SKILL GAP ASSESSMENT ACROSS GREEN HYDROGEN SECTOR IN INDIA

SAREP

Final Report

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DISCLAIMER

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FOREWORD

Green hydrogen is rapidly emerging as an unrivalled sustainable alternative towards global energy transition, especially for sectors that are most difficult to decarbonise. Under the guidance of Hon'ble Prime Minister, India has envisioned a leadership role in the global hydrogen economy which promises a range of transformative changes, and sustainable economic growth. The National Green Hydrogen Mission (NGHM) aims to make India the Global Hub for the production, usage, and export of Green Hydrogen and its derivatives. Along with the production, investment and emissions averted with the transition to Green Hydrogen, there is a potential for creation of 6,00,000 jobs across the value chain in the Green Hydrogen industry by 2030.

The development and application of Green Hydrogen technologies at scale will require specialized knowledge and skill sets. The Ministry of Skill Development and Entrepreneurship (MSDE) is anchoring the skilling initiatives under the NGHM aimed at skilling, re-skilling, and up-skilling the required human resources required across the value chain. This framework covers the entire tapestry of activities for skill development, including setting up of Centres of Excellence (CoEs), curriculum level interventions at Schools, Industrial Training Institutes (ITIs) and Higher Education Institutions (HEIs) and delivery of short-term skilling courses. A whole of government approach shall be taken to achieve the goal of building a proficient workforce for this rapidly evolving sector.

This report has drawn insights from industry experts and key stakeholders in putting across a detailed analysis and recommendations for creating a pipeline for skilled workforce in India's green hydrogen industry. I hope it becomes an important reference document and guide for all stakeholders towards the overall goal of leveraging green hydrogen for a cleaner and greener tomorrow.

Atultiwari

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FOREWORD

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The National Green Hydrogen Mission (NGHM) is a transformative initiative aimed at propelling India towards a sustainable and green future. As we embark on this journey, it is imperative to equip our workforce with the necessary skills and expertise to drive innovation and growth in the burgeoning green hydrogen sector.

The "Skill Gap Assessment Across Green Hydrogen Sector" report presents a detailed analysis of the current state of hydrogen skilling in India and outlines strategies to address skill gaps and meet the evolving demands of the industry. Supported by the South Asia Regional Energy Partnership Program (SAREP), this study sheds light on the challenges and opportunities in the green hydrogen space, offering valuable insights for policymakers, industry stakeholders, and skilling institutions.

Through extensive stakeholder consultations and international benchmarking, this report highlights international best practices in skilling and job creation in the green hydrogen sector. Drawing on learnings from leading countries such as Australia, the United States, Germany, Japan, and Saudi Arabia, it provides a roadmap for India to develop a skilled workforce capable of driving innovation and sustainability in the hydrogen economy.

I commend the Skill Council for Green Jobs (SCGJ) for their efforts in undertaking this study and thank all stakeholders who contributed their expertise and insights. I am confident that this report will serve as a valuable resource in shaping India's skilling ecosystem for the green hydrogen sector and accelerating our transition towards a cleaner, greener future.

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AE	Alkaline Electrolyser
AEM	Anion Exchange Membrane
BF-BOF	Blast Furnace-Basic Oxygen Furnace
BIL	Bipartisan Infrastructure Law
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CCS	Carbon Capture and Sequestration
CCUS	Carbon Capture, Usage and Storage
CNG	Compressed Natural Gas
CO2	Carbon Dioxide
CRU	Catalytic Reforming Unit
DAC	Direct Air Capture
DAP	Di Ammonia Phosphate
DOE	Department of Energy
DR-EAF	Direct Reduction-Electric Arc Furnace
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EOR	Enhanced Oil Recovery
ESG	Environmental, Social, and Corporate Governance
EU	European Union
EUR	Euro
EV	Electric Vehicle
FCET	Fuel Cell Electric Truck
FCEV	Fuel Cell Electric Vehicle
GHCO	Green Hydrogen Consumption Obligation
GHG	Greenhouse Gas
GoI	Government of India
GW	Gigawatt
GWh	Gigawatt-hour
H2	Hydrogen
H2S	Hydrogen Sulphide
HGU	Hydrogen Generation Units
ICE	Internal Combustion Engines
IEA	International Energy Agency
IIJA	Infrastructure Investment and Jobs Act
INR	Indian Rupee
IP	Intellectual Property
IRA	Inflation Reduction Act
IWT	Inland Waterways Transport
KTPA	Kilo Tonnes per Annum
kWh	Kilowatt Hour
LDT	Light Displacement Tonnes
LOHC	Liquid Organic Hydrogen Carriers
LPG	Liquified Petroleum Gas
MCH	Methylcyclohexane
MNRE	Ministry of New & Renewable Energy
MoU	Memorandum of Understanding
MtCO2	Million Tonnes of Carbon Dioxide
MTCO2e	Million Tonnes of Carbon Dioxide Equivalent
MTPA	Million Tons per Annum
MW	Megawatt
NDC	Nationally Determined Contribution
NG	Natural Gas
NOx	Nitrous Oxide
O2	Oxygen
PAFC	Phosphoric Acid Fuel Cells
PEM	Proton Exchange Membrane
PIF	Public Investment Fund
PSA	Pressure Swing Adsorption
Pt	Platinum
PtC	Power-to-X
PtL	Power-to-liquid
PV	Photovoltaic
R&D	Research and Development
RD&D	Research, Development, and Demonstration
RE	Renewable Energy
SMR	Steam Methane Reforming
SOE	Solid Oxide Electrolysis
SOEC	Solid Oxide Electrolyser Cells
SOFC	Solid Oxide Fuel Cells
STS	Ship to Ship
TAFE	Technical and Further Education
tCO2	Tons Of Carbon Dioxide
TPA	Tons per Annum
TPD	Thermal Pressure Relief Devices
TPS	Terminal to Ship
TRL	Technological Readiness Level
TTS	Truck to Ship
TWh	Terawatt-hour
US	United States
USD	United States Dollar

EXECUTIVE SUMMARY

The National Green Hydrogen Mission (NGHM) mission aims to achieve domestic hydrogen production of at least 5 MTPA by 2030, and potentially produce an additional 5 MTPA to cater to the export market. The mission document also estimates 6 lakh new job opportunities by 2030 to support the emerging green hydrogen market in the country.

To guide the skilling programs under NGHM, the existing supply gaps in skilling space across the Green Hydrogen value chain and the projected increase in demand for skilled personnel needs to be ascertained. South Asia Regional Energy Partnership Program (SAREP) is supporting Skill Council for Green Jobs (SCGJ) in undertaking a study –"Skill Gap Assessment Across Green Hydrogen Sector in India" to identify the skill gaps in the green hydrogen sector to fulfil the industry demand till 2030. The broad objectives of the study are as follows:

1. Support India's National Green Hydrogen Mission targets on skilling and job-creation.
2. Map the existing & potential new job roles across the green hydrogen value chain.
3. Identify skill gaps and outline opportunities to develop and implement skill interventions in the short term, medium & long term (until 2030).

Given the limitation of data, the study also conducted extensive stakeholder consultations with 20+ stakeholder including end use consumers (fertilizer, chemicals, refineries, iron and steel, cement, and shipping), green hydrogen producers, electrolyser manufacturers, industry experts etc.

Green Hydrogen Economy in India & overseas

Global H2 market is growing at a steady pace (~3%), and it is anticipated that it will see exponential growth with adoption of new policies. Most hydrogen producing units planned for the near future are expected to be low carbon; based on electrolysers or Carbon Capture, Usage and Storage (CCUS) technology.

The green hydrogen technology landscape in India is likely to transition from traditional alkaline electrolysers to proton exchange membrane (PEM) electrolysers, anticipating future cost parity. Further, initiatives by Indian research organizations underscore the multifaceted focus on production, storage, and end-use applications.

The current state of hydrogen skilling in India remains largely unorganized, relying predominantly on on-the-job training without established certifications or specialized modules. This underscores the imperative for structured workforce development strategies in the burgeoning green hydrogen sector.

International best practices in skilling and jobs in GH2 sector

The report explores the best practices across major active countries in the sector with primary focus on Australia, the United States, Germany, Japan, and Saudi Arabia. Key learnings for India from the best practices in green hydrogen skilling across these countries are:

1. **Investment in Skill Development** - India could consider budget allocation for skill development across various sectors like Australia and the United States which have dedicated significant funds to enhance skill development.
2. **Collaborative Approaches** - India could explore the adoption of similar collaborative strategies taking learnings from Queensland that embraced collaborative approaches by partnering with industry and institutions.
3. **Training and Courses on Hydrogen** - Utilize skill council for green jobs to identify and integrate green hydrogen sector skill requirements into vocational education across colleges,

engineering institutions, and ITIs in India like Australia and Germany. They have introduced specialized courses and training programs related to hydrogen within educational institutions and universities.

4. **Identification of Key Job Roles –** Taking learnings from Queensland, that has developed a roadmap for the hydrogen workforce that offers a structured approach to skill development, with a focus on different stages of the value chain. India should identify and sequence specific job roles aligned with the National Green Hydrogen Mission, ensuring training corresponds to the industry's development stages.
5. **Utilizing Micro-Credentials -** Australia has acknowledged the significance of micro-credentials in addressing immediate training needs across various industries. These micro-credentials encompass areas such as hydrogen fundamentals, safety, regulatory understanding, and emergency response. India could consider incorporating micro-credential subjects into the existing curriculum until a comprehensive study is conducted to identify specific job roles within the hydrogen sector, thus addressing the sector's immediate needs.

Skill Gap Assessment - Job Estimates, Priority Job Roles and Skills Required

Based on the assumptions in line with the national green hydrogen mission, by 2030 an estimated 3.15 lakh job opportunities are anticipated for various roles in renewable energy plants such as engineering, procurement, commissioning, operations, and maintenance, driven by the projected renewable Energy capacity of 125 GW. In the domain of hydrogen production, the workforce demand is expected to reach ~2.83 lakhs, encompassing roles in design and planning, installation, commissioning, and green hydrogen production units. Additionally, over 11,000 jobs are projected to be required in electrolyser manufacturing by 2030.

Further, based on the factors like criticality, demand, and availability 5 priority job roles are identified in this study. These identified priority job roles in green hydrogen production and electrolyser manufacturing are expected to face a significant skills gap. Although there is a current pool of skilled professionals from related sectors, the growing demand from planned and under-construction green hydrogen plants necessitates the development of structured skilling programs to ensure the availability of required skilled resources for these priority job roles.

The 5 priority job roles in the green hydrogen sector identified in the study are :

i) Green hydrogen plant Technician
ii) Process Engineer
iii) Electrolyser Technology Specialist *(Electrolyser manufacturing & Assembly)*
iv) Operations & Maintenance Head / Manager
v) System Integration Specialist

Based on the requirement of activities to be performed by the identified priority job roles, a broad outline of training curriculum has also been provided in this report.

Key recommendations of the study are as follows:

S.I	Recommendation	Rationale	Responsibility / owner	Timeline	Approach
1.	**Mandatory certifications for government tenders and PLI schemes**	This would ensure that requisitely trained personnel are manning the critical operations across the green hydrogen value chain along with	MNRE	Short Term	• Subsequent govt. tenders, PLI schemes in the green hydrogen sector can mandate deployment of certified personnel for key job roles like electrolyser operations.

S.I	Recommendation	Rationale	Responsibility / owner	Timeline	Approach
		ensuring initial demand for certification			• These certifications can be provided by PSUs (e.g. GAIL, BHEL) in collaboration with skilling institutes.
2.	**Integration of hydrogen-related subjects into existing curriculum of Engineering and other higher learning institutes**	It will provide students the flexibility to explore areas of interest in green hydrogen within their respective engineering disciplines and is likely to result in wider adoption of courses	UGC / Institutes	Medium Term	• The inclusion of electives in green hydrogen for engineering students (chemical / mechanical engineering) and other higher learning institutes • Designing the curriculum based on industry requirements. • Incorporating industry experience & insights.
3.	**Trainings through collaboration with industry**	It would ensure continuous update of training with the fast-evolving technology landscape. Onus on PSUs for training initiatives.	SCGJ / Industry/PSUs	Medium Term	• Create an ecosystem where relevant PSUs act as frontrunners for training initiatives. • Training programs with standardized training delivery mechanisms could be developed in collaboration with industry. • Collaboration with other institutions actively engaged in Research and Development (R&D), such as IOCL, BPCL, ONGC, and CSIR and international experts specializing in green hydrogen technology is recommended.

Other recommendations include :

S.I	Recommendation	Rationale	Responsibility / owner	Timeline	Approach
1.	**Collaboration with Original Equipment Manufacturing companies (international/ domestic) for training in green hydrogen technology.**	Collaborating with these entities offers the opportunity to develop video manuals and conduct training sessions with experts on the equipment / technology deployed across the green hydrogen value chain. Gaining insights from the best practices and standard operating procedures (SoPs) implemented by Original Equipment Manufacturers (OEMs).	SCGJ / Industry	Short Term	• Identify key OEM Partners • Establish a collaborative framework outlining roles, responsibilities, & contributions from both the educational institution and the OEM partners. • Tailor training programs to suit the specific needs of the Indian context and industry requirements. • Seek support from government agencies and relevant bodies to endorse

S.I	Recommendation	Rationale	Responsibility / owner	Timeline	Approach
					and recognize collaborative training initiatives.
2.	**Capability building for green hydrogen exports**	As per NGHM, India is focused on emerging as a leading green hydrogen exporter. Thus, it is important to introduce training programs in medium/long term for export-oriented capabilities to ensure India's readiness for export.	SCGJ	Medium / Long Term	• Training courses for developing export-oriented capabilities relating to Guarantees of Origins & certifications, as well as business development in foreign markets will have to be developed (L5 to L8) • Further, a comprehensive skilling requirement for export related job roles would need to be identified via industry consultations

1 BACKGROUND

Government of India (GOI), aware of escalating climate change concerns, is eager to adopt every possible measure to ensure sustainable development. India's commitment towards a sustainable future is evident from its NDC (Nationally Determined Contribution) goals, and its inclination to adopt low carbon hydrogen as a fuel for the next generation. To this end, Government of India has announced the National Green Hydrogen Mission on 4th January 2023 allocating a budget of INR 19,744 crore for a 6-year period from financial year 2023-24 to financial year 2029-30. The aim of the National Green Hydrogen Mission is to make India a global hub for production, usage and export of green hydrogen and its derivatives. The mission aims to achieve domestic hydrogen production of at least 5 MTPA by 2030, and potentially produce 10 MTPA to cater to the export market. The mission document also estimates 6 lakh new job opportunities to support the emerging hydrogen market in the country.

To guide the skilling and recruitment programs under the National Green Hydrogen Mission, the existing supply gaps in skilling space across the Green Hydrogen sector and the projected increase in demand for skilled personnel must be ascertained. The Skill Council for Green Jobs (SCGJ) is keen to assess the skill gaps across green hydrogen sector in India to gain insights into the future needs for reskilling and upskilling.

South Asia Regional Energy Partnership Program (SAREP) is supporting SCGJ in undertaking a study to identify the skill gaps in the green hydrogen sector, and the availability of qualified candidates in India to achieve its target. SAREP is a key initiative of the U.S.-India Strategic Clean Energy Partnership.

The primary objective of this study is to identify the qualifications and competencies necessary to fulfil the industry's demand for skilled personnel in the green hydrogen sector. The broad objectives of the study are as follows:

- Support India's National Green Hydrogen Mission targets on skilling and job-creation
- Map the existing and potential new job roles across the green hydrogen value chain and identify a source of skilled resources for them.
- Identify skill gaps and outline opportunities to develop and implement skill interventions in consultation with industry and other stakeholders over the short term (next 2 years), followed by the mid & long term (until 2030) periods.

Given the limitation of data, the study also conducted extensive stakeholder consultations with end use consumers (fertilizer, chemicals, refineries, iron and steel, cement, and shipping), green hydrogen producers, electrolyser manufacturers, industry experts etc.

To address the scope of the study, the report has been divided into nine distinct sections.

1. The first section elaborates on the need for the study, outlining the structure of the report.
2. The second section; "Type of Hydrogen & Value Chain" provides a brief introduction to different types of hydrogen, green hydrogen's value chain and the technology used for its production.
3. The third section; "Global Hydrogen Market Overview", presents a broad picture of the global green hydrogen market, including the technological advancements in leading countries (Germany, Japan, US, Saudi Arabia, and Australia).
4. The fourth & fifth sections "Indian hydrogen market" and "Case studies – Existing Hydrogen producing / consuming industries" respectively, provide a comprehensive picture of the Indian market, including technology for hydrogen production and downstream processes across the

industry, key drivers and market insights, and the challenges and opportunities that will arise in implementing the transition to green hydrogen. Further, section five presents six brief case studies on the existing hydrogen producing/consuming industries in India.

5. The sixth section; "Key findings from Task 1", summarizes the learnings from section one to section five (Task 1 as per scope of work).
6. Section 7; "Global insights on skilling and jobs in green hydrogen sector", provides an understanding of the global landscape on green hydrogen skills & jobs while mapping institutes offering training for expanding green hydrogen initiatives. The section also outlines the best global practices, along with learnings for India in green hydrogen skilling.
7. Section 8; "Skill gap assessment", focuses on identifying the existing skill gaps & five priority job roles in the domestic green hydrogen sector. The section also estimates of the number and type of jobs that could arise in the green hydrogen sector in India by 2030.

2 TYPES OF HYDROGEN AND VALUE CHAIN

2.1 TYPES OF HYDROGEN

Historically the use of hydrogen as an energy source dates back to the early 1800s. Today, it is widely used as a feedstock for refineries, in ammonia production, and in the chemical sector. Though traditionally hydrogen has been produced from fossil fuels, in recent years, hydrogen produced from electrolysis of water (using renewable energy) has gained significant attention as a potential clean energy source. Now, hydrogen is assigned a color code based on how it is produced. Figure 2 .1 elucidates the same:

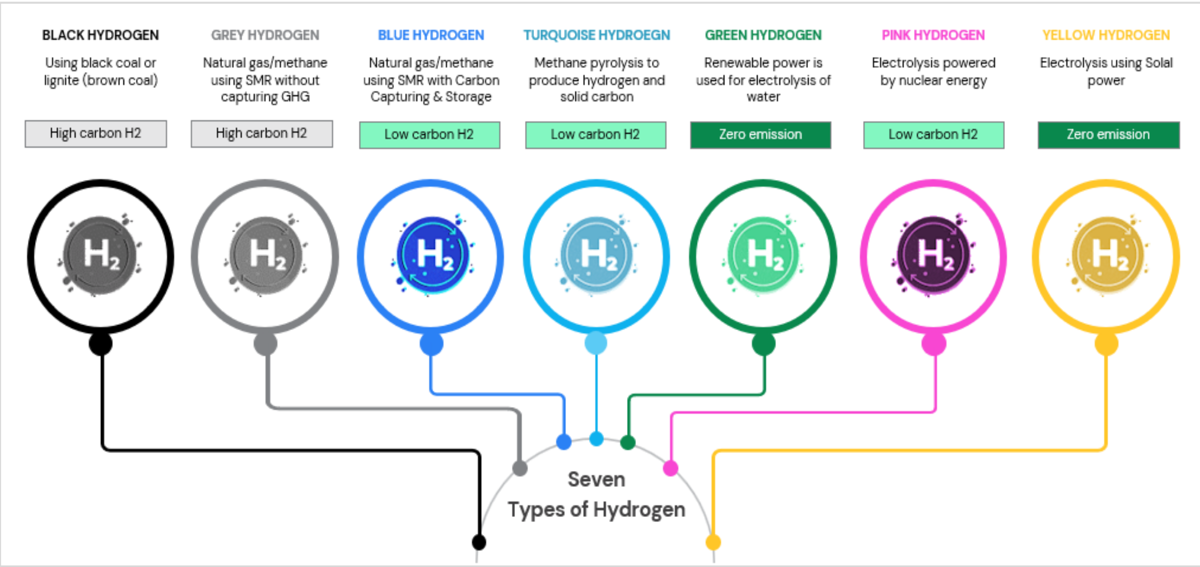

Figure 2.1: Different Types of Hydrogen

Black hydrogen - Hydrogen made from fossil fuels (including coal or lignite) through the process of 'gasification' is called black hydrogen.

Grey hydrogen - Grey hydrogen is produced from natural gas, or methane, using steam methane reformation, without capturing the greenhouse gases liberated in the process. This is the most common global hydrogen production technique.

Blue hydrogen - Blue hydrogen is essentially the same as grey hydrogen, but the carbon dioxide by-product is trapped and stored using carbon capture and storage (CCS).

Turquoise hydrogen - Methane pyrolysis is used to produce turquoise hydrogen and solid carbon.

Green hydrogen - Electricity from renewable energy sources, such as solar or wind power, is used to electrolyse water and generate green hydrogen, which accounts for ~4% (2021) of overall hydrogen production.

Pink hydrogen - Pink hydrogen is produced through electrolysis powered by nuclear energy.

Yellow hydrogen - Yellow hydrogen refers to hydrogen produced through electrolysis powered purely by solar energy.

As the study aims to assess the skill sets required across the green hydrogen industry, understanding the technological landscape across the green hydrogen value chain is important. Therefore, the ensuing sections detail the technological requirements and identify the parameters to assess the skilling needs for a technical workforce.

2.2 GREEN HYDROGEN VALUE CHAIN

The green hydrogen value chain comprises of 5 distinct stages i.e., renewable energy generation, hydrogen production, its transformation, storage & transport, and end-use applications, as illustrated in Figure 2.2. Each stage has its own technical, operational, and commercial workforce requirements. However, the most specialized expertise is required during the production cycle. Specializations required across the value chain is discussed in Chapter 7.

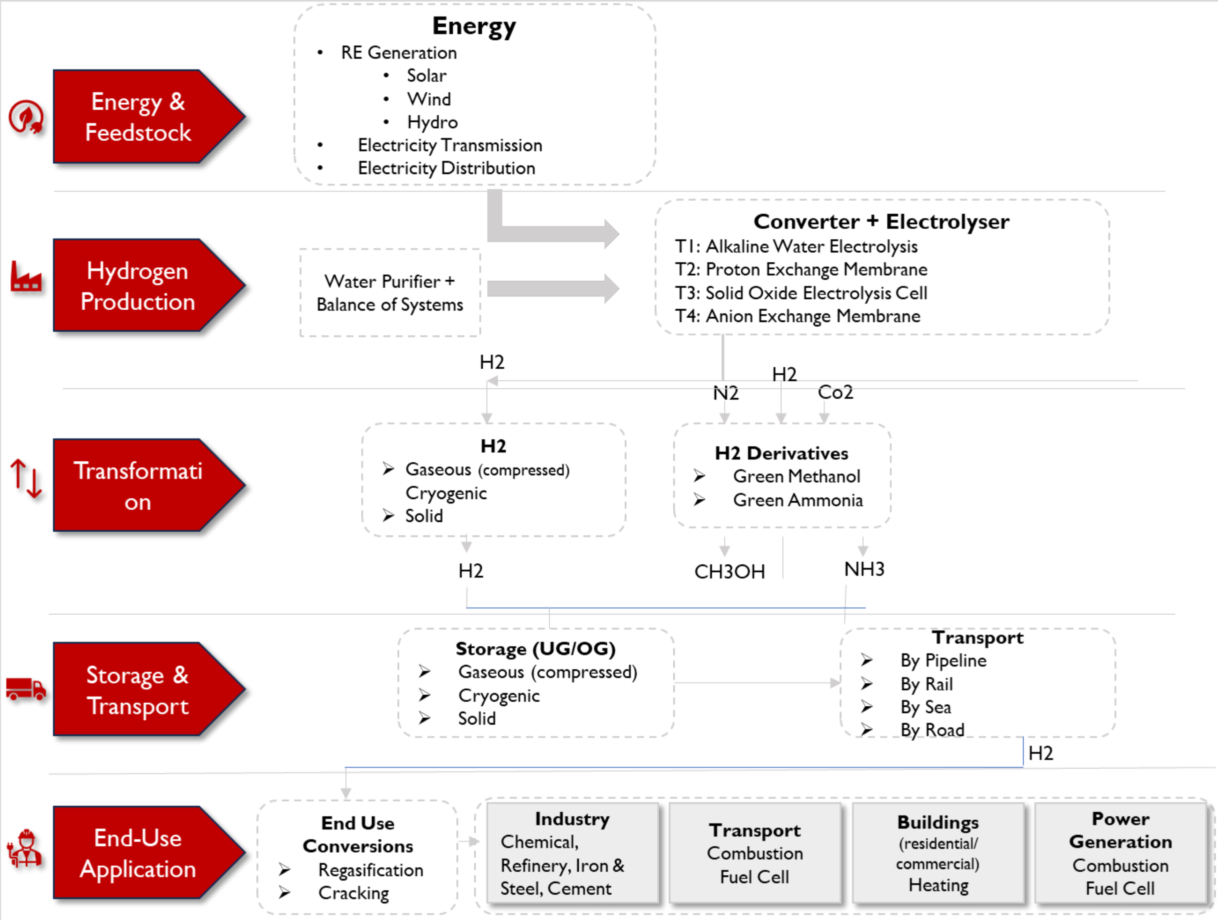

Figure 2.2 Hydrogen value chain

2.3 TECHNOLOGY FOR GREEN HYDROGEN PRODUCTION

Green hydrogen can be produced using four different types of technologies, namely alkaline electrolysers, solid oxide electrolysers, proton exchange membrane electrolysers, and anion exchange membrane electrolysers.

Alkaline Electrolysers

- Most mature technology.
- Have relatively low capital costs.
- Response times for start-up or shutdown are up to 10 mins.
- Ramp-up and ramp-down speeds in the range of 0.2 to 20% per second
- It is suited to be used in an industrial environment because of the rather complex maintenance required.

Polymer Electrolyte Membrane

- Under commercial stage.
- Higher capital costs due to the requirement of more expensive catalyst materials.
- Ramp-up and ramp-down sequences can be performed within seconds.
- It has limited land footprint (~ 0.05m²/kWhe)
- A preferable solution for distributed hydrogen production.

Solid Oxide Electrolyser

- Under demonstration stage.
- Higher overall cost due to high operating temperature.
- It needs to be coupled with a large source of waste heat - typically nuclear power plants or large industrials – and stable supply of power.
- Use of SOEC will be limited to specific locations and end-uses.

Anion Exchange Membrane

- Under development stage.
- Works in an alkaline environment.
- It requires non-noble metals such as nickel, cobalt, iron as a catalyst.
- The process is still at the R&D level.

Figure 2.3 Details of the four technologies for green hydrogen production

Of these four technologies, the alkaline method is the most developed, and has the highest lifetime in terms of stack hours. New green hydrogen projects are now based on the PEM method, because of its flexibility, such as fast start-response time (5 sec to 1 minute), quick shutdown-response time (within seconds) making it suitable for variable renewable energy. Additionally, PEM electrolysers come in diverse sizes, offering the adaptability to meet the hydrogen production requirements of both small-scale and larger-scale applications. However, the other two methods are still in the research and development and demonstration stages.

Table 2.1 Comparative Analysis of Electrolyser Technologies[1]

Type of Electrolysis	Efficiency (kWh/kg)	Operating conditions	Stack Lifetime (hours)
Alkaline Electrolysers	50-78	70-90⁰C ; 30 bar	50,000
Polymer Electrolyte Membrane	50-83	50-80⁰C ; <70 bar	60,000
Solid Oxide Electrolysers	40-50	700-850⁰C ; 30 bar	20,000
Anion Exchange Electrolysers	40-69	40-60⁰C ; 30 bar	5,000

To understand the adoption of various technologies across key geographies, detailed research was carried out on the global hydrogen market. Chapter 3 will discuss the same in detail.

[1] IRENA Report– Green hydrogen supply – A guide to policy making 2021

3 GLOBAL HYDROGEN MARKET OVERVIEW

The global demand for hydrogen has steadily grown at a rate of ~3%, from 18 MTPA in 1975 to 95 MTPA in 2022[2]. This growth has been driven by the inherent demand of the process industries where hydrogen is a key raw material. Refining and ammonia production are the two key sectors that have contributed to this rising demand, as illustrated in Figure 3.1 below. The global hydrogen demand is expected to increase further, as many countries have announced incentives to encourage the green hydrogen ecosystem.

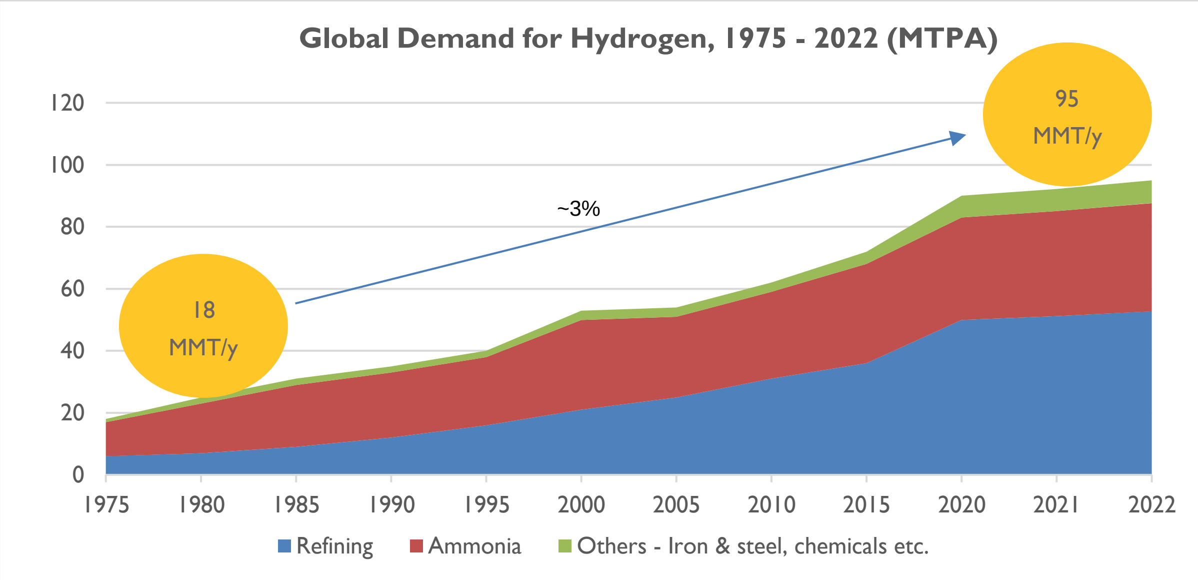

Figure 3.1 Global Demand for Hydrogen, 1975 - 2022 (MTPA)

At present the key sources for hydrogen are natural gas and oil as illustrated in Figure 3.2.

- Natural gas stands out as the predominant source, facilitating nearly half of the global hydrogen production. This is primarily due to the widespread use of steam methane reforming (SMR) technology, which relies on natural gas as a feedstock to generate hydrogen.
- Oil is the second-largest source, contributing around 30% of the hydrogen produced, often through processes like oil refining or hydrogen recovery from various oil-related industrial processes.

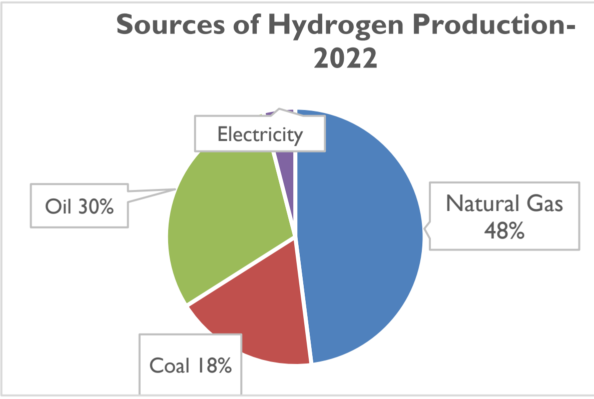

Figure 3.2 Sources of Hydrogen Production, 2022[1]

- Coal accounts for ~18% of hydrogen production, primarily through coal gasification techniques.

[2] https://iea.blob.core.windows.net/assets/8d434960-a85c-4c02-ad96-77794aaa175d/GlobalHydrogenReview2023.pdf

However, this trend is set to change significantly, as the majority of hydrogen producing units planned for the near future are to be low carbon; based on electrolysers or Carbon Capture, Usage and Storage (CCUS) technology.

3.1 GLOBAL CLEAN HYDROGEN TARGETS

Since 2017, there has been a notable surge in national hydrogen strategies / roadmaps and development across the globe. Japan led the way by unveiling the first hydrogen roadmap. Subsequently, France and Germany also announced their plans for hydrogen adoption. By December 2022 - more than 30 countries unveiled their strategies and goals for hydrogen. These nations have embarked on their unique H2 policy initiatives, each setting their own specific objectives for hydrogen adoption across a range of sectors. These objectives include expanding hydrogen infrastructure, promoting research and development, and encouraging the use of hydrogen in transportation, industry, and power generation.

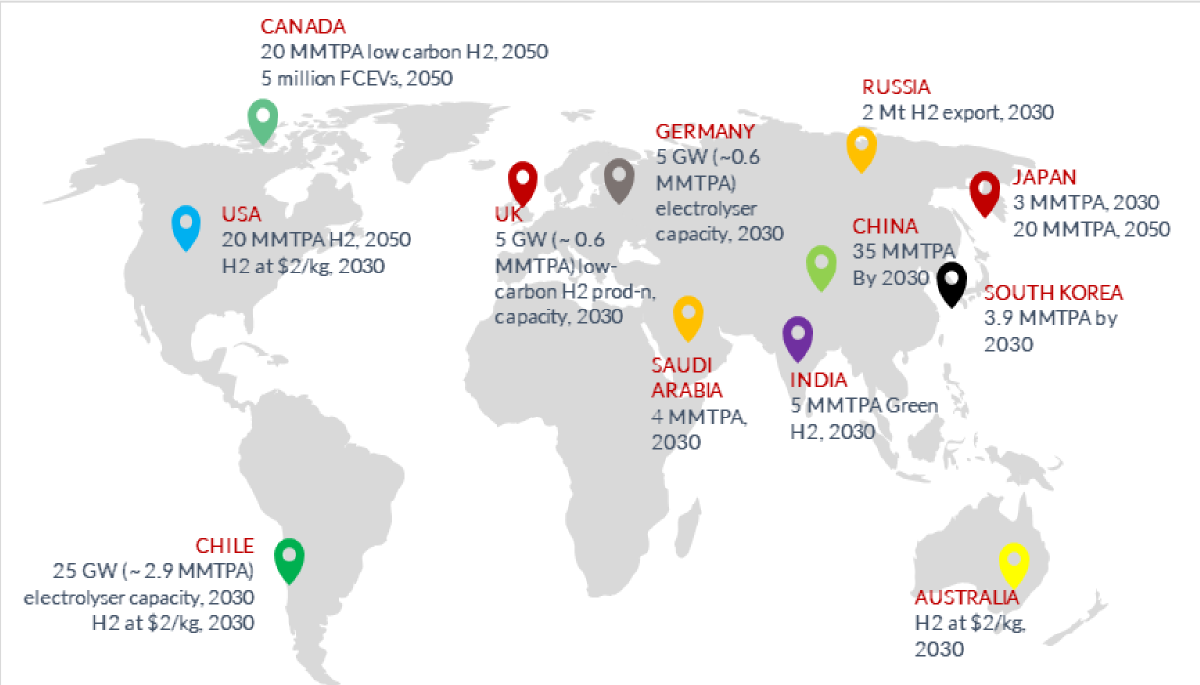

Figure 3.3 Global Targets[3]

The global clean hydrogen strategies / roadmaps can be categorized into five different buckets as follows:

[3] https://www.niti.gov.in/sites/default/files/2022-06/Harnessing_Green_Hydrogen_V21_DIGITAL_29062022.pdf and respective country green hydrogen strategy/policy documents –
Korea - https://isa-ghic.org/countries/the-republic-of-korea ,
UK - https://gh2.org/countries/united-kingdom#:~:text=The%20target%20for%20the%20government,for%20use%20across%20the%20economy.
USA - https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf,

Figure 3.4 Strategies prepared under 5 buckets.

Our observations and analysis indicate that the hydrogen strategies adopted by majority of the countries fits into the 5 buckets listed in the above figure and explained below:

- **Hydrogen hubs -** Countries such as Australia, the US & Canada, are focusing on hydrogen hubs, wherein they plan to create a centralized hydrogen demand center to promote hydrogen utilization.
- **R&D innovation** – Leading economies like EU, Japan, Australia, and the US have outlined their R&D focus areas in the clean hydrogen technology space. Many of these economies have their R&D focus on improving cost-effectiveness, performance of electrolyser technologies and exploring novel hydrogen production technologies.
- **H2 production** – More than 30 countries have announced their clean hydrogen production targets. The cumulative targets of these countries add up to ~155 MTPA[4] by the year 2030.
- **Price reduction** – Since clean hydrogen is currently more expensive than conventional fuel or hydrogen produced from fossil fuels, price reduction is a major component of the hydrogen strategy of most countries. Further, many economies like US, EU & Russia aim to reduce the price of green hydrogen to USD 1.5 – 2/kg by 2030.
- **Fuel cell electric vehicles (FCEVs)** – FCEVs are a major focus area of national hydrogen strategies for economies like Japan, Korea & EU.

Definitions of green hydrogen can vary from nation to nation due to differences in priorities, energy mix, policies, and environmental considerations.

In USA, clean hydrogen is considered as hydrogen produced with a carbon intensity equal to or less than 2 kilograms of carbon dioxide-equivalent produced at the site of production per kilogram of hydrogen produced.

In EU, it is the Hydrogen produced through the electrolysis of water powered by electricity from renewable sources or through the reforming of biogas or biochemical conversion of biomass.

[4] ICF analysis

Source : USA - https://afdc.energy.gov/laws/13033 and EU- https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/747085/EPRS_BRI(2023)747085_EN.pdf

Further, the support measures available to promote hydrogen ecosystem in the following four[5] countries were mapped – USA, Germany, Japan & Australia as follows:

Support Measure Type	USA	Germany	Japan	Australia
R&D Support	✓	✓	✓	✓
Regulatory Measures	✓	less relevant	✓	✓
Financial Support	✓	✓	✓	✓
Acceptance and Training	less relevant	less relevant	less relevant	✓
Governance and other	✓	✓	✓	✓

Key: ✓ main sector; less relevant; ✗ not addressed

Figure 3.5 Existing and Planned Hydrogen Support Measures[6] by Country[7]

Though, all the four countries have measures in place to promote green hydrogen ecosystem including R&D, governance & financial support, Australia is leading in the ability to provide the requisite support for workforce skilling.

3.2 UPCOMING HYDROGEN PROJECTS

As per IEA's report, globally about 25 MTPA of available hydrogen has been announced for end-use sectors by 2030. The majority of these projects are either blue hydrogen or green hydrogen projects. The cumulative hydrogen production capacity by 2030 categorized by sector and the technology used for production is shown in the figure below:

[5] Saudi Arabia has not announced any vision/strategy document. Limited literature available on developments in Saudi Arabia in green hydrogen domain, have been added in section 3.3.5 of this report.

[6] Acceptance and training - Promoting hydrogen-related training & acceptance among various stakeholders.

[7] LBST Report Template (en) (weltenergierat.de)

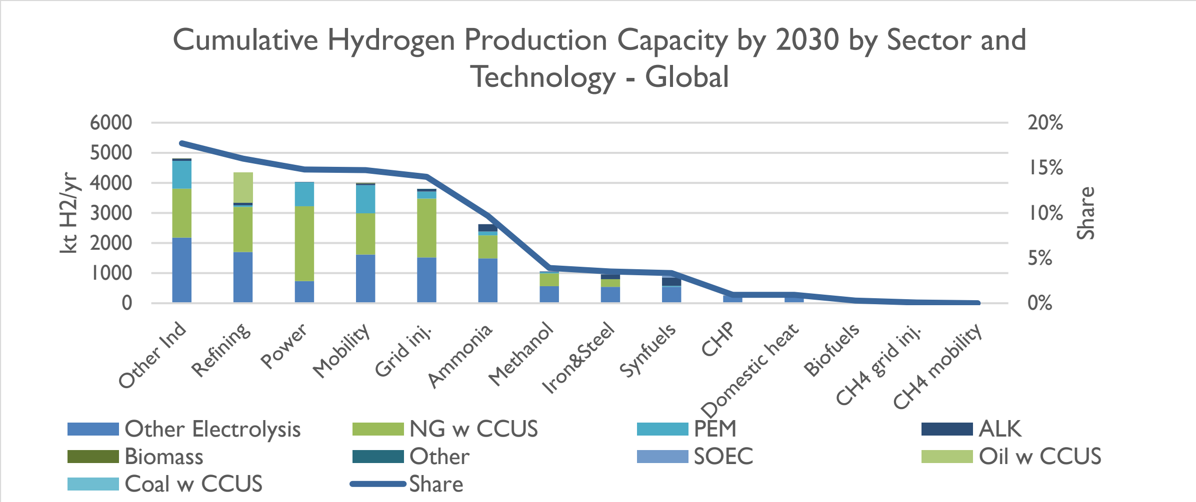

Figure 3.6: Cumulative Hydrogen Production Capacity by 2030 by Sector and Technology

Source: IEA

Majority of projects in hydrogen production are expected to either green hydrogen projects based on **Electrolysis or** blue hydrogen projects based on SMR of **Natural Gas with CCUS**

3.3 TECHNOLOGY IN GREEN HYDROGEN

Electrolyser based hydrogen production, accounting for approximately 4% (2021) of the total, has been dominated by alkaline electrolysers, which have a 60% share in electrolyser production capacity. Since 2019, global electrolyser based hydrogen production using PEM technology has grown at a rate of 43%.

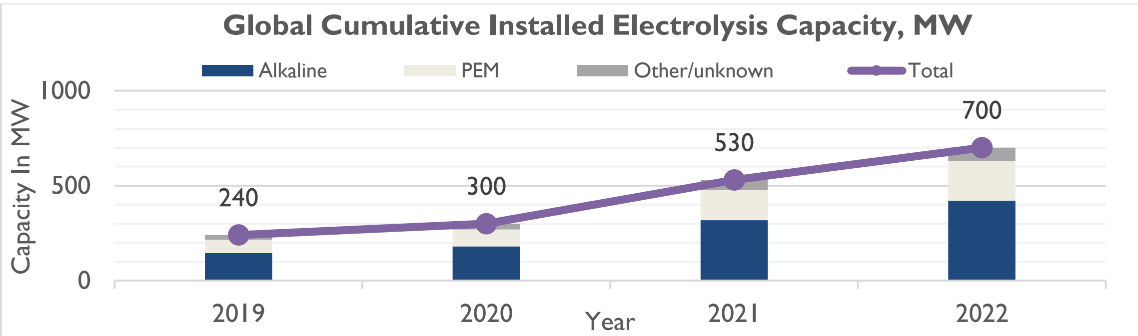

Figure 3.7.: Global Cumulative Installed Electrolysis Capacity[8]

The table below lists the number of upcoming hydrogen projects across the value chain corresponding to different production processes. Currently, 480[9] tons of green hydrogen is produced per year by the operational projects in Australia, and 0.12[10] million metric tons per year in USA. The operational green hydrogen project capacity in Germany and Japan are 8 KTPA and 1.8 KTPA respectively.

[8] Hydrogen-Insights-2023.pdf (hydrogencouncil.com)
9 https://www.iea.org/reports/hydrogen-projects-database
10 https://www.iea.org/reports/hydrogen-projects-database

Table 3.1 Country-wise number of Projects across Hydrogen Value Chain

Country	Hydrogen Production				Storage & Distribution		Hydrogen Utilization		
	PEM	Alkaline	Solid Oxide	Other	-	Gas Blending	Transport	Electricity Generation	Industrial Processes
Australia	85*				37	13	25	16	5
Germany	48	27	10	21	100	37	33	24	28
USA	18	3	3	6	42	5	14	11	7
Japan	17	2	0	5	25	0	12	15	2
Saudi Arabia	Similar data not found								

Source: IEA Hydrogen Projects Database, October 2021

**Aggregate figure for hydrogen production*

Acknowledging the transition from Alkaline to PEM electrolyser technology is paramount for workforce development and management in the hydrogen production sector. As the industry evolves and PEM technology becomes increasingly prevalent, a skilled workforce is essential to operate, maintain, and optimize related systems. Thus, focusing on skill development aligns the workforce with industrial advancements and technological transitions. Gradually as the industry matures, skill requirement shall be required for SOEFC and AEM as well. Additionally, countries worldwide have outlined their technology and research and development (R&D) priorities to achieve their individual clean or green hydrogen goals. Each nation will possess unique technological preferences within the hydrogen sector, shaping the specific skills needed for its workforce. The technology landscape and R&D priority areas are elaborated upon in annexure 9.1.

4 INDIAN HYDROGEN MARKET

4.1 MARKET OVERVIEW

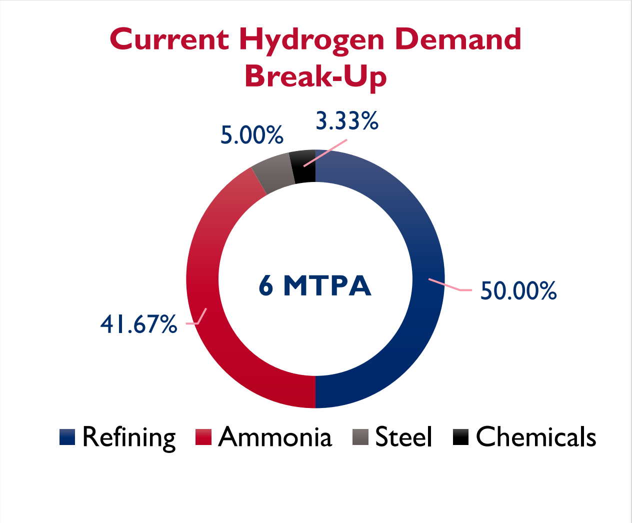

Figure 4.1 Current Hydrogen Demand Break-up

In 2022, India's hydrogen demand was approximately 6 MTPA[11], driven by captive consumption within refineries and fertilizer units. Hydrogen demand is largely split between captive (90%) and merchant (10%) usage. Captive consumption involves on-site hydrogen production by industrial facilities for self-sufficiency. Whereas, merchant hydrogen, sourced externally, caters to industries with intermittent or lower-volume hydrogen needs.

Given the cost-competitiveness of black / brown hydrogen compared to green hydrogen, 95 per cent of this total demand is met by fossil fuel–derived hydrogen[12].

The hydrogen demand is expected to reach 12 MTPA by 2030[13]. It is expected that around 40 percent of this demand will be met by green hydrogen, indicating an expecting five million tonnes per annum of domestic green hydrogen production by 2030[14].

The demand can increase to around 28 MTPA by 2050[15], driven by cost reductions in key technologies, as well as the growing imperative to decarbonize the energy sector. Demand will continue to be largely focused in industrial sectors, either expanding in existing sectors, such as fertilizers and refineries, or growing into new sectors, such as steel. Hydrogen will play some role in the transport sector in heavy-duty and long-distance segments, and a minor role in the power sector as a long-term storage vector.

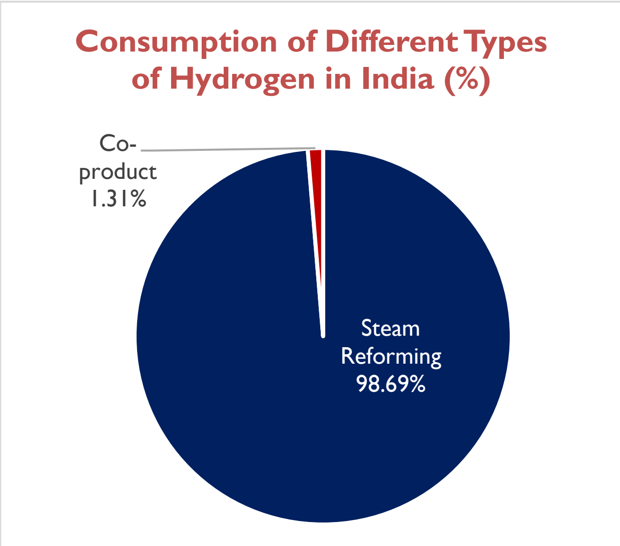

Figure 4.2 Consumption of different types of hydrogen in India

Beyond 2050, demand for green hydrogen is expected to continue growing, particularly in the steel and road transport sectors, as well as in

[11] https://www.niti.gov.in/sites/default/files/2022-06/Harnessing_Green_Hydrogen_V21_DIGITAL_29062022.pdf
[12] CEEW - https://www.ceew.in/cef/quick-reads/analysis/catalysing-green-hydrogen-growth-in-india
[13] Forbes India
[14] Forbes India
[15] https://www.teriin.org/sites/default/files/2020-12/potential-role-hydrogen-india.pdf

shipping and aviation. Reaching a net-zero target by 2060 could require around 40 MTPA of green hydrogen, a 7-fold increase over today's production capacity.[16]

India's Green Hydrogen target and Government initiatives

India notified the National Green Hydrogen Mission in January 2023 of its aim to produce 5 million metric tons of green hydrogen by 2030. The government has introduced incentive schemes to bolster the manufacturing of electrolysers and the production of green hydrogen. In June 2023, under the strategic intervention for green hydrogen program[17], an allocation of ₹17,490 crore was earmarked for this purpose. Of this amount, ₹13,050 crore is dedicated to incentivize the production of green hydrogen, while another ₹4,440 crore is allocated specifically for electrolyser production. These incentives reflect the government's commitment to fostering the growth of green hydrogen technologies.

How is Green Hydrogen defined in India?

In India, the Ministry of New and Renewable Energy (MNRE) [18] has defined green hydrogen as hydrogen produced from renewable energy sources, either through electrolysis or biomass conversion with carbon emissions not exceeding 2 kgs of carbon dioxide equivalent for every kilogram of hydrogen produced. This requirement pertains to the average over the previous 12 months, emphasizing a sustained and consistent adherence to emission standards.

4.2 INDIA'S TECHNOLOGY AND R&D LANDSCAPE - EXISITING

India primarily uses PEM technology which accounts for 70% of its green hydrogen production capacity[19]. This is followed by ~28% of alkaline electrolyser. The SOEC contribution is currently negligible with only one project – Simhadri micro-grid at final investment decision stage.

Details of all the operational, under construction and 'final investment decision' projects as per IEA Hydrogen Database 2021 is displayed below:

Table 4.1 Current projects in India – Technology Wise

Sl.	Project Name	Date	Status	Technology	Announced Size (TPA)
1	Centre of Fuel Cell Technology, Chennai	2012	Operational	PEM	1.6
2	Savli wind-hydrogen demo project	2013	Operational	Other Electrolysis	~1
3	Dahej, Reliance, back-up hydrogen supply	2014	Operational	ALK	350

[16] https://www.teriin.org/sites/default/files/2020-12/potential-role-hydrogen-india.pdf
[17] https://mnre.gov.in/hydrogen-schemes-guidelines/
[18] https://static.pib.gov.in/WriteReadData/specificdocs/documents/2023/aug/doc2023819241201.pdf
[19] Including operational, Under construction and final investment decision projects.

Sl.	Project Name	Date	Status	Technology	Announced Size (TPA)
4	Gwalpahari Solar-Hydrogen demonstration	2015	Operational	Other Electrolysis	21
5	Solar Energy Centre SmartFuel hydrogen station	2015	Operational	Other Electrolysis	0.0
6	Hazira, Reliance, back-up hydrogen supply	2005	Operational	ALK	536
7	Rajasthan pilot plant	2021	Operational	Other Electrolysis	0.0
8	Mathura refinery	-	Under construction	Biomass	5051
9	NTPC-Technip-L&T MeOH project, Vindhyachal	2022	FID	PEM	757
10	Simhadri micro-grid	2022	FID	SOEC	50
11	NTPC green hydrogen mobility project - Ladakh	-	FID	Other Electrolysis	0.0
12	GAIL Vijaipur project	2023	FID	PEM	1515

Announced Projects in India

Considering the recent announcements pertaining to green hydrogen production, an analysis of upcoming projects in India has been conducted. All projects listed here are expected to get commissioned in the next 2-3 years.

Table 4.2 Projects to be Commissioned in the Next 2-3 Years

Sl.	Developer	Plant	Technology	Metric Tons/Annum of Hydrogen	Date of Commissioning
1	IOC	Panipat Refinery	-	7,000	2025
2	HPCL	Andhra Pradesh	-	7300	2025-2026
3	MRPL	Karnataka	-	500	2025
4	Reliance	Jamnagar Gigafactory	Alkaline	400,000	2025
5	Greenko	Green Ammonia Plant, Una, Himachal Pradesh.	Alkaline	17800	2024
6	JSW Energy	Vijayanagar plant	-	3800	2024-25
7	Greenko	Kakinada Plant	Alkaline	178000	2025

Alkaline electrolysers have been traditionally used to produce green/by-product hydrogen via electrolysis of water/brine respectively. PEM electrolysers in relatively early stages of development, are nearly twice as costly as alkaline electrolysers. However, multiple R&D projects across various countries are working towards increasing their efficiency and reducing costs. So, PEM electrolysers are expected to achieve cost parity with alkaline electrolysers in future. While some companies prefer alkaline technology over PEM in the near future, others hope to reap the long-term benefits of championing installation of PEM technology.

Understanding the technology landscape in India will require examining the upcoming R&D areas. Table 4.3: Pathways Research organisations and their R&D Initiatives, highlights the current key R&D initiatives.[20] undertaken by key institutes in India. This helps in envisaging the nature and extent of skill requirement across the hydrogen value chain.

Table 4.3: Pathways Research organisations and their R&D Initiatives

Pathways	Research organisations and their R&D Initiatives
Production	• Indian Oil R&D Centre: Oxy-steam biomass gasification, Bio-CNG reforming-based generation. • ONGC Energy Centre (OEC): Closed-loop Cu-Cl cycle, Closed Loop I-S Cycle, Open Loop I-S cycle.
Storage	• IIT Kharagpur & Indian Oil (R&D): Developing Type 3 composite cylinder for storage of compressed H2 gas at 350 bar pressure. • DST – IIT Bombay Energy Storage Platform on Hydrogen: Synthesis of metal hydrides on a large scale, synthesis from industrial grade materials, effect of impurities, metal hydride-based systems simulation, design, development.
End-use	• CSIR and CSIR and KPIT: Developing automotive-grade LT-PEMFC using metal bipolar plates, Fuel Cell system architecture, powertrain integration, control strategy etc. • CSIR & RIL: Developing LT–PEMFC set ups for telecom towers.

Key takeaways -

- ONGC & Indian Oil have undertaken studies on ways to **reduce PEM costs**. The introduction of such electrolyser technology would require an already skilled workforce in PEM hydrogen production technology. Currently, there are **no focused study programs** or courses, available even in reputed universities and colleges for these production technologies.
- Storage feasibility studies are being carried out in IIT Kharagpur & Indian Oil (R&D Centre) on developing Type 3 composite cylinders with high pressure.
- Green hydrogen based transport is picking up, with new green hydrogen projects being undertaken in Mumbai and Delhi. A skilled workforce and R&D for FCEV and cost effective hydrogen vehicles is required to bolster its growth and development.
- The end use sector doesn't need a new program for reskilling. Instead, through stakeholder consultations, existing staff can conduct upskilling & refresher courses, and on-the-job courses to enable a smooth transition to hydrogen adoption.

4.3 INDIA'S TECHNOLOGY AND R&D LANDSCAPE - FUTURE (IDENTIFIED BY MNRE)

The rapidly emerging green hydrogen market in India will benefit from the multiple complex projects in the pipeline with varied technology and R&D requirements. In October 2023, India unveiled the

[20] 202310131572744879.pdf (s3waas.gov.in)

R&D Roadmap for the National Green Hydrogen Mission, delineating key R&D focus areas over short-term, medium-term, and long-term periods. These details are extensively covered in annexure 9.1. The table below highlights the comprehensive skill requirements that will be essential in the short term, medium term, and long term as defined in the roadmap.

Table 4.4: Skilling Requirement across Short, Medium, and Long Term

R&D phases	Skilling requirement
Short-term (0-5 years)	• Highly skilled workforce focused on specific electrolyser technologies to carry out the R&D activities. • Skilled & semi-skilled workforce in manufacturing hydrogen storage canisters & Type III tanks. • Research and development professionals in material science and related fields. • Workforce for infrastructure upgradation like piping and new technological developments in manufacturing & maintenance of hydrogen vehicles.
Medium-term (0-8 years)	• Skilled workforce for alternate hydrogen generation technologies like biomass gasification and biomethane reformers. • Personnel for manufacturing, installation, commissioning & operating indigenous green hydrogen technologies. • Personnel for large scale production of storage technologies. • Skilled workforce for hydrogen utilization in sectors like marine transport, power and locomotives is likely to increase.
Long-term (0-15 years)	• Highly skilled personnel to research novel technologies for hydrogen production. • Researchers for R&D of novel technologies to improve efficiency and reduce cost throughout the value chain. • Personnel for manufacturing & testing of established storage technologies. • Workforce for expansion of hydrogen infrastructure and integration processes.

5 CASE STUDIES – EXISITING HYDROGEN PRODUCING / CONSUMING INDUSTRIES

Secondary data on skilling requirement for hydrogen value chain is limited. To develop a more succinct understanding of the skill set requirements, detailed stakeholder consultations were carried out across key sectors. The study team approached around 30 companies and has received responses from around 11 players, including stakeholders from refineries and the fertilizer, chemical, iron and steel, shipping, and cement industries.

Table 5.1 Stakeholder Interactions

Refineries	Fertilizers	Chemicals	Iron & Steel	Shipping	Cement	Across H2 Value Chain
• **Indian Oil Corporation (IOCL)** • Hindustan Petroleum Corporation Limited (HPCL) • Nayara Energy • Petroleum Corporation Limited (BPCL) • Shell • Reliance • Jio BP	• **Indian Farmer Fertilizer Cooperative (IFFCO)** • Paradeep Phosphates • Deepak Fertilisers and Petrochemicals • DCM Shriram • National Fertilizers Limited • Rashtriya Chemicals and Fertilizers Limited • Chambal Fertilizers and Chemicals	• **Navin Fluorine International Limited** • Grasim Industries Limited • Aarti Industries • GACL • Yara Chemicals • Gujarat Heavy Chemicals Limited (GHCL) • Meghmani Finechem limited	• **Essar Steel** • Tata Steel • Jindal South-West (JSW Steel) • Jindal Stainless • Jindal Steel and Power (JSPL)	• **MOL Synergy Group** • Fast Freight Private Limited • Cochin Shipyard Limited • Zetnor • Anglo Eastern • Arcelor Mittal shipping	• **Ultra Tech Cement** • Dalmia Bharat • Shree Cement	• NTPC • ITM Linde • ACME cleantech solutions • GAIL • Greenko • Ohmium • Siemens AG • Air Liquide

Key: Case Study | Discussions Completed | Stakeholder Contacted

Discussions with stakeholders helped identify concerns regarding the role of hydrogen in various processes, the key drivers of and major challenges in hydrogen adoption and the current skill set availability and skills required in the future for transitioning to green hydrogen.

5.1 KEY FINDINGS FROM THE STAKEHOLDER INTERACTIONS

5.1.1 REFINERY AND FERTILIZER

There is no dedicated workforce responsible for managing hydrogen production. It is a shared responsibility alongside other operational process. With the adoption of green hydrogen, the following critical job roles and training will be required:

- **Critical job roles** as highlighted in stakeholder discussions, were primarily the roles of process or chemical engineers and electrical engineers involved in the power management team (for both refinery & fertilizer). In fertilizer plants, training process engineering team to necessitate process redesign for fertilizer plants (including additional PSA unit for N2 extraction & external CO2 requirement)

- **Critical training areas** for both these industries, to adopt green hydrogen, include hydrogen storage and safety verticals.
- **Major challenges** across both these industries include the high cost of green hydrogen, large renewable power requirement & managing its variability.

5.1.2 CHEMICAL AND IRON AND STEEL

With the gradual adoption of green hydrogen in chemical and iron and steel industry, critical job roles and training required will be:

- **Critical job roles** highlighted by the companies are the roles of degree holding engineers and diploma holding engineers and technicians.
- **Critical training areas** for the existing workforce include:
    - Safety and Disaster Management
    - Grid integration specialists
    - A dedicated staff for H2 storage facility may be required in the iron and steel industry.

Major skilling challenge for this transition will be hiring a competent workforce for hydrogen related processes due to the absence of certifications, standards, and certified courses in this area.

5.1.3 SHIPPING AND CEMENT

Shipping and cement industries have not yet planned to transition to green hydrogen because integrating green hydrogen in their processes is not yet economically viable. However, the conclusions from the stakeholder discussions in these sectors have been summarized below:

- **Critical job roles** in cement industry were found to be in Alternative Fuel and Raw Material Unit for the cement industry, and in crew members, that are responsible for running the engine and handling fuel transport in the shipping industry.
- **Critical training** requirements for the existing workforce were highlighted in the areas of Safety and Disaster Management for both industries.
- Currently, there is no major advancement in green hydrogen adoption for these sectors, thus posing a challenge for the smooth transition to green hydrogen processes.

Overall, the current hydrogen skilling set up in India is majorly unorganized and gets by with on-the-job training provided by seniors or experts in the organization. Moreover, certification training and specialized training modules are not yet considered as the staff involved is a shared resource.

6 GLOBAL INSIGHTS ON SKILLING AND JOBS IN GREEN HYDROGEN SECTOR

Green hydrogen stands poised to serve a pivotal role in the worldwide shift towards net-zero carbon emissions. This renewed interest in harnessing green hydrogen has gained significant momentum over the last two years. More than 30 major countries unveiled their green hydrogen strategies by the end of 2022.

Projections indicate that global green hydrogen production capacities are set to reach 21 million metric tons per annum (MMTPA) by 2030.[21]. These are backed by the hydrogen production/ electrolyser capacity targets set by various countries in their net-zero strategy. For instance, Germany aims to achieve a domestic electrolysis capacity of at least 10 GW by 2030.[22], while the United States has set the ambitious goal of achieving clean hydrogen production capacities of 10 MMTPA by 2030 and 50 MMTPA by 2050.[23]. Japan has its target set on using 3 MMTPA.[24] (includes ~0.3 MMTPA.[25] to be met through import) and 20 MMTPA of clean hydrogen by 2030 & 2050 respectively. Saudi Arabia is determined to produce 4 MMTPA.[26] of clean hydrogen by 2030 and intends to become one of the leading exporters of clean hydrogen to neighboring countries.

Many countries have also set pricing targets to ensure that hydrogen becomes competitive against conventional fuels. For instance, Australia is targeting hydrogen costs less than AU$2.[27] per kilogram by 2030, while the US aims to bring down the cost of clean hydrogen to $1 per kilogram by 2031.[28].

Several nations have also assessed employment potential associated with the growth of their green hydrogen production capacities. Australia estimated that its shift to green hydrogen will generate ~ 7,600 (lower limit) to 17,000 jobs.[29] (upper limit) by 2050, and the United States anticipates that its expanding economy could generate up to 100,000 net new direct and indirect jobs in the hydrogen sector by 2030.[30].

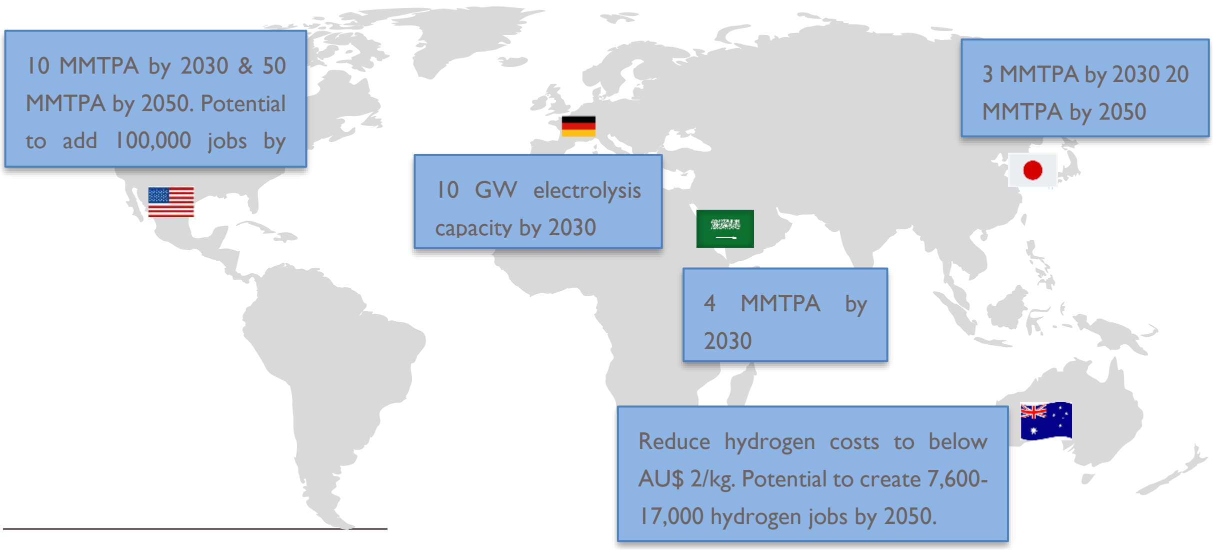

Figure 6.1 Global Green Hydrogen Scenario

[21] https://energy.economictimes.indiatimes.com/news/renewable/global-green-hydrogen-capacity-to-hit-21-mtpa-by-2030-cii-ey-report/103817213#:~:text=New%20Delhi%3A%20Global%20green%20hydrogen,Industry%20(CII)%20and%20EY.
[22] https://www.hydrogeninsight.com/policy/germany-doubles-its-green-hydrogen-production-target-for-2030-in-new-update-of-national-strategy/2-1-1491715
[23] https://liftoff.energy.gov/wp-content/uploads/2023/05/20230523-Pathways-to-Commercial-Liftoff-Clean-Hydrogen.pdf
[24] https://www.reuters.com/business/energy/japan-aims-boost-hydrogen-supply-12-mln-t-by-2040-2023-04-04/
25 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Global_hydrogen_trade_part_1_2022_.pdf
[26] https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/111522-cop27-saudi-arabia-targets-europe-asia-pacific-in-global-hydrogen-push
[27] https://www.infolink-group.com/energy-article/green-hydrogen-costs-in-australia-to-reduce-37-by-2030#:~:text=Cost%20estimation%20of%20Australian%20green,electrolyser%20are%20used%20for%20electrolysis.
28 https://www.energy.gov/eere/fuelcells/hydrogen-shot
29 https://www.dcceew.gov.au/sites/default/files/documents/australias-national-hydrogen-strategy.pdf.
30 https://www.energy.gov/articles/biden-harris-administration-releases-first-ever-national-clean-hydrogen-strategy-and#:~:text=Estimates%20indicate%20that%20America's%20growing,and%20indirect%20jobs%20by%202030.

This emerging hydrogen economy presents an extensive opportunity for employment generation, associated skill development and re-skilling of existing workforce. Countries like Australia and USA have gone a step ahead to prepare a detailed hydrogen-based Workforce Development RoadMap. This section delves in detail into the country-based roadmaps for skilling/ reskilling in hydrogen sector and explores the critical job roles and training currently in demand and job roles expected to be crucial in future. This section also maps out the institutions that provide training to facilitate knowledge sharing and the development of expertise in the field of green hydrogen. The primary focus countries of this study include Australia, the United States, Germany, Japan, and Saudi Arabia.

6.1 AUSTRALIA

Australia is committed to a national renewable electricity target of 82%.[31] by 2030 to meet its ambitious NDC goal of 43% emissions reduction by 2030, and net zero by 2050. The country aims to establish itself as a renewable energy superpower.[32], and green hydrogen is expected to be a critical enabler of such a transition. According to IEA, Australia is expected to become the second largest net-exporter of low carbon hydrogen by 2030 and the largest by 2050.[33]. The country has also set an ambitious target to become the global hydrogen leader by 2030 and currently, has the world's most extensive pipeline of potential domestic and export-oriented hydrogen projects.[34]. Current operational projects in the country produce 480[35] tons of green hydrogen per year. Additionally, 95 clean hydrogen projects are in various stages of development, with a total potential capacity of approximately 7 million metric tons per year. These projects are primarily focused on various end uses, including export, ammonia production, mobility, industrial applications, and methanol production as represented in Figure 6.2. Australia has a significant number of infrastructure projects in the developmental stage, which should ramp up their green hydrogen production capacity. 93% of these are primarily focused on export in the form of Ammonia, Liquid H2 and metal hydride.

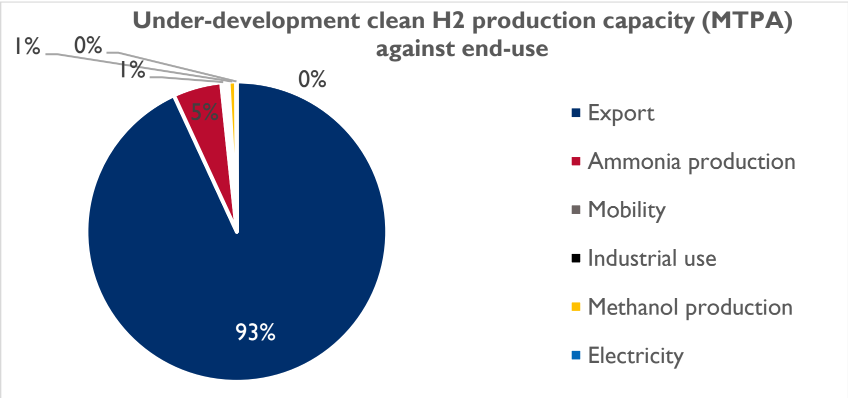

Figure 6.2 Under-development clean H2 production capacity (MTPA) against end-use.[36]

[31] https://www.globalaustralia.gov.au/industries/net-zero
32 https://www.themandarin.com.au/229483-australias-national-security-mandates-a-new-type-of-green-energy-statecraft/
33 https://www.globalaustralia.gov.au/industries/net-zero/hydrogen#:~:text=Hydrogen%20is%20a%20clean%2Dburning,Agency's%202022%20World%20Energy%20Outlook.
[34] https://energy.economictimes.indiatimes.com/news/renewable/australia-to-invest-1-4-bln-to-scale-up-renewable-hydrogen-industry/100101149
35 https://www.iea.org/reports/hydrogen-projects-database
36 https://research.csiro.au/hyresource/projects/facilities/

The federal budget 2023-2024 announced investment of more than $40[37] billion towards clean energy growth particularly in the green hydrogen sector. The investment of $40[38] billion comprises of $38.2 billion allocated to the Guarantee of Origin program, aimed at certifying renewable energy sources and monitoring emissions from clean energy products, with a particular focus on hydrogen. Additionally, $2 billion is earmarked for Hydrogen HeadStart, which serves as revenue support for large-scale renewable hydrogen initiatives.

In 2019, Australia became the 3rd nation to publish a hydrogen strategy, claiming that the industry could generate between 7,600 (lower limit) and 17,000 (upper limit) new jobs by 2050[39]. Figure 6.3 outlines the initiatives introduced since 2020 to address the skills shortage.

$95.6 million

Over 9 years to support 10,000 new energy apprenticeships towards the shift to a green workforce.

Source: https://www.energy.gov.au/news-media/news/new-energy-apprenticeships-power-

$2 billion

To offer free or low fee training in priority certifications

Source: https://www.dewr.gov.au/skills-reform/jobtrainer-fund

$922 million

Over next 5 years towards 480,000 fee-free technical and further education (TAFE) places & Technology Fund to modernize training facilities.

Source: https://archive.budget.gov.au/2022-23-

$12.9 million

Over next 3 years to establish the new Jobs and Skills Australia*

Source: https://archive.budget.gov.au/2022-23-

Figure 6.3 Initiatives taken by Australia since 2020 to address the jobs and skills shortage

In Australia, there is growing recognition of the need for training specific to the green hydrogen sector. The subsequent section discusses the country's projected skilling road map in terms of critical job roles, training etc.

Hydrogen Skills Roadmap 2022 by Swinburne University of Technology[40]: In February 2021, Swinburne University of Technology launched the Victorian Hydrogen Hub Initiative (VH2). A key component of VH2 is the development of a skills and training roadmap across the hydrogen value chain, designed to provide both government and industry with detailed analysis of sectors and job roles that will be affected, both now and in the future, by the production and use of hydrogen as an energy source. The study identified the job roles throughout the value chain that will be required in the near future. The detailed hydrogen job roles have been listed in Table 9.12. (Annexure)

[37] https://fuelcellsworks.com/news/australias-2b-hydrogen-headstart-boosts-renewable-energy-superpower-ambitions/
[38] https://fuelcellsworks.com/news/australias-2b-hydrogen-headstart-boosts-renewable-energy-superpower-ambitions/
[39] https://www.dcceew.gov.au/sites/default/files/documents/australias-national-hydrogen-strategy.pdf
*The Australian Government has established Jobs and Skills Australia to offer impartial guidance on the prevailing, forthcoming, and anticipated workforce, skills, and training requirements
[40] Source: Hydrogen Skills Roadmap report, September 2022 (Swinburne University of Technology)

The study highlights that the hydrogen sector development in the next few years will require significant shifts in job roles and skills, as well as a larger workforce once production scales up. Few of the job roles expected to be in demand have been listed below:

- **Skilled engineers** – Candidates with relevant qualifications in engineering, science, automation, mechanics, chemistry, electrical technology, or business and having knowledge & understanding of hydrogen technologies will be required.
- **Manufacturing workers (e.g., FCEVs manufacturing, electrolysers, and fuel cell manufacturing, hydrogen-specific appliances manufacturing), FCEV mechanics and auto electricians** – New skills related to FCEVs involving the ability to work with high voltage fuel systems that need to be installed and modified safely, will be required.
- **Gas workers, mechanical fitters, technicians, electricians, and gas fitters** – They may not need to learn new skills but build upon existing skills and adapt them to service the new systems.

  Emergency workers – While they may leverage upon existing skills, training, and certification to safely work with hydrogen and respond to hydrogen-related incidents will be necessary in the not-too-distant future.

Skilling Australian industry for the energy transition, 2023 by Australian Industry Energy Transitions Initiative: The study showed that by 2050, a total of 63,100 existing workers will require training in new skills specific to hydrogen industry. 59% of the total new jobs created will be higher skilled occupations, mainly consisting of technicians and tradeworkers.[41]. The detailed breakup is shown in Figure 6.4.

[41] https://energytransitionsinitiative.org/wp-content/uploads/2023/02/Skilling-Australian-industry-for-the-energy-transition-February-2023-Accenture-report-for-Australian-Industry-ETI-phase-3.pdf

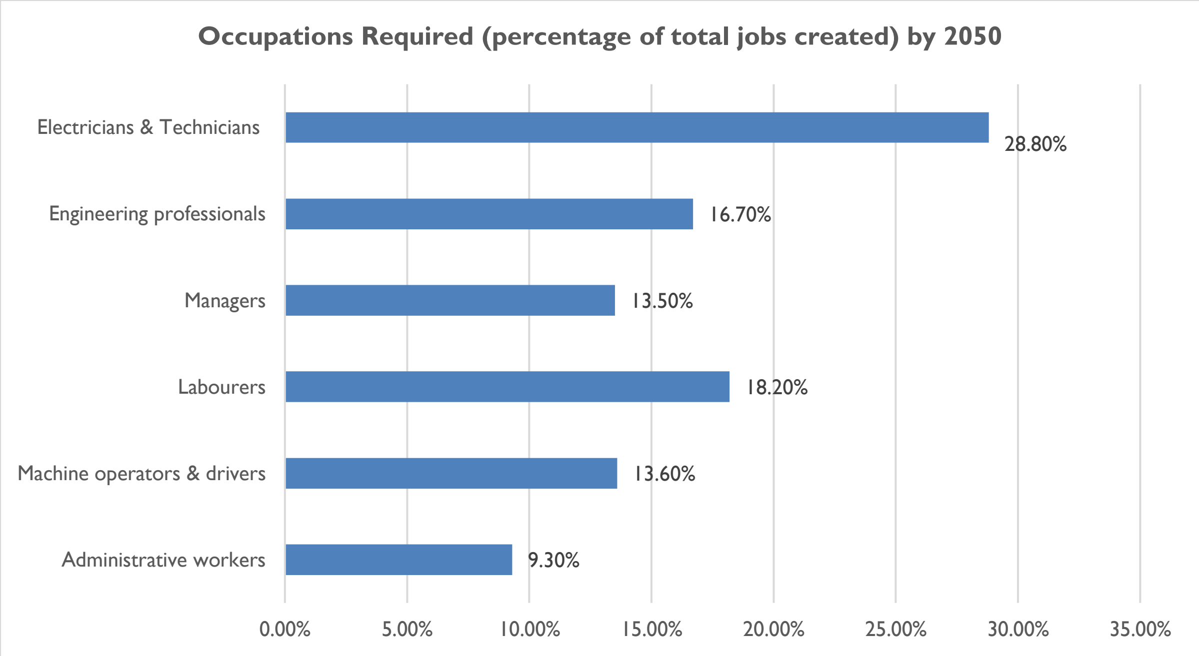

Figure 6.4 Occupations Required by 2050

The managerial roles encompass the construction, distribution, and production departments. Laborers, on the other hand, comprise individuals involved in construction and mining labor roles. The study suggests that the key skills in demand through the transition would be related to electrolysis and compressor technology, hydrogen electrolyser maintenance, hydro-testing for transmission pipeline, hydrogen properties and fuel cell design. The core base skillset of trades such as electricians can be leveraged to support the shift towards the production and storage of hydrogen. However, upskilling in hydrogen specific skills will be necessary across the sector, with targeted training opportunities to ensure the implementation of hydrogen systems and technologies is supported adequately.

6.1.1 CURRENT SKILLS IN DEMAND

To gain insight into the present job market for green hydrogen, job posting data from Glassdoor and LinkedIn was analyzed for the year (the graph below presents data for September 2023, month with maximum job posting). By utilizing the keyword "Green hydrogen," the most in-demand job opportunities were identified in the fields of manufacturing, consulting, engineering, and various roles in IT, media, and communications, as detailed in Figure 6.5.

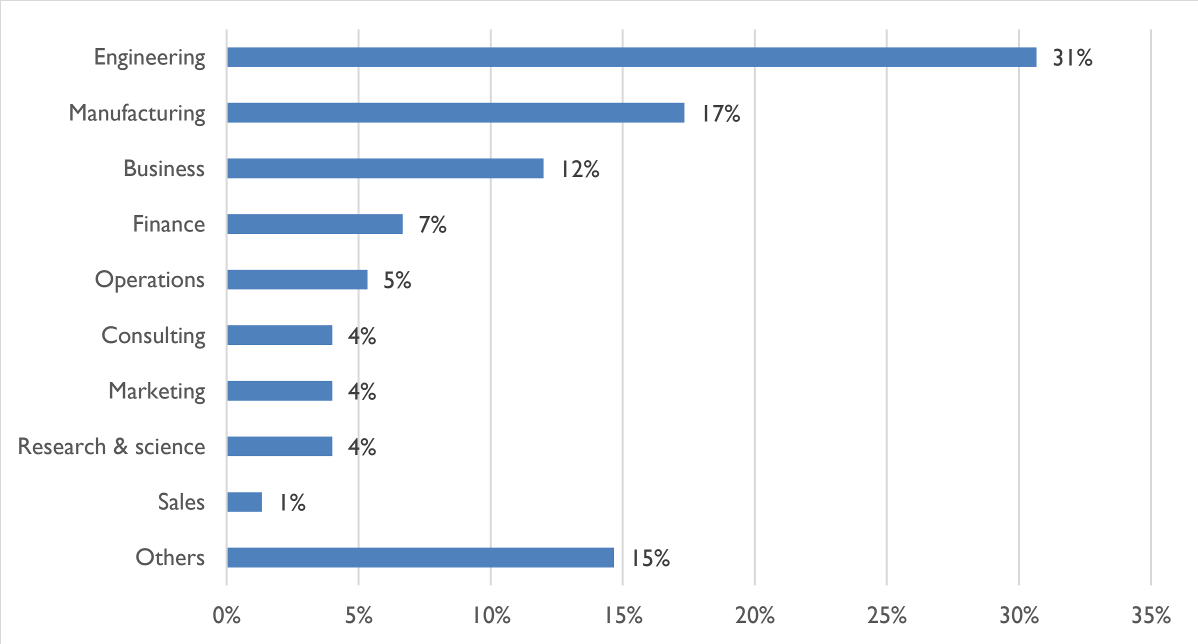

Figure 6.5 Hydrogen Job Openings in Australia (September 2023)

In September 2023, Australia witnessed a robust demand for skilled labor in the engineering and manufacturing sectors, resulting in approximately 70-80 job openings. The higher number of job opportunities in engineering and manufacturing indicates that most projects are in their early developmental stages. Most of the engineering job openings were targeted at mid-senior level professionals with over 5 years of relevant work experience, and the sought-after positions included electrical engineer, project engineer, grid integration engineer, and engineering manager. The next most sought-after roles were observed in the manufacturing sector at the mid-senior level, requiring 3-5 years of experience and a college/bachelor's degree. The in-demand positions in manufacturing comprised of instrumentation engineer, package engineer, supervisors, and technicians. The job qualifications needed for each of these highly sought-after positions are detailed in the Table 6.1

Table 6.1: Hydrogen Job Openings Qualification Requirements

Job Function	Minimum Qualification	Experience	Job roles
Engineering	Engineering degree	5+ years' work experience in relevant field	Electrical engineer, Project engineer, Grid integration engineer, Engineering manager
Manufacturing	Appropriate Trade Certificate in Electrical or Mechanical Disciplines. Working knowledge of work holding methods and fixturing	3 to 5 years of work experience post trade qualification	Instrumentation engineer, Package Engineer, Supervisors, Technicians
Business, Finance, Operations & sales	Bachelor's degree or vocational or technical and further education (TAFE) degree in Chemistry, Mechanical, Electrical, or similar field	2+ years' work experience in relevant field	Compliance Manager, Material Controller & Inventory Analyst, Project Dev. Analyst, Asst. Accountant, Finance operations Manager, Commissioning Manager
Consulting	Bachelor's degree in engineering, science, or business-related discipline	Advisor with a focus on sustainability and or energy transition in industry, consulting, or infrastructure projects At least 10 year's relevant experience in offshore projects within the renewables industry	Senior Associate – Green Energy and Resources

The analysis of current job openings reveals that most available positions are geared towards higher-skilled workers, particularly in two specific job categories: Engineering and Manufacturing. The research reveals a low current demand for professionals in fields like gas workers, electricians, technicians, plumbers, and emergency workers. This indicates that either these skill sets are already well-established, or their demand may increase in the future. Many of these professionals may not need to acquire entirely new skills but can instead build upon their existing expertise. However, it's worth noting that there will be a growing necessity for trained and certified emergency workers capable of safely handling hydrogen and responding to hydrogen-related incidents in the near future.

6.1.2 SKILLING AND TRAINING CAPACITIES

Training programs available in the country have been categorized as accredited program, non-accredited program, and higher education through universities. Accredited and non-accredited training programs focus on reskilling to enhance the capacity of the existing workforce to fulfill current job demands. Higher education programs are specifically focused on fostering the future development of the sector through innovation and expertise. The offered industry training programs have been listed in Table 6.2

Table 6.2 Industry Training Programs Offered

Organization/ Trainer	Name of Course	Description	Career Stage	Target Audience
Accredited training programs				
Training Systems Australia	Fuel cell technology, Hydrogen ready to-go kit	Training concepts includes understanding of fuel cell technologies	Entry-Mid level	Students of TAFEs, Universities, Schools, and Polytechnics
EDQUIP Timo Wohlin-Elkovsky	Hydrogen Fuel Cell Education and Training	Hydrogen fuel cell systems and equipment training	Entry-Mid level	Students of TAFEs, Universities, Schools, and Polytechnics
Technical and Further Education, South Australia (TAFE SA)	Hydrogen Fundamentals	The course has been designed to provide individuals with an understanding of the opportunities and challenges in working with hydrogen, its safety aspects and job opportunities in this growing sector. Self-paced course (approximately 10 hours)	Entry-Mid level	Anyone interested in exploring opportunities diversifying their business or career in hydrogen sector
Non-Accredited training programs				
Informa, Dr Hugh Outhren	Hydrogen Industry Fundamentals	Modules outline current production and uses of hydrogen in the process industries, technology, and costs of alternative approaches to the	Mid-Senior level	Managers; executives and staff from the electricity, gas, renewable energy, and storage industries; regulatory bodies and government; banks; brokers;

Organization/ Trainer	Name of Course	Description	Career Stage	Target Audience
		production of hydrogen.		lawyers; consultants; industry advisors; major energy users and other industry professionals seeking more knowledge about the current electricity industry and future trends.
Petroleum Gas Inspectorate (Resources Safety & Health Queensland)	Hydrogen Safety Mobility Webinar	Webinar on hydrogen safety and health for the workers at the operational level.	Mid-Senior level	Gas industry workers seeking information on licensing and legislative requirements when working with hydrogen.
Hydrogen Advantage	Hydrogen Fundamentals	An online course that delivers a detailed overview of hydrogen and its use as an energy carrier. The course would help in developing an understanding of the opportunities and challenges in the hydrogen industry, properties, and safety aspects of hydrogen.	Mid-Senior level	Managers and executives responsible for strategic decisions about hydrogen technologies; engineers responsible for designing hydrogen systems; technicians and tradespeople responsible for building hydrogen systems and interested first responder trainers.
Australian Renewables Academy	Training for the New Hydrogen Economy (under development)	The course structure would enable the environment to facilitate skills focus for the new hydrogen economy that is rapidly emerging in Australia	Entry level	General audience

At present, only 3 accredited programs being offered. Training concepts include understanding of fuel cell technologies, equipment training and understanding of the challenges involved in transitioning to hydrogen, its safety aspects and job opportunities in this growing sector. The remaining training options offered through non-accredited training programs consist of online short-term courses that provide foundational knowledge about hydrogen and are accessible to industry professionals. These training programs cater to diverse audience segments, as delineated below.

- **Students** – Training concepts include understanding of fuel cell technologies and equipment training.

- **Professionals from gas Industry** – Online courses include hydrogen safety and health concerns for the workers at the operational level, current production methods and quantities, uses of hydrogen in the process industries, technology, and costs of alternative approaches to the production of hydrogen.

- **Professionals from Electricity, Renewable energy, and Storage sector** – Online courses include detailed overview of hydrogen, current production, uses of hydrogen in the process industries, technology specific to hydrogen sector, and costs of alternative approaches to the production of hydrogen.

- **General audience** – The courses include an understanding of the opportunities and challenges associated with hydrogen as an energy source, its safety aspects and job opportunities in the sector.

Moreover, Australian universities presently provide courses related to sustainable energy, which incorporate essential knowledge about hydrogen. Additionally, three universities intend to introduce specialized programs focusing on hydrogen. Swinburne University of Technology is preparing to launch a 60-hour short-term course centered on hydrogen-based energy technologies. The University of Technology, Sydney is initiating a Hydrogen Energy Program, and the University of Queensland is set to introduce a 1.5-year Master of Sustainable Energy program. This program covers energy generation, distribution, supply, and the complexities of transitioning to sustainable energy solutions. Table 6.3 provides a listing of the available higher education courses.

Table 6.3: Higher Education Courses and their respective Universities

University/ Education Institution	Name of Course	Description	Target Group
Australian National University	Master of Energy Change (The Hydrogen Economy)	This 1-year program will provide foundation for specializations related to energy change.	Bachelor's degree or Graduate Certificate
University of Melbourne	Master of Energy Systems	This 18-month full-time course will help develop the unique set of skills required to analyze energy systems from a technical, commercial and policy standpoint.	Domestic and international students with an undergraduate degree in Engineering, Science, Business, Finance or Economics

University/ Education Institution	Name of Course	Description	Target Group
Royal Melbourne Institute of Technology	Master of Engineering (Sustainable Energy)	2-year full-time program providing an understanding of why managing the transition towards a more sustainable energy sector is a priority for governments, the private sector, and the general community with a final-year research project to apply the advanced engineering skills that the candidate has built.	Domestic and international students with an undergraduate degree in Engineering, Science, Information Technology, Physics and/or Chemistry
Swinburne University of Technology	Renewable Energy and Hydrogen Technologies Course (short course)	The aim of this elective course is to familiarize students with the fundamental principles and real-world applications of a wide range of renewable and hydrogen-based energy technologies. 60 hybrid contact hours	Undergraduates
University of Technology Sydney, Centre for Green Technology	Hydrogen Energy Program	The program aims to support the enormous potential for Australia to harness hydrogen as a competitive, low carbon energy alternative.	Workers
The University of Queensland	Master of Sustainable Energy, Master of Sustainable Energy	This 1.5-year program will enable students to learn about the complex nature of energy generation, distribution and supply, and the challenges in transitioning to a sustainable energy future	Domestic and international students with an undergraduate degree.

Research indicates that there is a shortage of courses catering to postgraduate students along the hydrogen value chain, and there are limited or no courses available for undergraduate students. The comprehensive courses encompassing various aspects of the hydrogen value chain have yet to be introduced by educational institutions and universities. A study conducted by Swinburne University of

Technology identified the following subjects as the most pertinent and critical areas for the development of micro-credentials:

Hydrogen fundamentals	Hydrogen safety	Emergency response
Understanding regulations	Electrolysis and compressors	Fuel cells
Hydrogen batteries & installation	Hydrogen vehicle drivers	FCEV service, maintenance and repair

Figure 6.6: Vital Areas for Micro – Credentials

In March 2023, a paper titled "Skilling the green hydrogen economy in Australia," was published by Swinburne University of Technology[42]. This study was based on a survey and a consultative approach, which helped identify significant deficiencies in the existing education and training programs. The findings indicate that individuals within the industry believe the current training opportunities and available expertise are inadequate to support the hydrogen sector in its present stage of expansion. This limitation extends to the reskilling of the workforce needed to fully harness the potential of the green hydrogen economy. The study also revealed that the shift towards green hydrogen would primarily affect specific job categories, including gas fitters, plumbers, drivers, and mechanics. In a broad sense, the key training gaps were related to technical knowledge, transport infrastructure, and safety issues. On the other hand, the major education and training topics included electrolysers, fuel cells, and hydrogen storage and refueling stations.

6.2 UNITED STATES OF AMERICA

The United States (US) has made a commitment to achieve net-zero emissions by 2050, with green hydrogen as a critical fuel source. In 2021, the Department of Energy (DOE) unveiled its Hydrogen Shot Initiative, which aimed to reduce the cost of clean hydrogen to $1[43] per kilogram within the next decade. In alignment with this objective, low carbon hydrogen has been integrated into two major clean energy bills: the Inflation Reduction Act (IRA) and the Infrastructure Investment and Jobs Act (IIJA). The IRA focuses on investments in domestic energy production and manufacturing, with a goal

[42] Skilling the green hydrogen economy: A case study from Australia (sciencedirectassets.com)
[43] https://www.energy.gov/eere/fuelcells/hydrogen-shot#:~:text=The%20first%20Energy%20Earthshot%2C%20launched,%221%201%201%22).

of cutting carbon emissions by approximately 40%[44] by 2030. The IIJA mandates the DOE to establish a comprehensive clean hydrogen strategy and a national roadmap, in addition to allocating $8 billion to fund a clean hydrogen hubs program.

In June 2023, through the National Clean Hydrogen strategy and roadmap, the US announced its intention to offer tax credits to reduce the cost of clean hydrogen, with the aim of achieving a price of $2[45] per kilogram for hydrogen produced via electrolysis by 2026. Furthermore, the strategy aims to produce 10 million metric tons of green hydrogen annually by 2030 and 50 million metric tons by 2050. In October 2023, $7[46] billion in funding from the Bipartisan Infrastructure Law (BIL) was earmarked for the establishment of seven regional clean hydrogen hubs. These selected hubs can potentially attract over $40 billion in private investment and create nearly 10,000 well-paying jobs. Collectively, these hubs aspire to produce more than 3 million metric tons of clean hydrogen each year, contributing significantly to the 2030 US clean hydrogen production goal[47]. Additionally, two of these hydrogen hubs have allocated resources for enhancing the workforce. For instance, the Mid-Atlantic hub has earmarked approximately $14 million[48] to bolster regional Workforce Development Boards and collaborate with community colleges to provide training and pre-apprenticeship programs. Meanwhile, the Pacific Northwest H2 Hub intends to make investments in joint apprenticeship initiatives.

Currently, operational projects produce 0.12[49] million metric tons of green hydrogen per year in the country. Additionally, there are 11 green hydrogen projects in various stages of development, with a total capacity of approximately 2.2 million metric tons per year. These projects are primarily focused on various end uses, including industrial applications, electricity generation, mobility, and ammonia production as represented in Figure 6.7. The US has a significant number of projects in their developmental stage, with approximately 95% of them primarily focused on industrial, electricity & mobility.

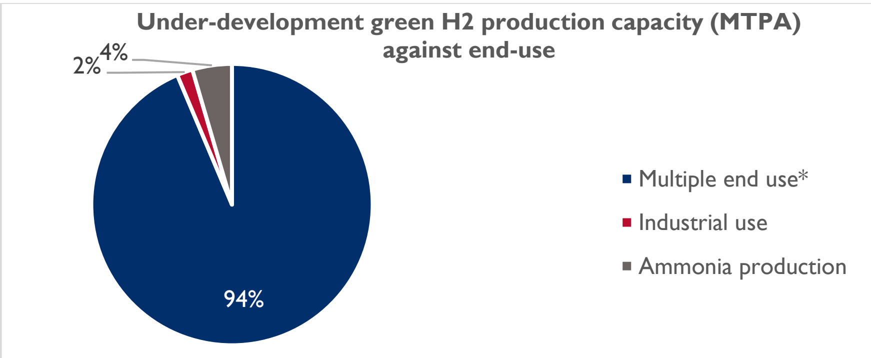

Figure 6.7 Under-development Clean H2 Production Capacity (MTPA) against End-Use[50]

[44] https://rhg.com/research/climate-clean-energy-inflation-reduction-act/
[45] https://www.hydrogeninsight.com/policy/us-unveils-national-clean-hydrogen-strategy-and-roadmap-based-around-three-key-priorities/2-1-1462445
[46] https://www.whitehouse.gov/briefing-room/statements-releases/2023/10/13/biden-harris-administration-announces-regional-clean-hydrogen-hubs-to-drive-clean-manufacturing-and-jobs/
[47] https://www.whitehouse.gov/briefing-room/statements-releases/2023/10/13/biden-harris-administration-announces-regional-clean-hydrogen-hubs-to-drive-clean-manufacturing-and-jobs/
[48] https://www.energy.gov/articles/biden-harris-administration-announces-7-billion-americas-first-clean-hydrogen-hubs-driving
49 https://www.iea.org/reports/hydrogen-projects-database
50 Multiple newsrooms

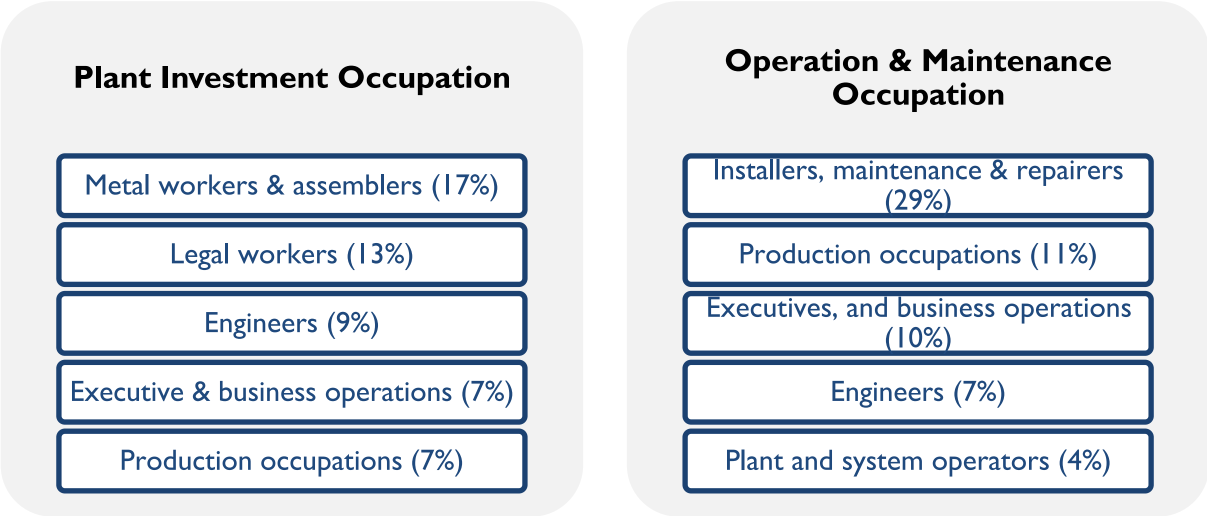

Figure 6.8 Plant Investment and Operation and Maintenance Job Roles

According to the analysis, a 100 MW electrolytic hydrogen facility is expected to generate jobs in various categories. It is projected that this facility will result in the creation of 150 jobs related to plant investment, 190 jobs within the supply chain, and 45 jobs in operation and maintenance.

Within the plant investment category, most jobs (approximately 17%) are for metal workers and assemblers, which predominantly include skilled professionals like welders and machinists. Following closely are legal workers, constituting 13% of the demand. Electrical, industrial, and mechanical engineers essential for constructing an electrolyser facility account for 9% of the jobs.

In the operation and maintenance sector, the largest fraction of the jobs (about 29%) are for installers, maintenance personnel, and repairers, who primarily engage in tasks related to maintaining and fixing the essential electrical systems and machinery. This is followed by production related occupations, including inspectors, testers, processing technicians, and chemical equipment operators and tenders who make up 11% of the workforce in this sector.

The study also aimed to understand the potential job opportunities associated with carbon capture retrofit of a conventional hydrogen production facility. This analysis was based on a facility with 500 kt annual CO2 capture capacity, considering a four-year construction period. The identified job types were categorized into two groups: plant investment jobs associated with construction and engineering of a retrofit project, and supply chain, operations & maintenance jobs, as depicted in Figure 6.9. The provided estimates do not include the employment positions that were preserved at the hydrogen production facility from before the introduction of carbon capture technology.

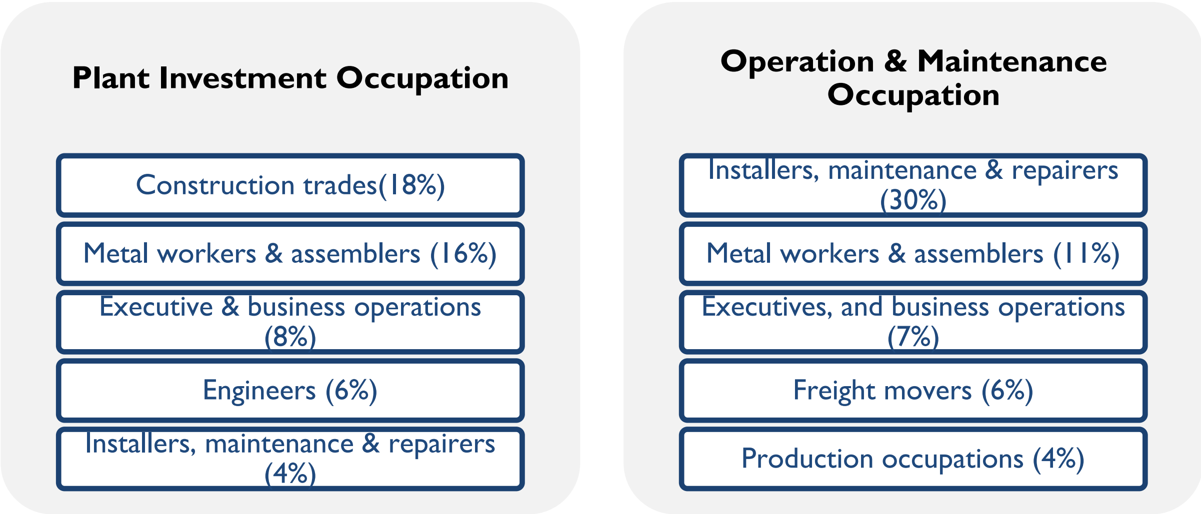

Figure 6.9 Plant Investment and Operation and Maintenance Job Roles

According to the analysis, 500 kt annual CO2 capture capacity might create 520 jobs per year; 300 across construction and engineering, 300 across materials and equipment used in the project via the supply chain and 80 to operate and maintain the carbon capture equipment.

In the plant investment category, the predominant employee requirements (roughly 18%) pertain to construction trades, encompassing a diverse range of occupations including construction laborers, managers, carpenters, electricians, plumbers, and pipe-layers. Metal workers and assemblers, constitute 16% of the demand, which predominantly consists of professionals skilled in welding, soldering, and assembly of electrical equipment. Additionally, engineers, particularly mechanical, civil, and industrial engineers, who occupy most of the engineering roles necessary for retrofitting conventional hydrogen production with carbon capture account for about 6% of the requirement.

In the operation and maintenance domain, installers, maintenance personnel, and repairers account for about 30% of the jobs, while metal workers and assemblers account for approximately 11%.

6.2.1 CURRENT SKILLS IN DEMAND

To gain insights into the current employment opportunities within the green hydrogen sector, an analysis of job listings related to hydrogen were conducted on popular job search platforms like Glassdoor and LinkedIn in September 2023. By using the keyword "Green hydrogen," the most in-demand job positions were identified in the fields of engineering, manufacturing, and project management as illustrated in Figure 6.10.

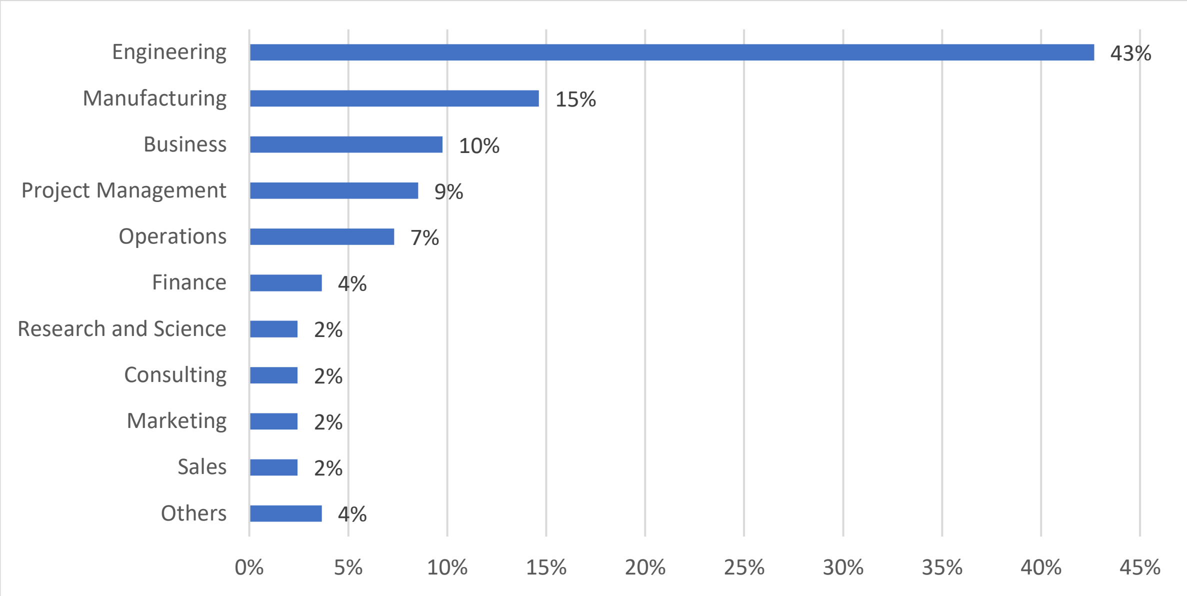

Figure 6.10 Hydrogen Job Openings in the US, (September 2023)

In September 2023, the job listings on Glassdoor were predominantly engineering positions, with approximately 70-80 job openings available for assessment. This trend can be attributed to the extensive hydrogen projects currently underway in the United States, leading to a growing demand for engineers who possess the necessary skills, expertise, and experience.

Engineering jobs typically require a minimum of 2+ years of experience and a bachelor's or master's degree in chemical, process, or mechanical engineering. Key job roles in this category included positions such as development engineering, hydrogen modeling & feasibility engineering, quality assurance specialist, mechanical engineering, process & design engineering, data engineering, fuel cell engineering, control systems engineering, civil & electrical engineering.

Following engineering, the next most sought-after positions were observed in the manufacturing sector, which typically required a minimum of 3 years of experience and a B.S. in engineering. The key job roles in manufacturing included chemical production technician, lead control room operator, electrode & wet coatings technician, safety engineer, service technician, electromechanical assembler, welder, fabricator, transmission assembly specialist, senior electrician, construction manager, electrical, instrumentation & control technician. The job qualifications needed for each of these highly sought-after positions are detailed in Table 6.4.

Table 6.4 Job Qualifications for Different Job Roles across Hydrogen Value Chain

Job Function	Minimum Qualification	Experience	Job roles
 **Engineering**	BS or MS in chemical, process, or mechanical engineering	2+ years in process design engineering 15+ years of experience working as a Process Engineer within the Energy & Chemical Industries	Development engineering, hydrogen modelling & feasibility engineering, quality assurance specialist, mechanical engineering, process & design engineering,

Job Function	Minimum Qualification	Experience	Job roles
			data engineering, Fuel cell engineering, control system, civil & electrical engineering
Manufacturing	B.S. in engineering	3 years' related experience	Chemical production technician, lead control room operator, electrode & Wet coatings technician, safety engineer, service technician, electromechanical assembler, welder, fabricator, transmission ass., Sr. electrician, construction manager, Electrical, Instrumentation & control technician
Business	Bachelor's degree: a scientific focus such as Biology, Chemistry, engineering, or related field required	5+ years' experience in Business Development or Sales management	Project Development Analyst, Hydrogen Business Development, Site Manager, Procurement Specialist
Project Management	Bachelor's degree in engineering, Business, or a related field	7+ years of relevant experience in Product Management/Application Engineering/Product Development Engineering/Finance/Marketing in an innovative, technical environment	Installation Project Manager, Project Manager, Manager – Project Estimation

An analysis of current job openings reveals that most available positions are geared towards higher-skilled workers, particularly in three specific job categories: engineering, manufacturing, and business. Most of the demand for skills is observed in the category of process engineers, typically requiring a bachelor's or master's degree in chemical, process, or mechanical engineering. This suggests the lack of sufficient number of engineers to meet the demands of these open positions. Consequently, the country needs to educate and train not only more specialists, but also engineers from various fields.

6.2.2 SKILLING AND TRAINING CAPACITIES

Presently the United States, is pursuing several avenues for training and skill development in the renewable energy sector. Non-accredited training programs help meet the demand of existing private sector participants by catering to current job demands. Higher education programs are specifically focused on enhancing skills and creating specialists and experts for the future growth of this sector. The available programs are detailed in the Table 6.5.

Table 6.5 Non-accredited training Programs Offered in the US

Organization/ Trainer	Name of Training Course(s)	Description	Career Stage	Target Audience
WHA International Inc.	Technical Training for Hydrogen and Oxygen Safety	Multi-day hybrid training series on hydrogen and oxygen safety categorized into different levels.	Entry-mid level	Technical, non-technical personnel
Your Safety Department	H2S (hydrogen sulfide) Certification	The module's goal is to instruct participants on topics like the physical and chemical attributes, toxicity, concentration thresholds, the use of personal protective equipment, detection methods, rescue procedures, and first aid.	Entry level	Personnel working on equipment exposed to H2S environment
College of the Desert and SunLine Transit Agency (funded by U.S. Federal Transit Administration)	Hydrogen Fuel Cell Engines and Related Technologies Course Manual	The online manual features technical information on the use of hydrogen as a transportation fuel.	Entry level	Not specified
US Department of Energy	Introduction to Hydrogen for Code Officials	This online training course provides an overview of hydrogen and fuel cell technologies.	Mid-senior level	Not specified

Current training programs predominantly emphasize fuel cell technologies and hydrogen safety. However, there is a dearth of accredited institutes or university-level courses in this field. This underscores the urgent necessity for the development of a curriculum to meet the increasing demand for hydrogen-related education in the country.

In the United States, universities are increasingly introducing undergraduate and postgraduate degree programs in fields related to hydrogen, including production, delivery, infrastructure, storage, fuel cells, and various applications in transportation, industry, and stationary power. Currently, there are five courses on hydrogen available at universities. These higher education courses are designed for industry professionals, undergraduate students, and graduate students. A comprehensive list of available higher education courses is provided in Table 6.6.

Table 6.6 Hydrogen Courses offered in the US

University/Education Institution	Name of Course	Description	Target Group
University of Houston	Hydrogen Economy Program	3-week long program that provides key insights into the evolving global energy system, sustainable energy development.	Industry professionals
Stanford University	Stanford Energy Hydrogen Initiative	This collaborative effort involving engineering, science, policy, and business researchers from Stanford University, aims to facilitate the utilization of hydrogen to significantly reduce global carbon emissions.	Students from Stanford University including Stanford's Graduate School of Business, School of Engineering, and School of Humanities and Sciences
Center for Hydrogen Safety	Hydrogen Safety Education	Delivering short courses on hydrogen systems, maintenance, operations, lab safety to help the industry build the safety skills needed to meet the demands of the growing hydrogen marketplace.	Undergraduates
University of South California	Hydrogen and Fuel Cell Center	Training and research in the areas of hydrogen production, storage,	Graduate students
Southwest Research Institute	Hydrogen Energy Research	Researching areas of using hydrogen as a combustion medium, infrastructure solutions for the hydrogen fuel cell supply chain and on-board storage solutions.	Not specified

The research indicates a shortage of courses addressing the hydrogen value chain for postgraduate students, and the availability of such courses for undergraduate students is almost non-existent. Comprehensive courses covering various aspects of the hydrogen value chain, have yet to be introduced by educational institutions and universities.

6.3 GERMANY

Unlike other countries, Germany has ambitious plans to establish itself as a leading provider of hydrogen technologies, including electrolysers and fuel cells, by the year 2030. Germany has limited its focus on domestic hydrogen production. Anticipating a hydrogen demand of 95 to 130 terawatt-hours (TWh) in 2030, the country is likely to import 50% to 70% of its hydrogen requirements.

To meet the hydrogen development goals outlined in its strategy, Germany has committed €18.6 billion.[51] (equivalent to approximately $20.5 billion) from the Climate and Transformation Fund, covering the period from 2024 to 2027. While €3.8 billion is allocated for the fiscal year 2024-25, it's important to note that no specific investment has been earmarked for the creation or upskilling of the workforce.

Germany is partnering with industries, by providing financial support for the establishment of fundamental infrastructure, supply chains, and projects to develop advanced technologies in the hydrogen sector. This approach will not only form the bedrock of the green hydrogen sector but also foster the confidence and technical skills necessary to achieve scalability. Some notable initiatives include, the joint declaration Task Force with South Africa, established in June 2023 within the framework of the South African-German Energy Partnership, to foster knowledge and information sharing concerning the establishment and expansion of a green hydrogen economy in South Africa and Germany.

Furthermore, in 2021, the ROSEN group.[52] inaugurated its first hydrogen test laboratory in Lingen, Germany, primarily researching the re-purposing of gas infrastructure for hydrogen utilization. Additionally, Germany has initiated a specialized graduate program dedicated to hydrogen, known as 'Trustworthy Hydrogen' (Science Business, 2022).

6.3.1 CURRENT SKILLS IN DEMAND

To gain insight into the present job market within the green hydrogen sector, an analysis of job listings related to hydrogen were conducted on popular job search websites like Glassdoor and LinkedIn during September 2023. By using the keyword "Green hydrogen," the most in-demand job opportunities were identified in the fields of engineering, finance and business as depicted in Figure 6.11.

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[51] https://www.hydrogeninsight.com/policy/german-government-to-spend-18-6bn-on-hydrogen-from-its-climate-and-transformation-fund-in-2024-27/2-1-1499546
[52] https://hydrogen-central.com/rosen-group-hydrogen-test-lab-lingen-germany-repurposing-gas-infrastructure/#:~:text=The%20ROSEN%20Group%20has%20opened,soccer%20fields%20after%20the%20expansion.

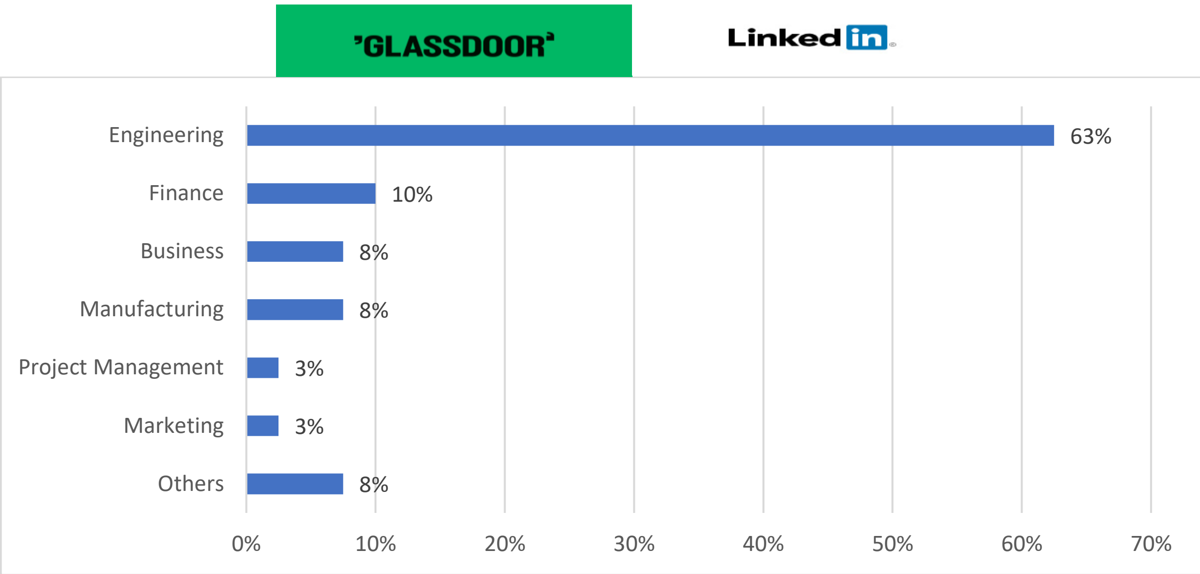

Figure 6.11 Hydrogen Job Openings in Germany, (September 2023)

In September 2023, there was a notable surge in job listings, with approximately 30-40 openings primarily focusing on engineering positions. This increase in demand for expert and experienced engineers can be directly linked to the considerable number of ongoing hydrogen projects in Germany. The engineering job vacancies required candidates to have at least 5 years of relevant experience and a university degree in mechanical engineering, production engineering, chemical engineering, or an equivalent field. Key positions included hydrogen project engineer, instrumentation, process engineer, biofuel & green gases specialist, electrical engineer, quality manager, and civil & structural engineer. The specific qualifications and experience needed for each role are provided in the accompanying Table 6.7.

Table 6.7 Hydrogen Job Openings Qualification Requirements

Job Function	Minimum Qualification	Experience	Job roles
Engineering	University degree in mechanical engineering, production engineering, chemical engineering or equivalent	Experience (> 5 years) working within an electrical and control engineering role.	Hydrogen Project Engineer, Instrumentation, process engineer, Biofuel & green gases, electrical engineer, quality manager, civil & structural engineer
Finance	Degree in business administration, industrial engineering, business informatics or a comparable field like Certified Internal Auditor (CIA)	3+ years of corporate finance experience within a reputable bank or advisory boutique	Commercial Asset Manager, Project Risk, and Internal Control Expert
Business	University degree in engineering, sustainability/ environmental sciences or in business	Plant Manager: At least 10 years work experience in production and management of a factory Expert Engineer: Minimum 3 years of experience within Mechanical design within the Hydrogen production industries or equivalent	Project Development Manager, Business Development Manager
Manufacturing	Master's degree – preferably in one of the engineering disciplines or the business side of Information technology	Expert: 10 years of experience in the application, customization, integration, and testing of digital tools	Plant Manager – Cell Fabrication, Green Gases Process Safety Engineer

The analysis of current job openings reveals that most available positions are for higher-skilled workers, particularly in engineering, typically requiring a bachelor's degree in mechanical engineering, production engineering, chemical engineering, or equivalent, to work in electrical and control engineering. This suggests a shortage of engineers to fill open positions. Consequently, it becomes necessary for the country to train, not only specialists, but also engineers various fields. Furthermore, the research indicates a currently low demand for professionals in fields such as gas workers, electricians, technicians, plumbers, and emergency workers. This suggests that either these skills are readily available in the workforce, or there's a potential for increased demand in the future. Many of these professionals may not need to acquire entirely new skills but can instead build upon their existing expertise. However, it's worth noting that there will be a growing necessity for emergency workers to receive qualifications and training to safely handle hydrogen and respond to hydrogen-related incidents in the near future.

6.3.2 SKILLING AND TRAINING CAPACITIES

Currently, in the Germany the skilling demand in the renewable energy sector is fulfilled through courses offered by reputed institutes. The offered courses are listed in Table 6.8.

Table 6.8 Hydrogen Courses offered in Germany

University/Education Institution	Name of Course	Description	Target Group
Southwest University Federation[53] ('Hochschulföderation SüdWest, HfSW)	Masters in Hydrogen and Fuel-Cell Technology	The course is closely related to electromobility and will prepare students to develop alternative energy concepts in mobile applications.	Postgraduates
German Jordanian University[54]	Series of Training on Green Hydrogen Technology	The objective is to provide essential courses covering various aspects of green hydrogen technology.	Academic staff at Jordanian universities and researchers
Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU)	Clean Energy Processes	The course will center its attention on the sustainable generation, distribution, and utilization of renewable energy within the chemical industry, with a specific focus on alterations in chemical processes.	Bachelor's/master's degree
Ingolstadt University of Applied Sciences	Hydrogen Technology and Economics (Master of Engineering)	Three semester postgraduate course focusing on hydrogen as an energy carrier, developing new products and solutions and	Postgraduates

[53] https://www.deutschland.de/en/topic/knowledge/first-courses-of-study-on-hydrogen-technologies
[54] https://www.gju.edu.jo/news/german-jordanian-university-launched-training-courses-green-hydrogen-technology-16802

University/Education Institution	Name of Course	Description	Target Group
		evaluating them in terms of economic efficiency.	
Würzburg-Schweinfurt University of Technology	Bachelor Hydrogen Technology	These 7 semesters (including internship semester) train engineers who can systematically design, construct, and operate hydrogen plants and systems along the hydrogen value chain.	Undergraduates
Dresden University of Technology	Modules on Hydrogen as an Energy Carrier	The production and application of hydrogen as well as safety issues relating to hydrogen technologies are a focus of the module.	Students of the diploma course in energy technology
Institute for Regenerative Energy Systems (IHRES), Stralsund University of Applied Sciences	Bachelor's Degree in Renewable Energies	Teaching which technologies (including hydrogen) are available and how they can be integrated into energy supply networks.	Undergraduate students
Rosenheim Technical University of Applied Sciences	Master's Degree in Hydrogen Technology	The course is based on the technologies necessary for developing a future hydrogen economy, covered over a duration of 3 semesters.	Postgraduates

Of the eight current courses, most of them are geared towards postgraduate students, but a few are suitable for undergraduate levels. However, comprehensive courses covering a wide range of topics across the hydrogen value chain have yet to be introduced by educational institutions and universities.

6.4 JAPAN

Japan, the 1st to adopt a "Basic Hydrogen Strategy" in 2017 aims to become carbon neutral by 2050. The country's Green Growth Strategy and Roadmap for Fuel Ammonia set targets of 3 million tons of hydrogen and ammonia consumption by 2030 and 20 million tons of hydrogen and 30 million tons of ammonia consumption by 2050.[55]. To achieve these targets, the Japanese Government is providing $2.5 billion in grants to hydrogen projects, ~$11 billion in tax incentives and is establishing a ~$6 billion scheme to subsidize finance interest.

The country's focus lies in increasing its hydrogen market, through importing blue and green hydrogen & it's derivatives from stable, low-cost producers around the world, transporting it back to Japan using hydrocarbons, ammonia, or methane as energy carriers. As an example, Chiyoda is engaged in the exploration of the practicality of utilizing methylcyclohexane (MCH) as a hydrogen carrier for transporting hydrogen from Brunei to refineries in Japan. This initiative falls under the umbrella of the Advanced Hydrogen Energy Chain Association for Technology Development. Meanwhile, the Japanese petroleum company ENEOS, in collaboration with Malaysia's Petronas, is aiming to reach a final investment decision in 2023 for the inaugural large-scale renewable hydrogen-to-MCH project. This project is intended to provide hydrogen to ENEOS' refineries.[56].

Additionally, Japan and Saudi Arabia announced a new joint effort, the "Manar" initiative, featuring a range of projects to enable the transition to clean energy, focusing on areas such as hydrogen and ammonia technologies.[57]. The Japanese government has been supporting a pilot project focused on the electrolysis-based production of hydrogen with the objective of eventually commercializing green hydrogen. In addition, demonstration tests of hydrogen power generation are being conducted to realize commercialization by 2030. However, the country remains silent on the skill gap assessment within the industry and the required skillset development going forward.

6.4.1 CURRENT SKILLS IN DEMAND

To gain insights into the prevailing employment opportunities within the field of green hydrogen, an analysis of job listings related to hydrogen were conducted on job search websites like Energyjobline and LinkedIn in September 2023. By utilizing the keyword "Green hydrogen," the most frequently advertised job openings identified were related to research and science, sales, project management, and operations, as outlined in the accompanying Figure 6.12.

[55] https://www.csis.org/analysis/japans-hydrogen-industrial-strategy#:~:text=Japan%20is%20focused%20on%20expanding,the%20current%20level%20by%202030.
[56] https://www.energypolicy.columbia.edu/japans-investments-in-hydrogen-and-its-derivatives-in-southeast-asia/
[57] https://www.mei.edu/publications/japan-looks-gulf-it-bets-big-hydrogen

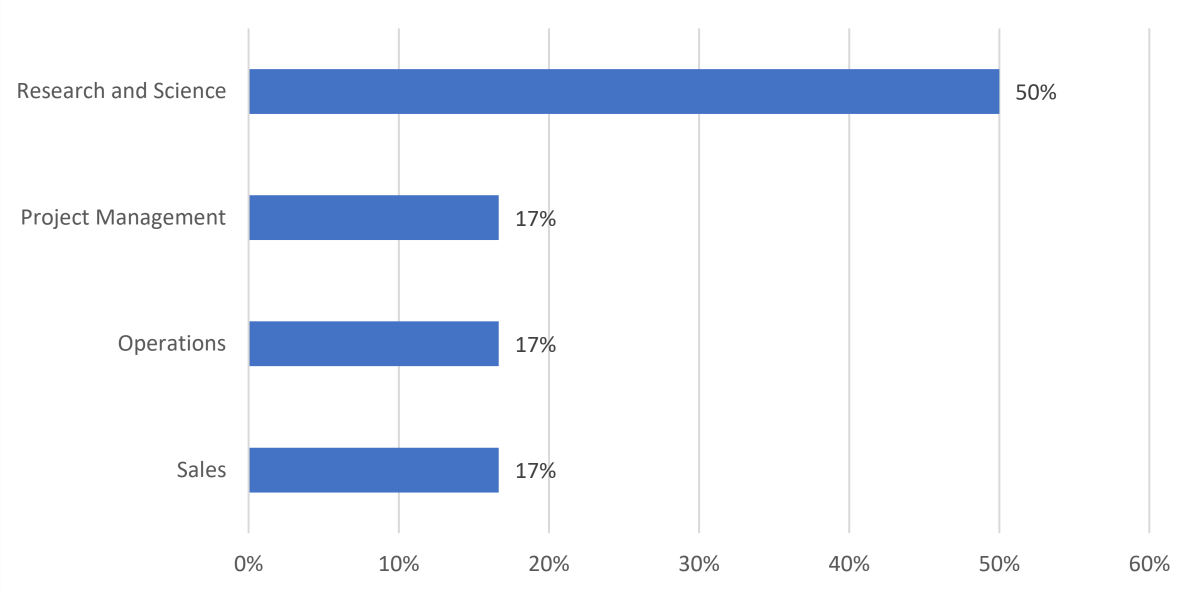

Figure 6.12 Hydrogen Job Openings in Japan, (September 2023)

A total of six job positions were identified, exclusively posted by a single company, De Nora, based in Japan. Notably, in September 2023, nearly 50% of the job vacancies were in research and science-related roles. This heightened demand can be attributed to the Japanese government's initiatives aimed at building a worldwide hydrogen supply network, involving the strengthening of partnerships with nations rich in renewable energy resources. The second most in-demand job categories included project management, requiring a minimum of 10 years of relevant work experience, and operations, which does not specify minimum experience requirements. A detailed list of job functions, along with their required experience and qualifications, is provided in Table 6-11.

