and computer facilities management activities (hardware engineer/embedded systems, software engineer/embedded software)	60	6	10
III	Manufacture of metal-forming machinery and machine tools / manufacture and repair of machinery	90	6	6.7
III	Manufacture of glass and glass products	48	4	8.3
III	Plastics products and synthetic rubber in primary forms	8	3	37.5
III	Paper and paper products	39	4	10.3
III	Manufacture of articles of concrete, cement, and plaster	37	3	8.1
III	Manufacture of consumer electronics	106	3	2.8





The photos in the report are sourced from publicly available materials, including stock image platforms such as Adobe Stock, Pixabay, Shutterstock, and Envato Elements.





United Nations Industrial Development
Organization (UNIDO)
Vienna International Centre
Wagramer Str. 5, P.O. Box 300,
A-1400 Vienna, Austria



+43 1 26026-0



<https://hydrogen.unido.org>



hydrogen@unido.org



UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION