In collaboration with

Employment and Skills in the Green Hydrogen Economy

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Introduction

Context: Energy transition for jobs

The global energy transition is at a critical juncture, driven by the urgent need to decarbonize hard-to-abate industries such as ammonia, methanol, and steel. These sectors collectively account for a significant share of global industrial emissions, making their transformation essential for achieving international climate targets. In this context, clean hydrogen is increasingly recognized as a strategic pathway to enable deep emissions reductions while supporting broader processes of industrial transformation. The World Bank's analytical frameworks and country-level engagements underscore the importance of aligning industrial decarbonization with inclusive economic development, job creation, and long-term competitiveness.

Emerging markets and developing economies (EMDCs) are at the forefront of this transition, particularly those with strong renewable resource endowments. Countries such as Namibia illustrate both the scale of the opportunity and the complexity of its realization. Recent assessments suggest that a limited number of large-scale green industrialization projects could generate on the order of tens of thousands of jobs over the coming decade, with employment concentrated primarily in construction and related activities and excluding indirect and induced effects. At the same time, these opportunities unfold in labor market contexts characterized by structural challenges, including high unemployment rates, limited industrial diversification, and significant gaps in workforce readiness. In Namibia, for instance, unemployment remains persistently high, including among youth, and addressing emerging labor demand would require a substantial expansion of technical and vocational education and training systems, as well as stronger alignment between skills supply and industry needs.

These dynamics highlight a central tension for EMDCs: while clean hydrogen and associated value chains can catalyze new industrial ecosystems and generate employment, their ability to deliver broad-based and sustained job creation is not automatic. Employment outcomes are shaped by multiple factors, including the degree of domestic value capture, the development of enabling infrastructure, the strength of local supplier ecosystems, and the capacity of education and training systems to respond to evolving skills demands. Moreover, the temporal distribution of jobs—often concentrated in short-term construction phases—raises important considerations for workforce planning, skills transferability, and long-term labor market integration.

Central to addressing these challenges is the concept of a "Just Transition[1]" which places jobs, skills, and equity at the core of the energy transition. The World Bank's operational experience highlights that successful decarbonization pathways must be accompanied by policies that foster decent work, support vulnerable communities, and ensure that the benefits of the green economy are widely shared. This includes investments in skills development, measures to promote inclusion—particularly for youth and women—and the design of labor market and industrial policies that facilitate structural transformation.

The global context is therefore defined by the interplay between ambitious climate goals, the imperative for industrial upgrading, and the need to deliver not just more jobs, but better and more inclusive jobs. Against this backdrop, this guideline aims to support policymakers, practitioners, and investors in assessing employment and skills implications across the clean hydrogen value chain, providing a structured basis to inform decision-making and align decarbonization efforts with socio-economic development objectives.

Just transition: Jobs, Skills and Equity

A Just Transition[2] is central to the narrative towards a clean energy transition, ensuring that the shift to green hydrogen supports decent work, local capacity building, and regional equity.

This refers to the process of shifting toward a low-carbon, climate-resilient economy in a manner that is fair, inclusive, and equitable for all stakeholders, especially workers and communities most affected by the transition.

According to the International Labor Organization (ILO), it means "greening the economy in a way that is as fair and inclusive as possible to everyone concerned, creating decent work opportunities and leaving no one behind." The World Bank's "Just Transition for All"[3] framework further emphasizes putting people and communities at the center of the transition, with three pillars: (1) governance and strategic planning, (2) people and communities, and (3) repurposing land and assets, implemented across the phases of pre-closure, closure, and post-closure.

Additionally, the World Bank Just Transition research emphasizes on: (1) The importance of upskilling and reskilling workers from carbon-intensive sectors[4]; (2) address gender disparities and promoting inclusion in new green jobs[5], and (3) developing robust labor management procedures, occupational health and safety standards, and grievance mechanisms to protect workers during the transition

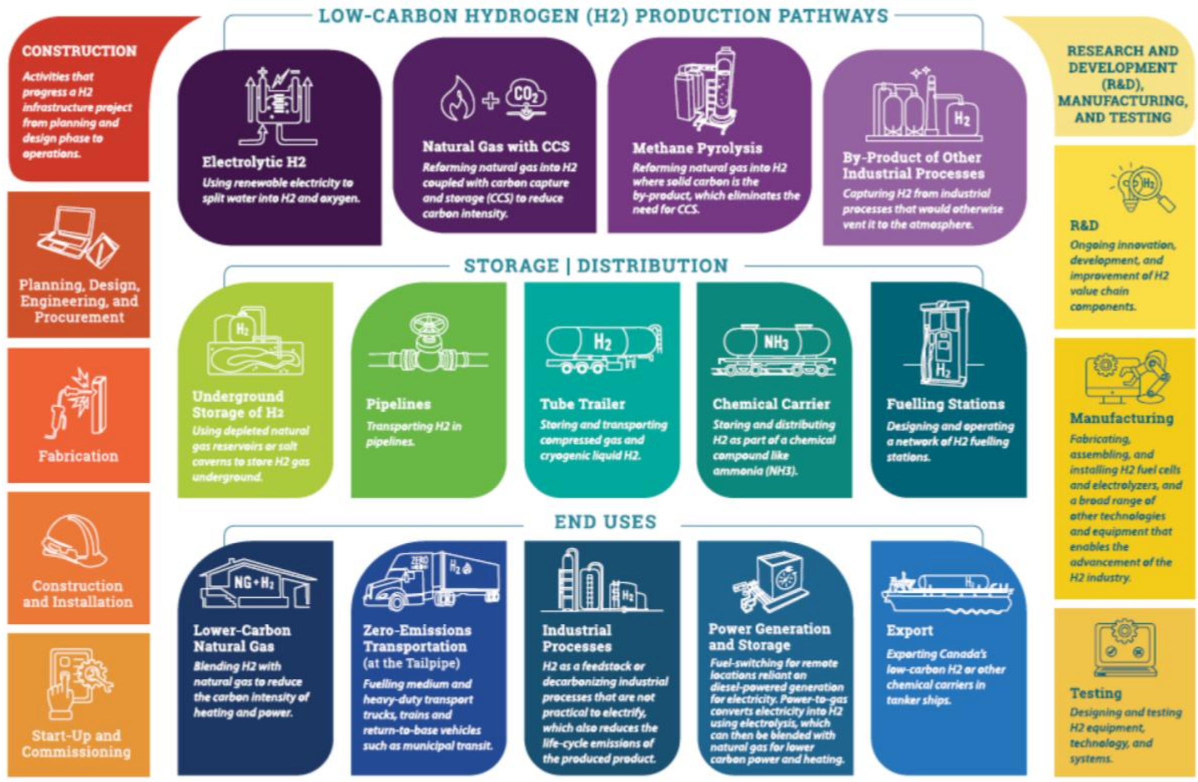
The Clean Hydrogen Opportunity

Clean hydrogen is increasingly recognized as a strategic pathway for decarbonizing hard-to-abate industrial sectors, including ammonia, methanol, and steel. Beyond its mitigation potential, its relevance for EMDCs lies in its capacity to support industrial upgrading, infrastructure development, and new forms of domestic value creation.

These opportunities are not limited to emissions reduction. The development of clean hydrogen value chains can generate employment across project lifecycles, from engineering, manufacturing, and construction to operations and maintenance [6], while also creating new demand for technical, managerial, and regulatory capabilities. However, the scale and quality of these employment outcomes depend on the extent to which countries are able to capture local value, strengthen workforce readiness, and align hydrogen investments with broader industrial and skills strategies.

A value-chain perspective is therefore essential. The clean hydrogen economy spans renewable power, hydrogen production, derivative conversion, storage, transport, and end-use applications, each associated with distinct actors, infrastructure needs, and labor requirements. Figure 1 provides a system-level overview of these interdependencies and serves as the conceptual foundation for the employment and skills framework developed in this report.

Figure 1. Clean Hydrogen Value Chain: System Overview and Key Components



Source: IPHE, 2025, page 26.

Clean hydrogen transition can generate substantial employment opportunities, particularly during construction and manufacturing phases, with additional long-term jobs in operations and maintenance. However, the scale, quality, and distribution of these employment effects vary significantly across regions and depend on countries' ability to capture local value, strengthen workforce readiness, and align hydrogen investments with broader industrial and skills development strategies.

Just Transition principles into hydrogen deployment pathways, including local capacity building and stakeholder engagement, to ensure that employment gains are widely shared and contribute to sustainable economic transformation. Policy implications highlight the need for integrated workforce planning, targeted investments in education and training systems, and the establishment of robust labor standards and institutional frameworks. By aligning employment and skills strategies with industrial decarbonization efforts, countries can maximize the socio-economic benefits of the hydrogen economy while mitigating transition risks for workers and communities. There is a need to embed employment metrics and labor market considerations into decarbonization strategies from the outset, rather than relying on aggregate "green jobs" estimates

Against this backdrop, this paper addresses four central questions, based on literature review:

- How many jobs can be created by clean hydrogen production projects, and how are these distributed across the value chain, project lifecycle and job types (direct, indirect, induced)?
- What types of jobs are created across the clean hydrogen value chain and project lifecycle, and what skills and qualification profiles do they require?
- Under what conditions can clean hydrogen investments in EMDCs translate into sustained domestic value creation, rather than short-lived construction employment or imported capabilities?
- How can EMDCs overcome workforce readiness constraints and skills mismatches to benefit from the clean hydrogen economy?

This report develops a framework to quantify employment effects associated with renewable ammonia and methanol production projects. The analysis covers the upstream supply chain from renewable electricity generation, seawater desalination, and electrolysis, to derivative synthesis, as well as direct air capture for methanol production. Downstream activities such as product transport, storage, and end-use applications are excluded due to their strong dependence on project-specific context, such as export pathways or local industrial use. Employment impacts are assessed for the entire project lifecycle, from project planning, manufacturing and procurement to construction, operation and maintenance, and decommissioning.

The framework applies a bottom-up modelling approach based on employment factors derived from the literature, enabling the estimation of direct, indirect, and induced jobs. It further incorporates varying levels of local content through three scenarios, reflecting different degrees of domestic value creation across project stages. The results provide a range of potential employment outcomes, highlighting the sensitivity of job creation to key assumptions rather than presenting a single estimate.

[Short explanation for skills needed]

The report discusses first job creation, followed by skills and training needs.

Job creation in the hydrogen economy

The hydrogen economy is widely expected to create significant employment opportunities, but these effects are neither uniform nor automatic. The scale and distribution of job creation depend on how projects are structured, where value chain activities take place, and how supply chains are organized. A more granular understanding of employment effects is therefore required to move from high-level expectations to project-level assessments.

Employment impacts in hydrogen projects can be understood across **four defining elements**. First, jobs can be distinguished by type, typically classified as **direct, indirect, and induced employment**. Direct jobs are generated within the project boundary, including activities such as renewable energy supply, hydrogen production, and derivative synthesis. Indirect jobs arise in upstream industries that provide inputs and services, while induced jobs reflect broader economy-wide effects driven by increased household spending.

Second, employment varies across **value chain segments**, with different stages—such as electricity generation, electrolysis, and downstream processing—exhibiting distinct employment intensities. Third, jobs are distributed over the **project lifecycle**, with construction phases generating large volumes of temporary employment, while operation and maintenance create fewer but longer-term positions.

Fourth, the extent of local benefits depends on the **type and share of total jobs created within the host country**. This reflects differences in industrial capacity, technical expertise, and the ability to localize project activities and supply chains. For example, significant work on clean hydrogen projects in EMDCs, especially in manufacturing and specialized services, may be accomplished from abroad or filled by imported labor. As a result, the domestic employment impact of hydrogen projects can vary substantially across countries.

Together, these dimensions highlight the need for a structured approach to estimating employment impacts, capturing not only the total number of jobs, but also their distribution across job types, value chain segments, project phases, and local economic contexts.

Methods for estimating jobs across the clean hydrogen value chain

To operationalize the analysis of employment impacts, it is necessary to map where and when jobs are generated across the clean hydrogen value chain. This requires a structured representation of value chain segments, associated assets, and project lifecycle phases. This is particularly important given that employment in the hydrogen economy is distributed across a highly fragmented value chain, spanning multiple sectors and requiring diverse skill sets[7].

In practice, employment assessments are typically conducted using three main approaches: Input-Output models (I/O), Computable General Equilibrium (CGE) models, and bottom-up employment factor methodologies. These approaches differ in scope, level of detail, and underlying assumptions, and therefore provide complementary but not interchangeable insights, as summarized in Table 1. I/O and CGE represent a macro-economic perspective, while employment factor methodologies simplify and are inherently more cautious on broader economic effects.

Macroeconomic approaches are designed to capture economy-wide, dynamic effects, assessing how the development of a hydrogen economy influences employment across sectors. I/O models estimate employment impacts based on inter-industry linkages using national accounting frameworks that describe how outputs from one sector serve as inputs to another. This allows for the quantification of direct, indirect, and induced employment effects across the broader economy. However, the degree of sectoral aggregation used by macroeconomic approaches limits their ability to reflect the specific characteristics of emerging industries such as clean hydrogen. In practice, hydrogen-related activities are often approximated using proxy sectors (e.g. chemicals or oil and gas), which can lead to inaccuracies and potential overestimation of employment impacts. At the same time, I/O models remain one of the few approaches that explicitly capture induced employment effects at the economy-wide level.

CGE models extend this perspective by incorporating behavioral responses, price adjustments, and resource constraints, allowing for the analysis of structural economic changes and competition across sectors. They simulate how different actors in the economy (e.g. firms and households) respond to policy shocks—such as the introduction of clean hydrogen production—and how these responses interact across markets to reach a new equilibrium. This makes them well suited for assessing broader transition dynamics. However, many CGE applications rely on simplifying assumptions—such as fully clearing labor markets—that imply job losses in one sector are offset by gains elsewhere. While this ensures internal consistency, it limits the ability of such models to capture short- to medium-term labor market frictions, unemployment effects, and adjustment dynamics. In addition, results are sensitive to assumptions about economic growth and future structural change, which may not fully reflect the development of emerging sectors such as hydrogen.[1]

Bottom-up approaches, by contrast, estimate employment impacts at the level of individual technologies and projects, using employment factors deriving from empirical studies and industry data (e.g. jobs per unit of capacity). This allows for a more detailed representation of hydrogen-specific value chains, including differentiation across technologies, project configurations, and lifecycle phases. As a result, bottom-up methods are particularly well suited for project-level assessments, where employment effects are estimated based on defined technical and operational parameters. However, these approaches do not capture wider macroeconomic feedback effects, such as changes in relative prices, labor reallocation across sectors, or broader economic adjustments. Table 1 presents an overview of the strengths and weaknesses of the different approaches.

Across all approaches, employment estimates are subject to uncertainty, reflecting both data limitations and structural challenges in modeling labor markets, including skill mismatches, limited labor mobility, and differing institutional contexts—particularly in emerging and developing economies. This uncertainty is particularly pronounced for indirect and induced employment effects, which are more sensitive to methodological assumptions and data limitations than direct job estimates.

Evidence from related analyses, including H2Global's work on social license to operate (SLO), indicates that the chosen assumptions tend to inflate job estimates and may lead to unrealistically high expectations. Transparent and realistic employment estimates for single projects are, however, particularly important in the context of stakeholder engagement, as overstated job creation figures can undermine project acceptance over time.[2]

Table 1: Comparison of approaches for estimating employment impacts

	I/O models	CGE models	Bottom-up approach
Scope	Economy-wide	Economy-wide	Project-level
Level of detail	Aggregated (sector-level)	Aggregated (sector-level)	High (technology- & project-specific)
Typical use case	Economy-wide impact assessment	Policy & economy-wide analysis	Project-level job estimation and planning
Data requirements	High (national accounts)	Very high	Moderate (literature + project data)
Captures indirect & induced jobs	Included	Included	Included (via multipliers)
Ability to reflect hydrogen value chains	Limited	Limited	High
Strengths	Captures supply chain linkages	Captures structural economic changes	Transparent, technology-specific, flexible
Limitations	Low sector resolution	Complex, assumption-heavy	Does not capture macroeconomic feedbacks

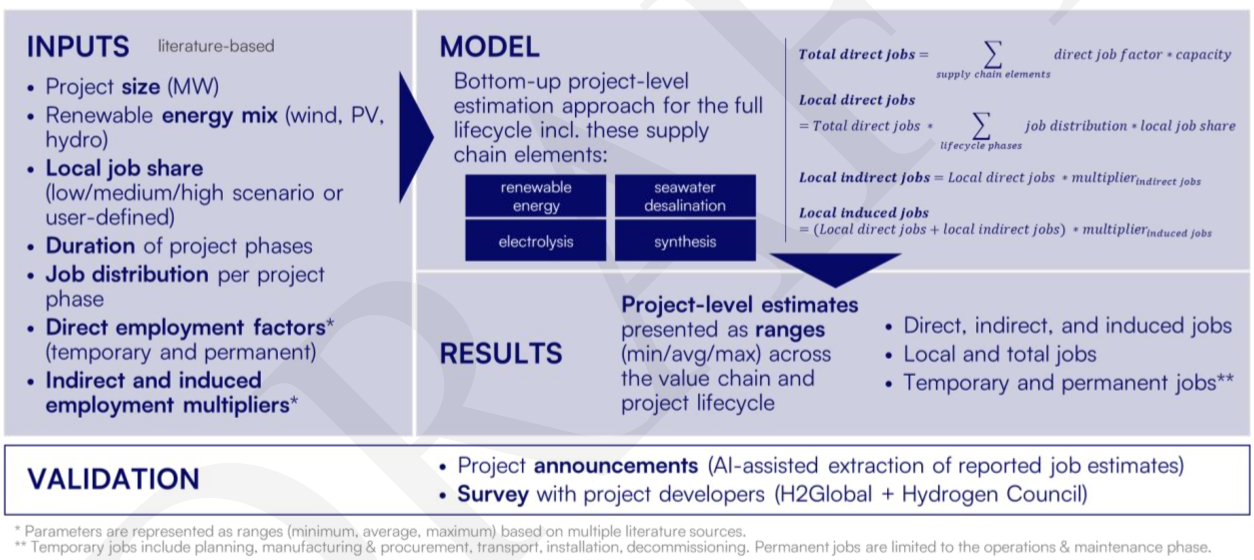
Against this background, this report applies a bottom-up, project-level approach, focusing on the employment impacts associated with a single hydrogen project. This perspective is particularly relevant for understanding the local employment effects that materialize on the ground, which are most directly experienced by communities in the vicinity of projects. In contrast to macroeconomic approaches, which assess economy-wide adjustments and redistribution effects, the bottom-up approach provides a more tangible and location-specific representation of employment outcomes.

At the same time, the bottom-up approach entails simplifications, particularly in the estimation of indirect and induced jobs. These effects are derived using multipliers from the literature, which vary significantly depending on methodology, sectoral scope, and geographic context. Rather than presenting single point estimates, this report explicitly reflects this uncertainty by applying ranges of multipliers (minimum, average, and maximum values). This allows for a transparent representation of the potential scale of employment effects, while avoiding over-precision and acknowledging the limitations of available data.

H2Global's model for estimating employment impacts

To quantify employment impacts, this report applies a **bottom-up, project-level employment estimation model developed by H2Global**, implemented as a flexible calculation tool to link project characteristics to job creation across the hydrogen value chain and project lifecycle. Key inputs include project size, renewable energy configuration, and assumptions on local job share, which are combined with employment factors derived from the literature to estimate direct, indirect, and induced jobs. Figure 2 provides an overview of the model structure, key inputs, employment calculation logic, and validation approach.

Figure 2. Overview of the project-level employment estimation framework



The model calculates direct employment for each value chain segment using employment factors expressed in jobs per unit of capacity (e.g. jobs per GW). The assessment covers the core upstream hydrogen production chain for two reference cases: renewable ammonia and renewable methanol production. Included value chain elements comprise renewable electricity generation (PV, wind, and hydropower), seawater desalination, electrolysis, and synthesis processes. For renewable methanol pathways, the model additionally includes CO_2 supply via direct air capture (DAC). Employment factors are compiled from multiple literature sources and differentiated across these supply chain elements.

The analysis focuses on project-level employment impacts within the defined production boundary and therefore does not include downstream activities such as product transport, storage, distribution, or end-use applications. These downstream effects are highly context dependent and may differ substantially depending on whether products are exported or used domestically, for example in local fertilizer production or industrial applications.

Direct jobs are allocated across all project phases, including project planning, manufacturing and procurement, transport installation, operation and maintenance, and decommissioning, allowing for a detailed representation of where employment is generated across the project lifecycle. Indirect and induced jobs are estimated by applying literature-derived multipliers to direct employment. Given the limited availability of hydrogen-specific data, these multipliers are primarily derived from studies on renewable energy sectors.

The underlying data is characterized by limited availability and high variability across sources. Reported employment factors differ significantly depending on methodology, system boundaries, geographic context, and project assumptions. To address this, the model compiles values from multiple sources and derives minimum, average, and maximum estimates, producing a range of plausible employment effects.

As host countries vary in industrial capacity, technical expertise, and the ability to localize supply chains, the model applies a scenario-based approach to gauge the share of jobs created domestically. For example, EMDCs may still have limited manufacturing or renewable energy capabilities. Thus, the three scenarios capture low, medium, and high levels of domestic job creation across project stages, respectively. In low local job share scenarios, a substantial share of manufacturing, engineering, and project planning is assumed to take place outside the project country or to rely on imported labor. By contrast, high local job share scenarios assume stronger domestic participation in construction, manufacturing, and operational activities. Scaling effects account for non-linear relationships between project size and employment intensity.

The model is complemented by a two-step validation approach. First, outputs are compared with publicly available data from announced hydrogen projects, using an AI-assisted analysis of hydrogen project announcements to extract reported employment estimates. Second, validation is supported through a targeted survey of project developers, conducted jointly with H2Global and the Hydrogen Council, to collect additional empirical data on expected job creation. Together, these steps provide a check on the order of magnitude and robustness of the results, while acknowledging current data limitations.

Results: Employment impacts of hydrogen projects

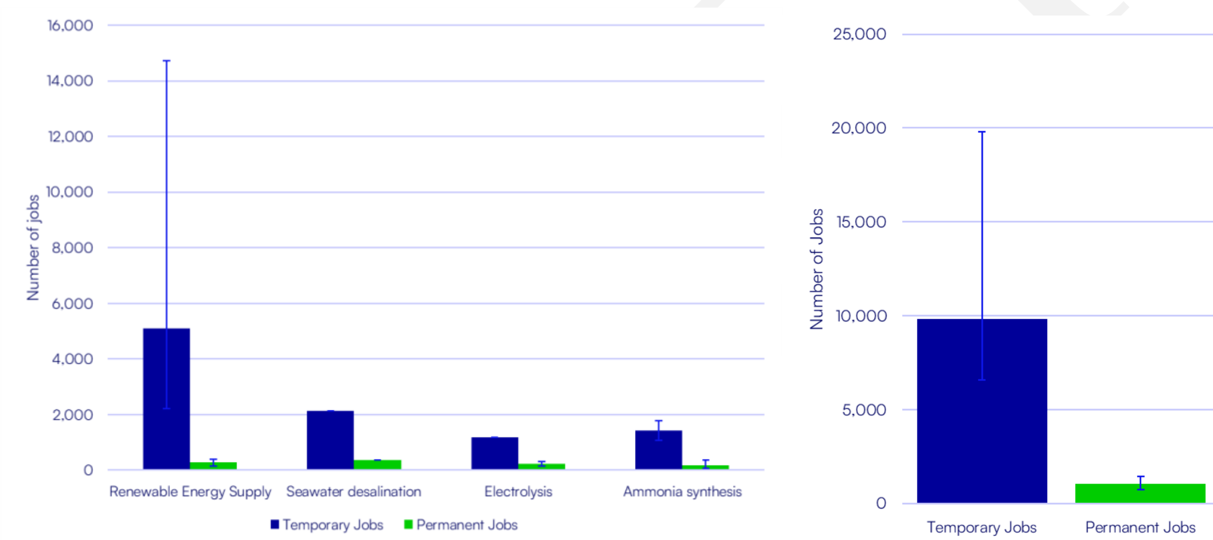
Note: The Excel tool framework is complete, but the underlying data from the literature review is not yet complete. The figures are intended to illustrate the structure and functionality of the employment estimation framework rather than provide final employment estimates.

- Assumption: All results refer to a 1 GW electrolysis project for ammonia production. (The data and results on methanol will follow later)

Total direct jobs across the supply chain

- The majority of direct employment is temporary, with jobs concentrated in project development, manufacturing, and construction phases, while permanent jobs in operation and maintenance remain comparatively limited.
- Employment is unevenly distributed across value chain segments, with the largest share of direct jobs associated with renewable energy supply.
- Downstream segments such as electrolysis and synthesis contribute smaller but more specialized employment, often requiring higher technical expertise.

Figure 3. Estimated temporary and permanent direct jobs for a 1 GW renewable ammonia project (preliminary data)

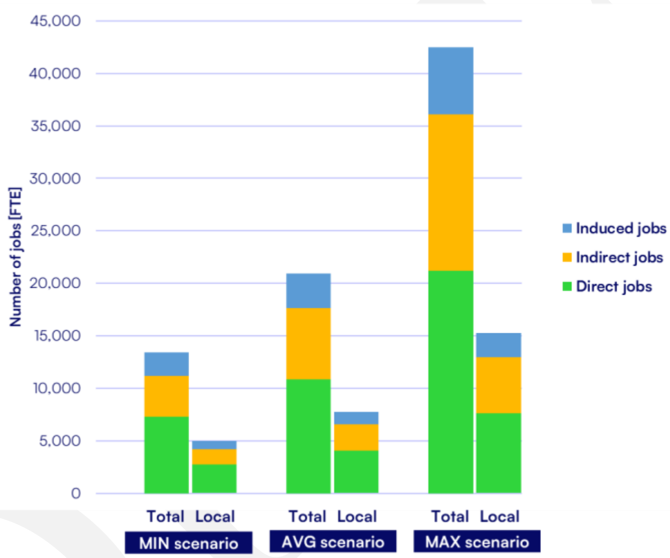


Total and local employment effect

- Total employment impacts vary substantially across minimum, average, and maximum scenarios, reflecting the wide range of employment factors and multipliers reported in the literature for emerging hydrogen value chains.
- Direct employment remains the largest and most robustly quantifiable component of total job creation, while indirect and induced effects are associated with significantly higher uncertainty.
- Indirect and induced effects represent a substantial share of total employment in many scenarios. Reported multiplier values in the literature vary considerably depending on methodology, sectoral scope, and geographic context. [A more detailed discussion of multiplier assumptions and literature ranges will be included once the underlying data analysis is finalized]

- The comparison between total and local employment highlights the importance of domestic industrial capacity and workforce capabilities for translating hydrogen investments into local economic benefits.
- Local employment outcomes can differ significantly even for projects of identical size. In low localization scenarios, a substantial share of employment—particularly in manufacturing, engineering, and project planning—is assumed to occur outside the project country or rely on imported labor, reducing local employment impacts.

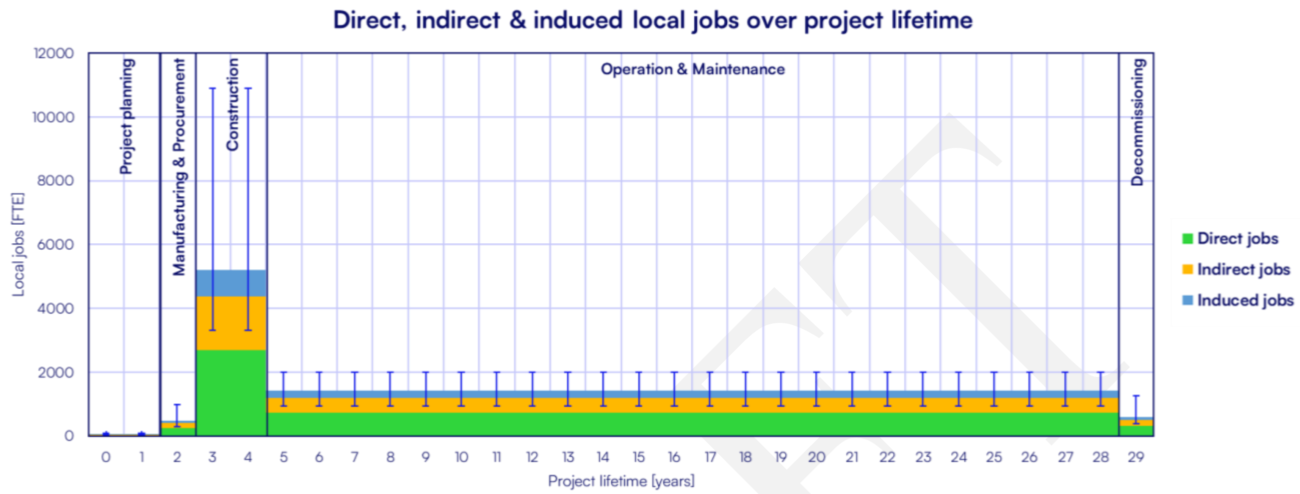
Figure 4. Estimated total and local employment impacts for a 1 GW renewable ammonia project under minimum, average, and maximum employment factor scenarios (low local job share scenario) (preliminary data)



Employment over the project lifetime

- Employment is highly concentrated in the construction phase, which generates the largest number of jobs over a short period.
- In contrast, the operation and maintenance phase provides fewer but more stable, long-term employment opportunities, resulting in a lower annual job intensity.
- This temporal distribution implies that hydrogen projects create short-term employment peaks rather than sustained high employment levels over time.
- Sequencing multiple hydrogen projects over time could help extend construction-related employment, smoothing short-term peaks and supporting more continuous labor demand.

Figure 5. Estimated local direct, indirect and induced jobs over the project lifetime for a 1 GW renewable ammonia project (preliminary data)

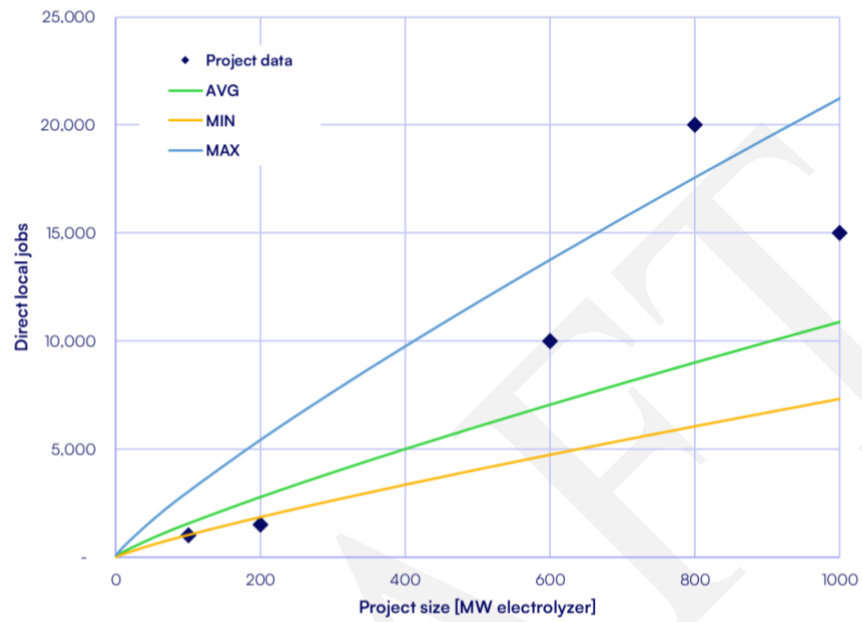


Model validation (not yet conducted)

Note: The AI-assisted data collection on project announcements will take place in May/June. The survey is expected to be sent out at the end of May.

- Model results exhibit significant variation, primarily driven by the wide range of employment factors reported in the literature and differences in underlying assumptions.
- A validation exercise based on AI-assisted analysis of project announcements of planned hydrogen projects indicates that model outputs fall broadly within the range of reported project-level estimates.
- Additional validation is supported through a survey of project developers, conducted jointly with H2Global and the Hydrogen Council, aimed at improving the empirical basis for employment estimates.
- Overall, the validation process confirms the order of magnitude of results, while reinforcing the need to interpret employment estimates as ranges rather than precise forecasts.

Figure 6. Comparison of model results for local direct jobs with project announcements (preliminary data)



Skills needs in the hydrogen economy

Hydrogen-related skills requirements are best understood as an evolution of existing industrial and energy sector competencies rather than the emergence of entirely new occupational categories. As such, workforce development strategies should prioritize the adaptation and upgrading of existing skill bases across the value chain.[8]

International supply chain analyses highlight that employment outcomes are closely linked to the structure and maturity of domestic industrial ecosystems. While many hydrogen-related components and services are transferable from existing sectors such as oil and gas, petrochemicals, and power systems, critical gaps often persist in specialized equipment and infrastructure, including electrolyzer systems, high-pressure compressors, and hydrogen-compatible transport and storage assets.

The high degree of skill transferability from adjacent sectors—particularly oil and gas and renewable energy, suggests that workforce transition strategies can play a central role in accelerating deployment while minimizing skills gaps.

Mapping Skills needs across the Hydrogen value chain

To complement the structural mapping of the hydrogen value chain, a more granular understanding of employment dynamics requires identifying the specific occupations, skills, and qualification levels associated with each segment.

The matrix presented below in Annex 1 provides a detailed mapping of key hydrogen-related job roles across the value chain, linking each occupation to its corresponding stage, core activities, and skill requirements. In addition, it introduces indicative analytical dimensions, including job intensity, localization potential, and transferability from adjacent sectors such as oil and gas and renewable energy, which are critical for assessing workforce development strategies in EMDCs.

This framework enables a more operational assessment of where employment opportunities are likely to materialize, the extent to which they can be locally captured, and the degree to which existing industrial capabilities can be leveraged or repurposed.

IPHE Jobs and Skills tools

Part 1: Hydrogen skills need assessments and workforce estimation *has been developed for those commissioning, designing and interpreting hydrogen skills needs assessment and workforce estimation studies. By sharing international case studies and methodological insights, it aims to enable the streamlining of hydrogen workforce planning at a country/regional level and to identify methodological needs and knowledge gaps that could be addressed through international research, development and collaboration to strengthen hydrogen workforce development efforts globally.*

Part 2: Training – International Case Studies *has been developed to provide inspiration and practical guidance for countries and institutions seeking to engage more deeply in the development of hydrogen-related training. By presenting examples from a range of countries, it highlights how training initiatives and ecosystems can be built and scaled.*

Part 3: Workforce development *(forthcoming) provides examples of how countries are approaching workforce development at a strategic and practical level, and highlights in particular how this is done to enable transitions from other sectors, the inclusion of youth and unskilled workers, and the promotion of diversity, equity, inclusion and access.*

Also, the IPHE's H2Skills Task Force has developed an interactive database as a resource to support stakeholders in navigating the emerging hydrogen workforce landscape. The tool consolidates information from published hydrogen skills needs assessments and enables users to explore key job roles and their characteristics, including qualification requirements, skills gaps, hydrogen-specific competencies, and recruitment risks and opportunities. It is intended to support authors of future skills needs assessments, as well as those involved in workforce planning, education and training development, and policy design.

Part 1

Methodologies for skills needs assessments and workforce estimation studies Examples of skills needs assessments from countries including Australia, Canada, the European Union (EU), France, India, Namibia, South Africa and the United Kingdom (UK) illustrate how different regions have approached skills needs assessments. Approaches vary depending on context and objectives, but steps typically include:

- Scoping and value chain mapping; occupation and job role identification;
- skills mapping;
- education and training system analysis;
- workforce quantification and scenario modelling;
- identification of talent bottlenecks and transition opportunities;
- diversity, equity, inclusion and access considerations; and
- development of conclusions and strategic recommendations.

These steps are underpinned by initial- and ongoing literature- and data review, and industry- and wider stakeholder engagement. Examples of workforce estimation studies include those for Canada, Chile, the EU27 and the UK, India, South Africa, South Korea as summarized by IPHE.

A diverse array of workforce estimation methodologies has been applied, but these can be grouped into two categories: macroeconomic- and employment factor approaches. The suitability of an approach is largely dependent on the exact need for quantitative information, and the selection of specific methodology may be informed by factors such as technical complexity, data availability, need for analytical depth etc.

Emerging insights, challenges and gaps insights for commissioning and delivering hydrogen skills needs assessments include:

- Clear goal-setting and scoping is important to ensure skills needs assessments generate context-specific insights that are actionable.
- Early (and ongoing) stakeholder involvement increases the likelihood of implementing recommendations effectively.

- Reflecting the region/country's own situation is essential to enable any policy- or planning interventions based on the findings of the skills needs assessment to be inconsistent with the actual nature, pace and scale of the hydrogen sector development in the target region/country.
- Including roles in the enabling environment (e.g. policy makers, regulators and financiers), alongside technical roles, is important to avoid barriers to development.
- To provide a true reflection of the status quo, training analysis needs to cover both accredited and non-accredited training pathways.
- The selection of workforce estimation methodologies needs to be informed by the type of information needed (e.g. economy-wide impact or direct impact only). Methodological and data limitations and assumptions need to be clearly communicated.
- Careful interpretation and communication of hydrogen workforce estimates, robust planning in response, and periodic updating of workforce estimates are advisable.
- Drawing on multidisciplinary expertise improves the efficiency and quality of skills needs assessments, and enables recommendations to be more targeted and implementable.
- Stakeholder engagement and validation throughout the assessment is critical.
- Adequate time and budget needs to be made available to enable this.

Insights on hydrogen skills needs assessment methodological challenges and gaps include:

- Current international, regional and national occupational classification frameworks do not fully capture hydrogen-related roles, especially for renewable and low-carbon hydrogen pathways, highlighting the need for updates.
- Classifying hydrogen job roles using occupational classification frameworks enables better linking of information on labour demand and training provision, and supports workforce planning and associated support, training alignment, and regional coordination. Enabling hydrogen job roles to be more fully included in occupational classification systems will require a list of agreed or "definitive set" of hydrogen-related occupations. The IPHE hydrogen job roles and skills database can serve as a useful starting point.
- Identifying hydrogen-related training is difficult, because content is often embedded in general qualifications and inconsistent terminology is used. Developing standardised descriptions of hydrogen-related skills is essential to improve alignment and communication on skills needs with industry and across the skills ecosystem.
- There is a need for better country-specific data to enable more context-specific workforce estimation, and also for methodologies and data to enable hydrogen workforce estimations to better account for industry dynamics (e.g. technology developments, automation etc.).
- Capacity building and/or clearer communication is needed to enable understanding of the nature of hydrogen workforce estimation methodologies and their applicability to the specific goal at hand. This is important to enable selection of appropriate methodologies, critical analysis of workforce estimation results, and ultimately informed decision making about the attendant nature, scale and timing of interventions for skills and workforce development.

Insights on hydrogen skills and workforce development emergent from skills needs assessments done internationally include:

- Insights on occupations and skills − There are no fundamentally new occupations unique to hydrogen, but some occupations and specific roles may be new to a particular country. − Whether new occupations are needed in a specific region or country depends on its existing foundation industries and the maturity of its hydrogen economy. − Various degrees of augmentation of (existing) occupations through hydrogen-specific skilling may be required for different hydrogen-specific roles.
- Insights on training − Currently hydrogen training is led mainly by industry, in line with the emerging and developing nature of the industry. − Where rapid growth is expected, embedding hydrogen skills in formal education can enable hydrogen skills development at scale. − Flexible options like micro-credentials and short courses can meet immediate needs, enable the transition of workers from other sectors, and build the foundation for more formal, accredited training in time as the industry grows.
- Insights for workforce development − Many of the clean energy sectors draw on the same set of foundation qualifications and skills. On the one hand this presents a challenge: the hydrogen sector may compete with other clean energy sectors for skills. On the other, this has the benefit that those with relevant foundation qualifications can pivot to where the demand in the clean energy sector or hydrogen value chain is the greatest at the time. − Investment in building foundation skills is thus a robust strategy to support workforce development for hydrogen- and other clean energy sectors.

Strategies for skills building

The IPHE report is structured into five sections, each addressing a key dimension of hydrogen related training.

1. Awareness raising and dissemination of training opportunities: How information platforms and awareness campaigns make training visible and accessible.

2. Networks and platforms for trainers: How collaboration between universities, industry, and training providers strengthens both content and reach, additionally highlighting the importance of training the trainers.

3. Training infrastructure for hydrogen: How different physical and mobile learning facilities provide the necessary hands-on experience in a nascent sector.