Table 6.9 Hydrogen Job Openings Qualification Requirements

Job Function	Minimum Qualification	Experience	Job roles
Research & Science	Not specified	Not specified	Researcher
Project Management	University degree or higher, technical college degree also acceptable	At least 10 years of relevant work experience	Project Controller
Operations	Bachelor's degree in engineering	No minimum experience required	Facilities Design Specialist
Sales	Major in chemistry, chemical engineering, machinery, or mechanical engineering	7 years or more in B-to-B sales, business developing, consulting, or similar experience.	Sales Specialist

An analysis of current job openings reveals that most available positions are directed towards higher-skilled workers, particularly in four distinct job categories: Research & Science, Project Management, Operations, and Sales. Among these, the roles of Research & Science, and Project Management require prior experience within the relevant sector. The predominant demand for skills is notably concentrated in the field of Research & Science.

This demand is underscored by the Japanese government's efforts to establish a global hydrogen supply chain, which includes bolstering relationships with countries rich in renewable resources, such as oil and gas producers in the Middle East. Several collaborations[58] since 2020 illustrate this strategy:

- Japan's largest refiner, ENEOS Corporation, signed a Memorandum of Understanding (MoU) with Aramco to explore the development of a CO2-free hydrogen and ammonia supply chain.
- JERA Co., Inc., the largest power generation company in Japan, entered a MoU with Saudi Arabia's Public Investment Fund (PIF) to collaboratively undertake the development of green hydrogen projects and related products.
- Marubeni Corporation of Japan has entered into an agreement with PIF to initiate a feasibility study aimed at generating clean hydrogen for use in both domestic and global markets.

Furthermore, Japan and the UAE have recently entered into an agreement to strengthen industrial cooperation and pursue new opportunities in the fields of hydrogen and renewables.

6.4.2 SKILLING AND TRAINING CAPACITIES

Currently, in Japan the training and skilling demand of the renewable energy sector is fulfilled through courses offered by reputed institutes/ Universities. The offered programs have been listed in Table 6.10.

Table 6.10 Hydrogen Courses offered in Japan

University/Education Institution	Name of Course/Degree	Description	Target Group
Kyushu University	Hydrogen Energy Systems	The course is designed to assist students in comprehending and creating machines and equipment for hydrogen energy within a systems framework by means of education and cutting-edge research within the interdisciplinary energy domain.	Graduates and Postgraduates

[58] Japan looks to the Gulf as it bets big on hydrogen | Middle East Institute (mei.edu)

University/Education Institution	Name of Course/Degree	Description	Target Group
Fukuoka Education Center	Personnel Training Center for Hydrogen Energy	The center provides industrial engineers multi-day courses in hydrogen and fuel cell technologies, through hands-on training, facility tours and lectures.	Managers, Engineers, Ph. D.
Institute for Materials Research, Tohoku University	Materials Science of "HYDRIDES" for Energy Applications	Focus on developing high-density hydrogen storage materials to support hydrogen energy technologies such as fuel cells	-

Currently, 3 courses pertaining to the hydrogen value chain are available for employees and graduate students. The courses covering a vast range of topics across the hydrogen value chain, for undergraduates, graduates and employed groups are yet to be implemented by the institutes/universities.

6.5 SAUDI ARABIA

In 2019, Saudi Arabia, aiming to be a major player in the global hydrogen market, launched its National Hydrogen Strategy. The strategy emphasizes the production of blue hydrogen derived from natural gas with the incorporation of CCS technology, along with green hydrogen sourced from renewable energy resources. The plan aims to produce 1.2 million tons of green hydrogen and to supply 10% of the global demand for hydrogen by 2030.[59] Furthermore, Saudi Arabia PIF has been investing in several energy projects globally, including a joint venture with Power and Air Products to develop a $5 billion green hydrogen-based ammonia production facility in NEOM, Saudi Arabia.

A study conducted by Department of Mechanical Engineering, University of Diyala, Iraq in 2023[60] on energy futures and green hydrogen production, identified a few key challenges for green hydrogen adaptability in the country, such as, the high cost of production, the need to develop a comprehensive regulatory framework and distribution and infrastructure related limitations.

[59] https://www.sciencedirect.com/science/article/pii/S259012302300292X
[60] https://www.sciencedirect.com/science/article/pii/S259012302300292X

6.5.1 CURRENT SKILLS IN DEMAND

To gain insights into the contemporary employment opportunities within the green hydrogen sector, an analysis of job listings related to hydrogen was carried out on job search websites like Glassdoor and LinkedIn during September 2023. By using the keyword "Green hydrogen," it was observed that the most prominently advertised job openings pertained to project management, operations, engineering, legal, emergency response, and internships, as detailed in the accompanying Figure 6.13.

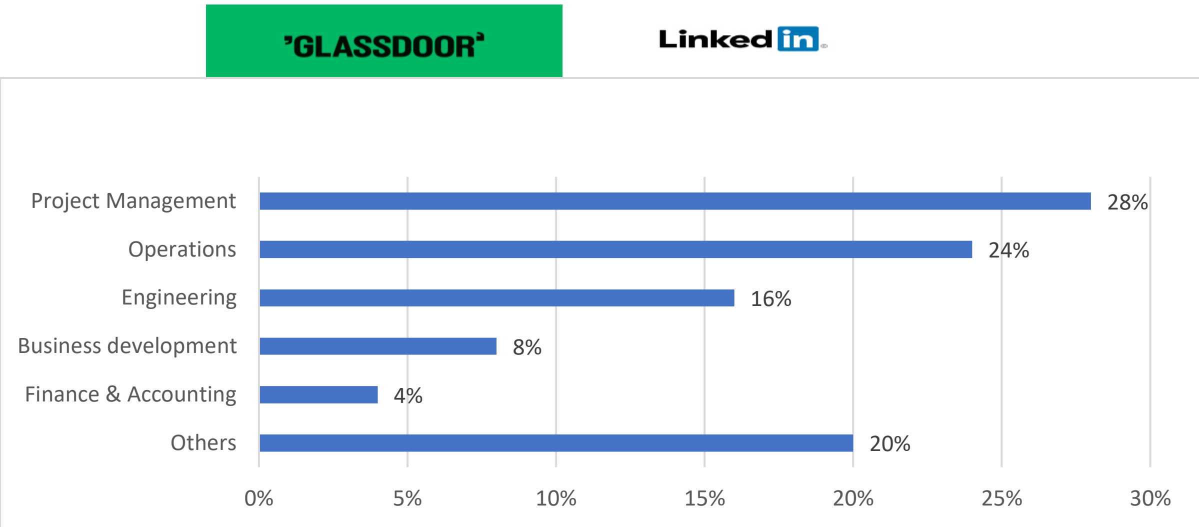

Figure 6.13 Hydrogen Job Openings in Saudi Arabia, (September 2023)

A total of 25 job positions were documented, with most of the available openings pertaining to the Air Products NEOM projects. Project management positions constituted the largest share of job openings on Glassdoor in September 2023. The available positions typically required candidates to possess a minimum of 3 years of experience in project controls or project management, along with a bachelor's degree in environmental engineering, management, chemistry, or a related field. A detailed breakdown of job functions, including the specified experience and qualifications, can be found in Table 7-12.

Table 6.11 Hydrogen Job Openings Qualification Requirements

Job Function	Minimum Qualification	Experience	Job roles
Project Management	Bachelor's degree in environmental engineering or management, chemistry, or related field	3+ years of experience in Project controls or Project Management.	Integration Project Coordinator, Project Reporting Coordinator, Project Director
Operations	Engineering / Science degree	8 years' experience on international mega-projects	Head of Quality, Environmental Lead, Electrical Construction Manager, Facilities Supervisor, EH&S Supervisor
Engineering	A minimum qualification of Degree (or equivalent) in Electrical Engineering	2+ years in relevant field	Project Engineer, Senior Project Engineer, Electrical Engineer, Interface Engineer
Business Development	Bachelor's degree	Professional experience in international project acquisitions	Industrial Cluster Manger, Senior Industrial Cluster Planner

The analysis of current job openings reveals that most available positions are geared towards highly skilled workers, particularly in four specific job categories: Project Management, Operations, Engineering and Business Development. For all these positions, prior experience within the relevant sector is not a prerequisite. Experience may be more generalized to fulfil the job function. Furthermore, the research reveals a low current demand for professionals like gas workers, electricians, technicians, plumbers, and emergency workers. This indicates that either these skill sets are already well-established, or their demand may increase in the future. Many of these professionals may not need to acquire entirely new skills but can instead build upon their existing expertise. However, it's worth noting that there will be a growing necessity for trained and certified emergency workers to safely handle hydrogen and respond to hydrogen-related incidents in the near future.

6.5.2 SKILLING AND TRAINING CAPACITIES

For green hydrogen production, a skilled workforce capable of designing, building, and operating green hydrogen infrastructure needs to be developed via training programs, apprenticeships, and partnerships with technical colleges and universities. Further, there is a need for a center for excellence for green hydrogen that brings together industry experts, academic researchers, and policymakers to share knowledge and best practices.

Currently, in the Saudi Arabia, the skilling demand in the renewable energy sector is fulfilled through courses offered by reputed institutes or universities. The offered programs have been listed in Table 6.12.

Table 6.12 Hydrogen Courses offered in Saudi Arabia

University/Education Institution	Name of Course	Description	Target Group
International Continental Exchange (ICE)	Hydrogen - An Evolving Economy	A 2-day workshop designed to explore the hydrogen economy in greater detail.	No restriction
ACWA Power and vocational institute (Water and Power Technologies)	Renewable Energy and Occupational Safety Program	The program focuses on training women in technical disciplines related to renewable energy and water.	Entry level workers
King Abdullah University of Science and Technology	Clean Combustion Winter School	2-month winter school with a focus on combustion physics, chemistry and diagnostics including a 3-week long research experience.	Bachelor and Master students

Currently, 3 courses are available pertaining to the hydrogen value chain for employees and graduate students. Courses covering a vast range of topics across the hydrogen value chain for undergraduates, graduates and employees are yet to be implemented by the institutes/universities.

6.6 KEY LEARNINGS FOR INDIA

Major international markets like Australia, United States and EU are actively addressing the need for skill development in the hydrogen sector as they transition to cleaner energy sources. Australia, for instance, has allocated $12.9 million over the next three years to establish new jobs and skills programs, aiming to bridge skill gaps and meet the demands of the emerging hydrogen industry.

In the US, the BIL has earmarked $741 billion in funding to create seven regional clean hydrogen hubs, which are expected to generate approximately 10,000 well-paying jobs, providing a significant boost to the hydrogen workforce. Queensland, a state in Australia, has outlined crucial steps for workforce skilling and has established pathways for skill development, ensuring that workers are equipped with the necessary skills to participate in the growing renewable energy and hydrogen industry. Additionally, EU introduced the "European Hydrogen Skills Strategy". in October 2023 that outlined the current and future demand for occupational profiles related to hydrogen.

Some countries are also adopting collaborative approaches to address their skill gap. For example, Germany and South Africa have signed a joint declaration to share knowledge and information to ensure a well-prepared workforce during the transition to clean energy.

To avoid a critical shortage of skilled workers during the energy transition, it is recommended that India consider adopting best practices from other global policy leaders. The practices identified and adopted by the countries under study have been summarized in Table 6.13 as a reference for India to follow. These practices encompass strategies to develop and upskill the workforce to meet the demands of the emerging hydrogen and renewable energy sectors.

Table 6.13: Best practices identified and adopted by the countries

Key Initiatives	Stage	Country	Description
Policy initiatives / funds	Adopted	Australia, Queensland, US	In Australia: • $95.6 million for 10,000 new energy apprenticeships. • $2 billion for free or low-cost priority certifications. • $922 million for 480,000 fee-free TAFE and Technology Fund for facility modernization. • $12.9 million to establish new Jobs and Skills Australia. In Queensland: • Queensland has dedicated $10.6 million to the development of hydrogen and renewable energy training facilities. In the United States: • ~$14 million through Mid-Atlantic to support regional Workforce Development Boards, partnering with community colleges for training and pre-apprenticeships (Oct 2023). • Pacific Northwest H2 Hub is investing in joint apprenticeship programs.
Collaborate with industry and university partners	Adopted	Queensland	• Construction Skills Queensland (CSQ) with CSIRO for local workforce development solutions of hydrogen industry in Queensland • Cape York Institute and HDF Energy Australia plans to offer traineeships in Queensland. • The government-owned corporation CS Energy and the Toowoomba and Surat Basin Enterprise (TSBE) have collaborated to introduce an online portal designed to facilitate participation in emerging opportunities within the hydrogen industry in Queensland. • Fortescue Future Industries (FFI) to establish a Vocational Training and

Key Initiatives	Stage	Country	Description
			Employment Centre (VTEC) program at the Gladstone facility in Queensland.
Hydrogen related course within Institute/ Universities	Implementation	Australia, Germany	• Renewable Energy and Hydrogen Technologies Course by Swinburne University of Technology and Hydrogen Energy Program University of Technology Sydney (UTS), Centre for Green Technology, Australia. • Germany launched a dedicated graduate program for hydrogen, named 'Trustworthy Hydrogen'.
Hydrogen related trainings	Implementation	Australia	• Training initiated for entry-mid level workforces such as fabricators, contractors, technicians, engineers, draftspersons, workers from the electricity, gas, renewable energy and storage industries and other industry professionals. • Training courses consists of topics hydrogen fundamentals, hydrogen for transportation & hydrogen Plants, operations, safety, and fuel cell technology
Identify key job roles required across the hydrogen value chain	Adopted	Queensland, EU	Queensland: • Notified of the nation's first hydrogen workforce development roadmap in 2022. • Skilling pathways identified across 8 different value chains viz Planning & design, Construction & installation, Operation & maintenance, Transport, Export, Manufacturing, Water treatment and Energy. Across the value chain, skilling is planned to be done majorly through Vocational Education and Training **EU:** • Notified "European Hydrogen Skills Strategy" in October 2023. • Future demand for occupational profiles identified across job functions including managers, policy & legal strategy

Key Initiatives	Stage	Country	Description
			specialist, environmental HSE, engineers, technicians, experts & specialists.
Identify micro-credentials	Implementation	Australia	• Identified micro-credentials such as hydrogen fundamentals, safety, understanding regulations, emergency response etc. to be incorporated in training packages to address immediate training needs across industries.

This section emphasizes the key findings about current skills and current and future needs for training and education in the hydrogen sector from the countries in the study, that could help strengthen the skilling ecosystem in India.

1. **Investment in Skill Development:** Both Australia and the US have dedicated significant funds to enhance skill development. Australia has committed $12.9 million over a three-year period to establish new job and skills programs, while the US has allocated ~$14 Mn through Mid-Atlantic to support regional Workforce Development Boards, partnering with community colleges for training and pre-apprenticeships candidates. Pacific Northwest H2 Hub is investing in joint apprenticeship programs, potentially leading to the creation of numerous well-paying jobs. India could similarly consider budget allocation for skill development across various sectors.
2. **Collaborative Approaches:** Nations like Queensland have embraced collaborative approaches by partnering with industry and academic institutions. This collaborative approach is designed to bridge skill gaps and foster knowledge-sharing platforms. India could explore the adoption of similar collaborative strategies.
3. **Training and Courses on Hydrogen:** Australia and Germany have introduced specialized courses and training programs related to hydrogen within educational institutions and universities. These initiatives aim to provide comprehensive education and training on diverse aspects of hydrogen technology. India can leverage the Skills Council for Green Jobs to identify its skill and training requirements in the green hydrogen sector and introduce vocational education in schools, universities, and engineering institutions.
4. **Identification of Key Job Roles:** Queensland & EU have developed a roadmap for their hydrogen workforces, outlining the essential job roles needed across the hydrogen value chain. This roadmap offers a structured approach to skill development, taking into consideration different stages of the value chain. There is a requirement to identify specific job roles compatible with the sectoral development envisioned in the National Hydrogen Energy Mission. The training map and timeline should be organized to match the sequence and intensity of the functions that will be required as the green hydrogen industry is designed, planned, and implemented.
5. **Utilizing Micro-Credentials:** Australia has acknowledged the significance of micro-credentials in addressing immediate training needs across various industries. These micro-credentials encompass areas such as hydrogen fundamentals, safety, regulatory understanding, and emergency response. India could consider incorporating micro-credential subjects into the existing curriculum until a comprehensive study is conducted to identify specific job roles within the hydrogen sector, thus efficiently addressing the sector's short-term and urgent needs.

These key learnings summarize the global awareness of the importance of skill development in the hydrogen sector and highlight the diverse strategies being employed to build a skilled workforce to support the growth of the hydrogen industry.

Summary of key Job roles across the value chain – Global Practice

Table 6.14: Summary of key Job roles

Country/state	Hydrogen value chain	Job roles
Australia	Planning & design	Fuel cell design engineers
	Construction & installation	• Engineers for hydro-testing transmission pipeline • Hydrogen batteries & installation
	Operations & maintenance	• Electrolysis & compressor technology experts • Hydrogen electrolyser maintenance operators • FCEV service, maintenance, and repair technicians • Hydrogen safety • Emergency response
Queensland	Planning & design	• Systems/Integration, Robotics, Automation, Mechanical, Electrical, Chemica engineers • Drafts people • Planners, Regulatory Officers, Project Managers and Consultants
	Construction & installation	• Project Managers • Electrolyser Technicians • Instrumentation & Electrical Technicians, Mechanical Fitters • Pipeline Technicians
	Operations & maintenance	• Specialist Hydrogen Process Operators • Electrical, Gas, Chemical, Quality and Safety Managers • Mechanical fitters, • Electrolyser Technicians, • Instrumentation & Electrical Technicians, including Supervisory Control and Data Acquisition (SCADA), • Pipeline Technicians • Safety Managers
	Manufacturing	• Manufacturing, Robotics, Automation Engineers • Manufacturing Workers

Country/state	Hydrogen value chain	Job roles
	Others	• Pipeline & electrical technicians • Plumbers • Process Operators • Specialists in treatment, testing, and compliance of water quality • Gas Fitters
USA	Construction & installation	• Electrical, civil, industrial, and mechanical engineers • Inspectors, testers, processing technicians, and chemical equipment operators • Machinists • Construction laborers and managers, carpenters, electricians, plumbers, and pipelayers • Welders, solderers and electrical equipment assembler
	Operation & maintenance	• Installers, maintenance, and repairers • Plant system operators • Electrical, process, and mechanical engineers • Inspectors, testers, processing technicians, and chemical equipment operators
European Union	Project development	• H2 business development manager, Business development manager, Fuel cells design engineer, International project developer, Legal and regulations specialist, Public relations specialist, Public strategy specialist, Technology development manager, Specialists including economy & finances
	Construction & production	• Robotics & production engineer, H2 Project manager, Renewable generation, Interconnections, Grid operation, Engineers (fuel cell, electrical, electromechanical H2 production, chemical process, mechanical, system integration, process, materials, design, simulation, infrastructure repurposing), Industrial process project manager, Chemical project manager, Green fuel project manager, Gas facilities construction manager, H2 production project manager
	Operation & maintenance	• Power electronics engineer, fuel cells design, chemical process, mechanical engineer,

Country/state	Hydrogen value chain	Job roles
		Technicians, System operator, Refueling stations operator
	Health & safety	• Hazardous materials engineer, , Environmental engineer, Health, safety, and risk engineer, Safety, and hazards specialist

7 SKILL GAP ASSESSMENT - JOB ESTIMATES, PRIORITY JOB ROLES AND SKILLS REQUIRED

With the launch of National Green Hydrogen Mission, India has set a clear target to emerge as one of the key green hydrogen markets in the South Asia. Achieving this vision requires development of a robust human resource pool with apt skill sets to manage the critical activities in the green hydrogen value chain. From the previous sections, it is evident that even today there are job roles catering to hydrogen production in India. However, the workforce is deployed as a shared resource across multiple processes. To achieve the target of 10 MTPA green hydrogen production by 2030, a dedicated skilled workforce trained through structured curriculum-based approach is required in the green hydrogen sector. Thus, this section discusses in detail the job roles across the key sections of the green hydrogen value chain and the necessary skilling requirement. Figure 7.1 highlights the key activities across the hydrogen value chain that have been analyzed for skill gap assessment.