4. Innovative content delivery: How gamification of learning, the use of digital tools, and novel teaching methods increase engagement and improve the effectiveness of the teaching.

5. Recognition of training: How accredited and non-accredited schemes, from microcredentials to academic frameworks, ensure that skills are recognised and accreditation of hydrogen-related training expanded.

Training practices covered include ones from Belgium, Brazil, Canada, Costa Rica, the European Union, India, South Africa and the United States.

Conclusions

- A significant body or literature exists related to jobs and skills for hydrogen.
- There is a general recognition that hydrogen projects are very capital-intensive and most jobs are related to equipment supply, construction and possible hydrogen use. Operation of hydrogen facilities is generally not very labor intensive.
- Job creation is not evenly distributed across the value chain, with a large share of employment linked to renewable energy supply and supporting infrastructure, rather than core hydrogen production processes.
- The analysis shows that the majority of jobs are temporary, concentrated in construction and installation phases, while long-term employment during operation remains comparatively limited. Therefore, a programmatic approach that results in numerous sequential projects may suit better to ensure continuation of the construction activities.
- Preliminary model results for a 1 GW electrolysis-based ammonia project indicate the creation of approximately 10,800 direct jobs across the project lifecycle, including around 9,800 temporary and 1,000 permanent jobs. Under a low local job share scenario, local employment effects are estimated at approximately 3,300 temporary and 740 permanent jobs. Indirect and induced effects may contribute an additional ~3,600 jobs. *[Values based on preliminary employment factor data and subject to revision as the literature database is finalized]*
- The reported employment estimates reflect project-level impacts associated with individual hydrogen production projects and therefore differ from broader economy-wide employment effects estimated in macroeconomic studies. While economy-wide effects may be larger, they are also associated with significantly higher uncertainty and depend strongly on assumptions regarding economic adjustment and spillover effects.
- The share of jobs created domestically can vary substantially depending on industrial capacity, skills availability, and supply chain localization, meaning that total job figures do not necessarily translate into large local employment benefits.
- Indirect and induced jobs represent a significant share of total employment, although estimates remain highly sensitive to multiplier assumptions and underlying methodologies. *[Further discussion of multiplier assumptions and literature ranges will be added once the underlying data analysis is finalized]*
- Due to limited and highly variable data, employment estimates should be interpreted as ranges rather than precise values, reflecting differences across sources and assumptions.
- Scaling the project-level results suggests that large-scale hydrogen deployment could generate substantial employment during construction phases. For example, deployment of 50–100 GW of electrolysis capacity could correspond to roughly 1–2 million jobs based on the model assumptions. However, relative to total regional employment levels, these effects would still represent only a modest share of overall employment. These estimates should therefore be understood as localized and sector-specific employment impacts rather than transformative economy-wide labor market effects. Broader macroeconomic effects may differ and depend on wider economic spillovers and

structural adjustment dynamics captured in CGE or I/O models.*[Values based on preliminary employment factor data and subject to revision as the literature database is finalized.]*

- Hydrogen project construction jobs can benefit from expertise in buildings & infrastructure construction, oil and gas industries as well as chemical industry.
- The potential to create national jobs in equipment manufacturing depend on the market size. Important economies of scale exist in equipment manufacturing therefore only large plant are cost efficient.
- Employment intensity does not scale linearly with project size, as economies of scale in larger projects can reduce jobs per unit of capacity. Most skills needs are not very profound and can be trained fast (PV installers, crane operators, truck and equipment drivers, electricians)

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Annex: Hydrogen and Fuel Cell Careers

Hydrogen and Fuel Cells Careers (DOE, https://www.energy.gov/eere/fuelcells/hydrogen-and-fuel-cells-career-map)

Carrer Level	Research and development, engineering and manufacturing	Operations and Management	Communications, Training and Outreach
Advanced	Engineering Manager	Finance Manager Project Developer Attorney Regulatory Expert Economist Plant Manager Asset Manager Budget Analyst	Communications Manager Professors
Mid-Level	Chemical Engineer Mathematical Scientist Environmental Scientist Software Engineer Civil Engineer Research Engineer Environmental Engineer Electrical Engineer Mechanical Engineer	Project Manager Safety and Occupational Health Specialist Computational Scientist Buyer Industrial Engineer Power System/Transmission Engineer Sales Engineer Power Marketer Logistician	Public Affairs Specialist Editor Writer
Entry	Electrician Instrumentation and Electronics Technician Advanced Manufacturing Technician Assembler and Fabricator Computer Numerical Control Operator (CNC) Plant Operator Industrial Equipment Mechanic	Legal Assistant Salesperson Trade Worker Construction Worker Transportation Worker	Educational Aide

Source: U.S Department of Energy, 2017

Annex: Job estimates for renewable energy

A more granular breakdown of gross employment requirements to support planned renewable hydrogen and renewable ammonia projects, as well as associated storage and distribution infrastructure through 2030, highlights the distribution of jobs across specific job families. The analysis disaggregates employment by value chain stage and job family, presenting both the share of jobs within each segment and the total number of jobs per stage. Results indicate that approximately 75 percent of total jobs in the renewable hydrogen value chain are expected to be non-permanent or non-recurring, concentrated in the construction phase (35 percent; 4,900 gross jobs) and end-of-life management (40 percent; 5,500 gross jobs). In contrast, only 13 percent (around 1,800 jobs) correspond to permanent or recurring roles associated with operations and maintenance.

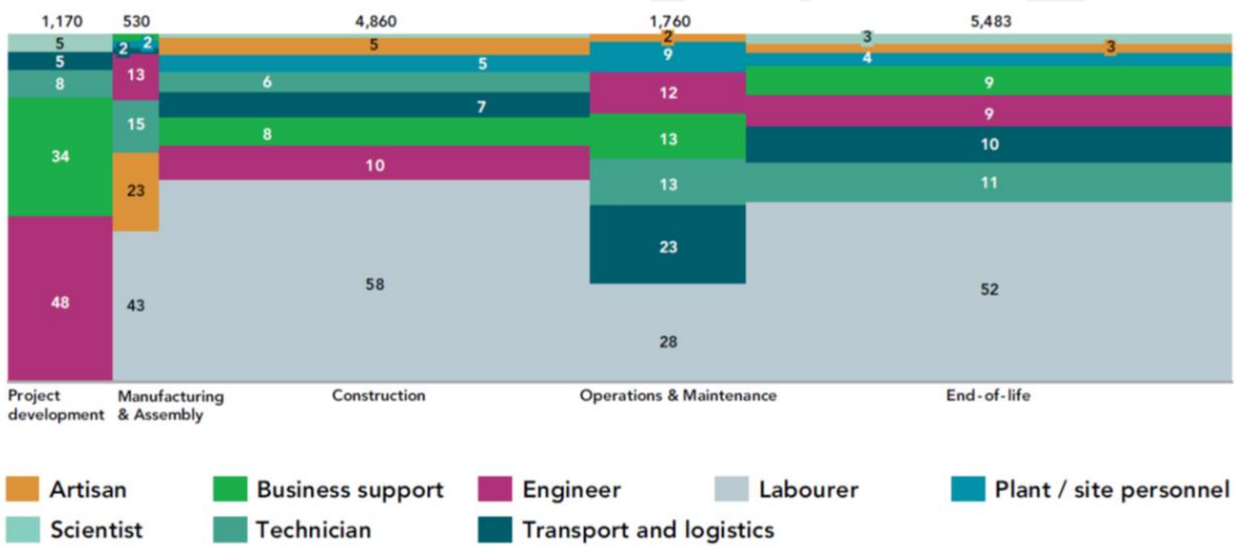

Figure 21 Job estimates for renewable hydrogen per value chain stage and job family (2024 — 2030) (upper bound)

Annex Tables

Table 2. Hydrogen Jobs and Skills Detailed Matrix

Job Role	Value Chain Stage	Qualification Level	Focus Areas	Key Activities	Core Skills	Job Intensity*	Local vs Imported Jobs*	Transferability (O&G / RE)*
Solar PV Technician	Upstream	TVET	O&M, Electrical	Install/maintain PV systems	Electrical systems, maintenance	High	Local	Very High (RE)
Wind Turbine Technician	Upstream	TVET	O&M	Maintain turbines	Mechanical, electrical systems	High	Local	Very High (RE)
Grid Integration Specialist	Upstream	Bachelor	Electrical	Grid balancing, integration	Power systems modeling	High	Local	Very High (RE)
Power Systems Engineer	Upstream	Master	Engineering	Design grid connection	Grid modeling, simulation	High	Local	High
Substation Technician	Upstream	TVET	Electrical	Maintain substations	Electrical safety	High	Local	High
Energy Systems Analyst	Upstream	Master	Digital	System optimization	Energy modeling tools	Medium	Local	High
Electrolyzer Engineer	Production	Master	Engineering, R&D	Design electrolyzers	Electrochemistry, system integration	High	Mixed	Medium
Electrolyzer Technician	Production	TVET	O&M	Operate electrolyzers	Equipment operation	High	Local	Medium
Hydrogen Plant Operator	Production	TVET	O&M, HSE	Operate plant	Process control, safety	High	Local	High (O&G)
Process Engineer (Hydrogen)	Production	Master	Chemical	Optimize production	Thermodynamics, process design	High	Mixed	High

Water Treatment Specialist	Production	Bachelor	Engineering	Treat water input	Filtration, purification	Medium	Local	Medium
CCUS Specialist	Production	Master	Engineering	Carbon capture integration	CO_2 capture systems	Medium	Mixed	Very High (O&G)
Commissioning Engineer	Production	Bachelor	Engineering	Plant start-up	Systems integration	High	Imported → Local	High
Ammonia Process Engineer	Processing	Master	Chemical	Design ammonia plants	Process engineering	High	Mixed	Very High
Methanol Engineer	Processing	Master	Chemical	Design methanol systems	Catalysis, synthesis	Medium	Mixed	High
PtX Systems Engineer	Processing	Master	Engineering	Integrate systems	System integration	High	Imported	Medium
Chemical Plant Operator	Processing	TVET	O&M	Operate plant	Process operations	High	Local	Very High
Quality Control Specialist	Processing	Bachelor	QA	Product testing	Lab analysis	Medium	Local	High
Storage Engineer	Storage	Master	Engineering	Design storage	Pressure systems	High	Mixed	High
Compression Specialist	Storage	Bachelor	Mechanical	Gas compression	Gas handling systems	High	Local	Very High (O&G)
Liquefaction Engineer	Storage	Master	Cryogenics	Hydrogen liquefaction	Cryogenic systems	Medium	Imported	Medium
Tank Maintenance Technician	Storage	TVET	O&M	Maintain tanks	Mechanical systems	High	Local	High
Pipeline Engineer	Transport	Master	Engineering	Design pipelines	Fluid dynamics	High	Mixed	Very High (O&G)
Logistics Coordinator	Transport	Bachelor	Logistics	Manage supply chain	SCM tools	Medium	Local	High
Shipping Specialist	Transport	Bachelor	Maritime	Manage shipping	Maritime logistics	Medium	Mixed	High

Terminal Operator	Transport	TVET	O&M	Operate terminals	Equipment operation	High	Local	High
Fuel Cell Engineer	End-use	Master	Engineering	Develop fuel cells	Materials science	Medium	Imported	Medium
Mobility Technician	End-use	TVET	O&M	Maintain vehicles	Mechanical systems	High	Local	High
Industrial Integration Engineer	End-use	Master	Engineering	Integrate hydrogen in industry	Process integration	High	Mixed	High
Power Generation Specialist	End-use	Bachelor	Energy	Operate turbines	Power systems	Medium	Local	High
Hydrogen Project Manager	Cross-cutting	Bachelor	Management	Project oversight	Financial, coordination	High	Local	Very High
HSE Specialist	Cross-cutting	Bachelor	Safety	Risk management	Safety standards	High	Local	Very High
Policy & Regulatory Specialist	Cross-cutting	Master	Policy	Develop frameworks	Policy analysis	Medium	Local	Medium
Financial Analyst (Hydrogen)	Cross-cutting	Bachelor	Finance	Investment modeling	Financial tools	Medium	Local	High
Data / Digital Analyst	Cross-cutting	Bachelor	Digital	Performance analysis	Data analytics	Medium	Local	High
Research Scientist	Cross-cutting	PhD	R&D	Innovation	Advanced research	Medium	Imported	Low–Medium
Training & Skills Specialist	Cross-cutting	Master	Education	Develop programs	Curriculum design	High	Local	High

Source: Author's analysis, based on IPHE databases.

Note: Job intensity, local vs imported Jobs, and transferability are derived from analytical variables based on IPHE skills gaps, recruitment risks, and complementary hydrogen workforce literature.

Table 3. Hydrogen and Fuel Cells Careers

Carrer Level	Research and development, engineering and manufacturing	Operations and Management	Communications, Training and Outreach
Advanced	Engineering Manager	Finance Manager Project Developer Attorney Regulatory Expert Economist Plant Manager Asset Manager Budget Analyst	Communications Manager Professors
Mid-Level	Chemical Engineer Mathematical Scientist Environmental Scientist Software Engineer Civil Engineer Research Engineer Environmental Engineer Electrical Engineer Mechanical Engineer	Project Manager Safety and Occupational Health Specialist Computational Scientist Buyer Industrial Engineer Power System/Transmission Engineer Sales Engineer Power Marketer Logistician	Public Affairs Specialist Editor Writer
Entry	Electrician Instrumentation and Electronics Technician Advanced Manufacturing Technician Assembler and Fabricator Computer Numerical Control Operator (CNC) Plant Operator Industrial Equipment Mechanic	Legal Assistant Salesperson Trade Worker Construction Worker Transportation Worker	Educational Aide

Source: U.S Department of Energy, 2017