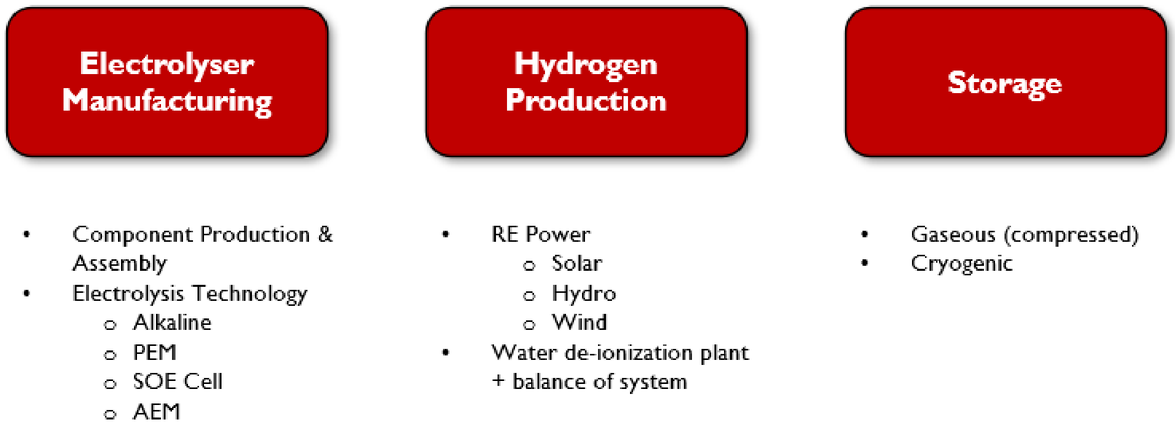

Figure 7.1 Green Hydrogen Value Chain

This chapter elucidates in detail the following key areas of concern –

- Estimation of the number of jobs and types of job roles that may emerge within the domestic green hydrogen sector by the end of 2025, and subsequently, on a year-on-year basis until 2030.
- To identify the current skill gaps in the market.
- To identify the types of skilling required, including upskilling and reskilling, to meet the industry's needs across the sector.
- To identify the top 5 priority job roles that are immediately required.

7.1 EMPLOYMENT ESTIMATES ACROSS DOMESTIC GREEN HYDROGEN SECTOR

This section focuses on identifying potential job roles within the domestic green hydrogen sector throughout the value chain. Additionally, it aims to estimate the number of jobs and the types of roles that might emerge in the domestic green hydrogen sector by the conclusion of 2025 and provide annual projections for job growth until 2030.

7.1.1 IDENTIFICATION OF JOB ROLES ACROSS GREEN HYDROGEN VALUE CHAIN

The possible job roles within the domestic green hydrogen sector are distributed across two segments in the value chain: hydrogen production (including planning and design, installation and commissioning, operation and maintenance and storage in compressed tanks) and electrolyser manufacturing (encompassing manufacturing and assembly, maintenance, supply chain management, business development, equipment testing and certification, and safety). The job roles have been identified based on analysis of global job roles across the green hydrogen value chain (as outlined in the previous sections) and stakeholder consultations.

In contemporary practices, it is more logical to delegate tasks that are non-recurring, meaning those not permanently required but periodically necessary, to external entities. For instance, the solar/wind companies often outsource tasks such as installation & commissioning and operation & maintenance to organizations specialized in these activities. Similarly, in the green hydrogen sector, specific functions like design & planning and installation & commissioning may be outsourced to other organizations. However, due to the nascent nature of the green hydrogen ecosystem, there is a current limitation in India regarding companies specializing in specific functions across the green hydrogen value chain. Consequently, major corporations entering the green hydrogen sector are strategically choosing to internally develop capabilities across the entire value chain. Some notable participants have already initiated this approach, including public sector undertakings (PSUs) such as GAIL, IOCL, HPCL, and private entities like Reliance, Adani, and L&T.

In the analysis, it is assumed that companies will initially establish in-house capabilities across the entire value chain. As the industry matures and skill sets evolve, there may be a reshuffling of workforce to form separate entities with specialized expertise. The existing workforce with the necessary skills could either transition into other operational roles or be reallocated to the new entities, minimizing the overall need for significant new skill sets.

7.1.1.1 HYDROGEN PRODUCTION

Hydrogen production can be classified into three broad stages - pre-construction, construction, and post-construction. These stages have been further categorized into different domains such as planning and design, financing and compliance, installation and commissioning, pipeline construction and commissioning, equipment testing and certifiers, safety, operations, maintenance, water treatment, plant, power management, storage and support activities as shown in

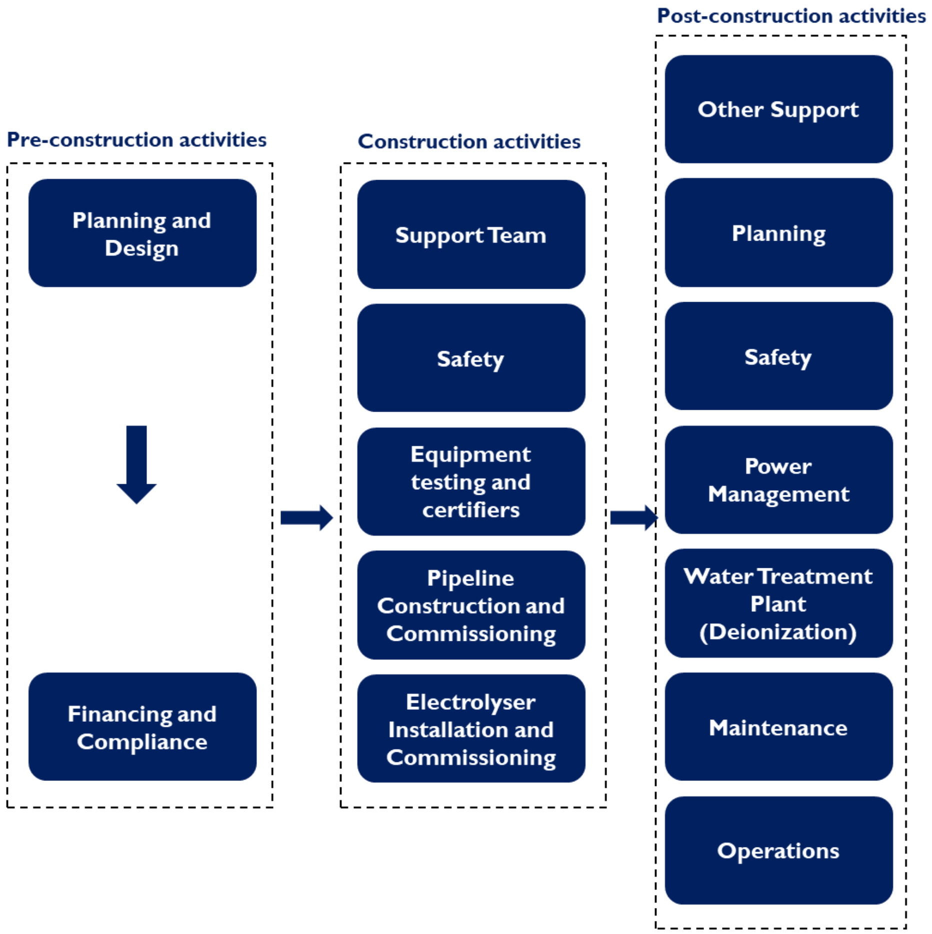

Figure 7.2. The various domains across the value chain, along with their corresponding job roles, are discussed in the subsequent sections.

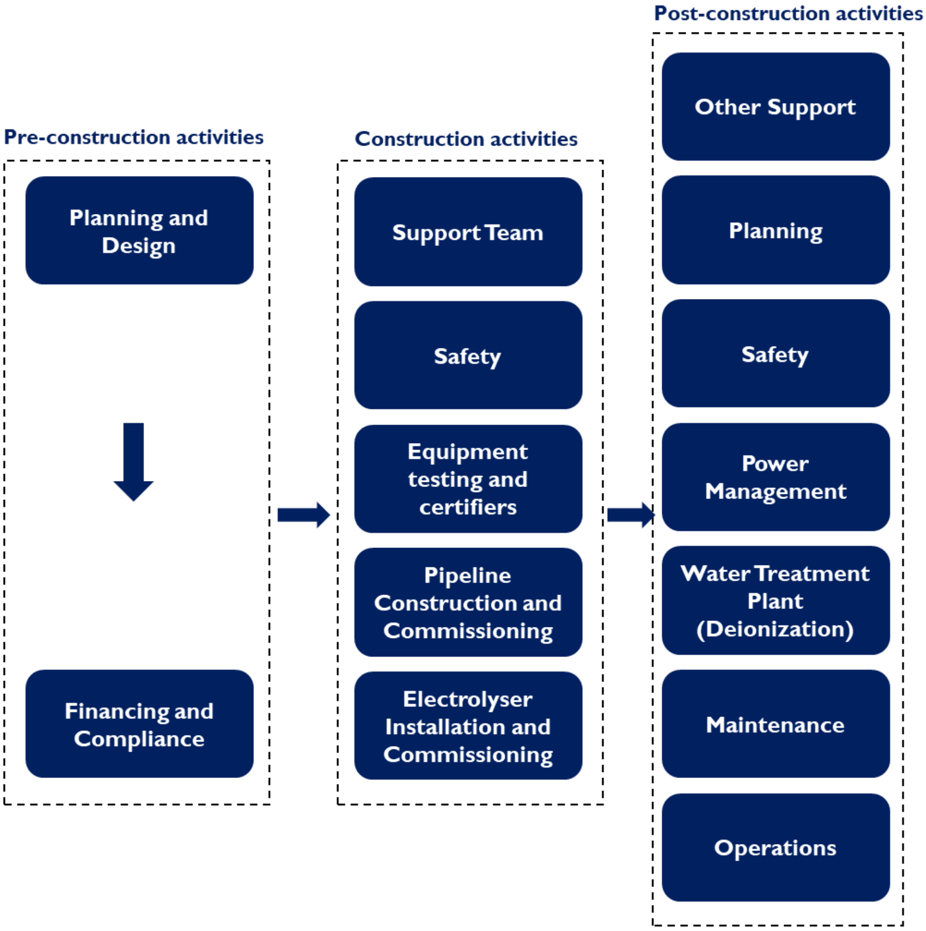

Figure 7.2 Hydrogen Production

Planning and Design

Within the planning and design phase, primary tasks involve optimizing the type, location, and size of facilities. This phase generally has non-recurring job roles in hydrogen system & facility design vertical. This includes preparing hydrogen system sizing, testing, and characterizing procedures, optimizing systems with renewable energy integration, addressing electrolyser stacks, gas treatment, and ensuring overall system integration. Additionally, tasks encompass the creation of the basic layout of the plant, developing general arrangement and fabrication drawings for hydrogen plants, preparing equipment drawings, and addressing interdisciplinary interface requirements. Detailed activities also involve the preparation of piping material specifications for processes, the creation of pipe isometric drawings, and ensuring compliance with regulations and safety guidelines. This phase also involves some roles which are recurring in nature. These include the workforce in planning, financing and compliance department. These departments may either be internal or typically outsourced. Design and planning projects generally have a duration of around six months.

Within this domain, job positions are categorized into six levels namely, L8, L7, L6, L5, L4 and L3. Each of these levels aligns with the occupational standards defined by Skill Council for Green Jobs.

Planning and Design

Level	Hydrogen System & Facility Design	Planning, Financing & Compliance Department
L8	Head of Design (structure design, electrical design, site survey) (1)	
L7		Head of Project Development (1) (look after land development, regulatory approvals and pre- feasibility analysis)
L6	Design Managers (2)	Planning Manager (1), Business development Manager (2)
L6	Hydrogen System Integration (2), Industrial Designers for Hydrogen System & Facility (2), Solutions Architect (1), Site Surveyor (2)	Regulatory officer (1), Safety compliance officer (1), Project financing officer (2)
L5	Engineers – Integration (1), Robotics (1), Automation (1), Industrial Design (1), Civil (1), Mechanical (1), Electrical (1), Chemical (1)	Planner (Short term + Long term) (2), Analyst (2)
L4	Civil Draftspeople (1), Draftspeople for Hydrogen System & Facility (1), Computer-Aided Design (CAD) Drafter (4)	
L3		

Figure 7.3 Planning and Design Job Roles

Fig 7:3 illustrates the distribution of these job roles and the corresponding workforce requirements (for a 1 GW plant size) across various levels in the planning and design phase. The job roles within the planning, approvals & compliance department are recurring in nature indicating that the workforce will be engaged across other phases.

Installation and Commissioning

Installation and commissioning encompass a wide range of activities, including setting up the electrolyser plant, constructing the water treatment plant, installing oxygen gas / liquid separators, hydrogen gas / liquid separators, compressors, cooling towers, deoxidizers, dryers, and other required infrastructure. It also involves connection, erection, testing and commissioning of the electric supply. These jobs are non-recurring in nature as installation and commissioning is generally a one-time activity. Within this domain, job positions are categorized into six levels namely, L8, L7, L6, L5, L4 and L3. Each of these levels aligns with the occupational standards defined by Skill Council for Green Jobs.

The organizational hierarchy of job roles at different levels is shown in

Installation & Commissioning

Level	Electrolyser Installation & Commissioning	Pipeline Construction & Commissioning	Equipment Testing & Certifiers	Safety & Others
L8	Project Head (1)			
L7				
L6	Project Managers (6), Supply Chain Manager (1) Structural (1), Hydrogen system integration specialist (2), Commissioning (6), Power Systems (2), Hydraulic (1), Purchase executive (1), Logistic executive (1)	Project Manager (1) Site Surveyor (1)	Equipment Testing Lab Manager (1) Equipment Certifiers (4)	H&S Manager (2) (high voltage; explosive atmospheres)
L5	Engineers – Electrical (6), Process (3), Chemical (3), Mechanical (6), Civil (6)	Engineers - Pipeline (3), Process (2), Chemical (1), Civil (1)		
L4	Green Hydrogen Plant Technician (2)			
L3	Welder (9), Plumber (2) Junior technician – Electrolyser (4), Instrumentation (6), Electrical (Power sources) (6), High Voltage Electrical (2), Mechanical (6)	Junior technician – Pipeline (3), Gas (1), Welder (6)		

Figure 7.4. The workforce required has also been mapped, for a 1 GW plant capacity. Additionally, the support team includes the human resources manager, payroll personnel, accounts team personnel, etc., comprising of 25 workers.

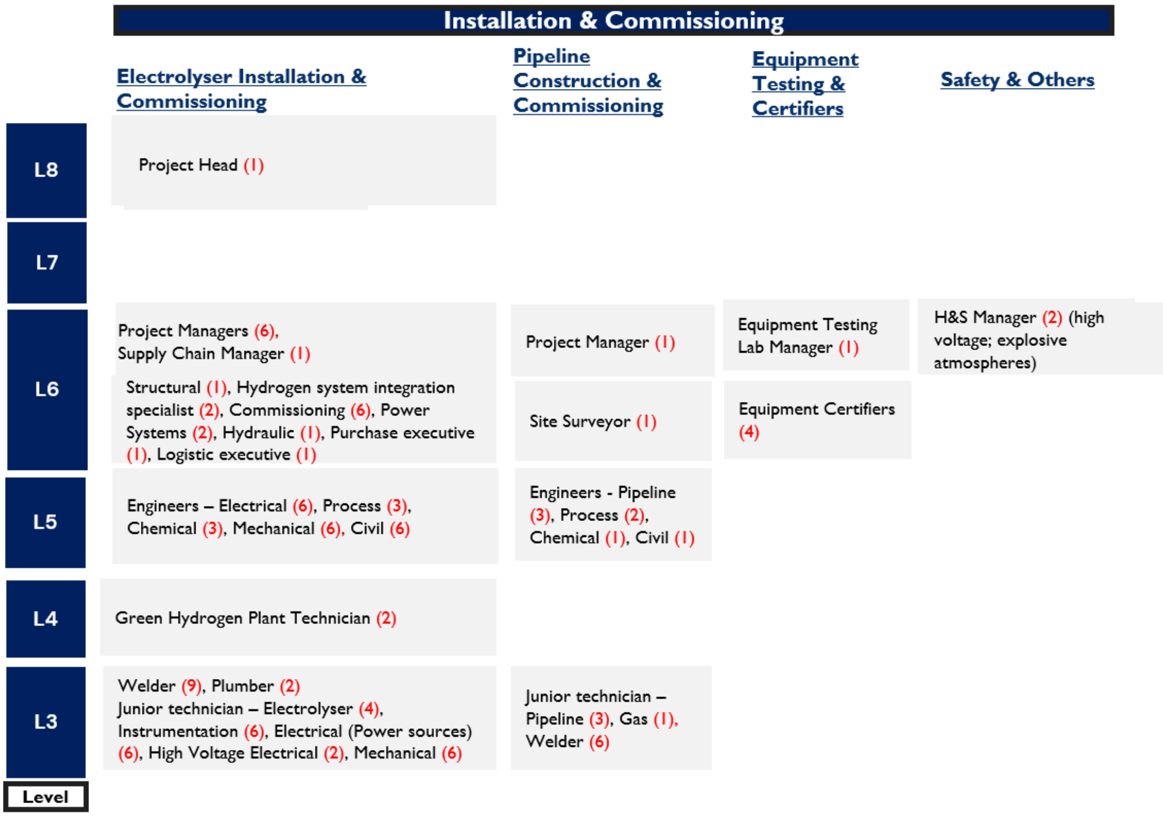

Figure 7.4 Installation and Commissioning Job Roles

Green Hydrogen Production

The production of hydrogen encompasses essential steps such as electrolysis, hydrogen purification, compression, integration with renewable energy, and activities related to monitoring and control. These activities fall under six distinct domains: operations, maintenance, planning, power management, water treatment plant, safety, and others. The support team includes HR managers, accounts personnel, payroll specialists, and other roles. Within this domain, job positions are categorized into six levels namely, L8, L7, L6, L5, L4 and L3. Each of these levels aligns with the occupational standards defined by Skill Council for Green Jobs. Job roles categorized across the different levels, under green hydrogen production are depicted in Figure 7.5. The number of workers required at each of these levels has also been mapped for a 1 GW plant capacity. The support team including the HR managers, accounts team, payroll personnel, etc. consists of about 25 workers for the same plant capacity. Activities integral to green hydrogen storage involve implementing power electronics and control systems for hydrogen compression and storage, temperature and pressure control, operating valves, and ensuring safety compliance. Adherence to regulatory standards and compliance requirements for hydrogen storage, safety, and environmental considerations are of paramount importance. Quality control measures include monitoring the purity levels of stored hydrogen and addressing any contamination issues. Regular integrity tests on storage tanks and associated equipment are conducted to identify and rectify potential issues. Implementation of safety protocols and measures is crucial for handling and storing hydrogen safely, given its highly flammable nature. Additionally, compression or liquefaction processes are employed in the storage of green hydrogen.

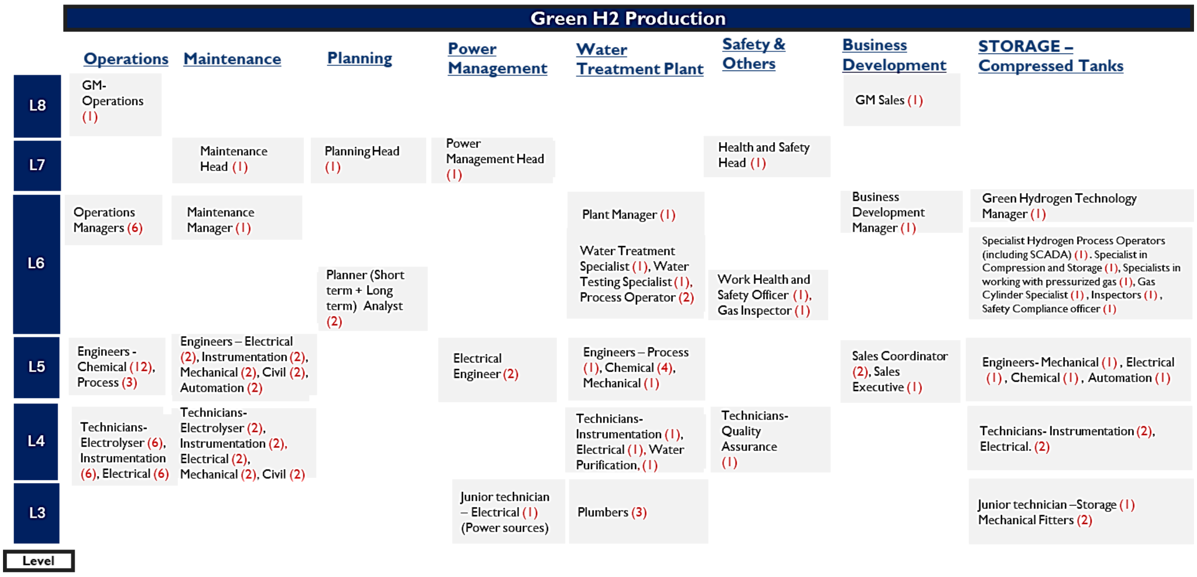

Figure 7.5 Green Hydrogen Production Job Roles

7.1.1.2 ELECTROLYSER MANUFACTURING

During the electrolyser manufacturing / assembly phase, activities are organized into three stages: cell manufacturing, stack development, and final system integration. Cells comprise of electrodes, electrolytes, and other essential components like bipolar plates. Subsequently, stacks are created by connecting multiple cells in series, consolidating the electrolysis capacity into a single element. Production involves using spacers (for isolating electrodes), gaskets, frames, and plates (for mechanical stability and preventing fluid leakage). Lastly, stacks integrate with the equipment for hydrogen production, including cooling devices, hydrogen processing, water and electricity supply, and gas outlets. Each of these tasks are executed within distinct functions, as illustrated in Figure 7.6.

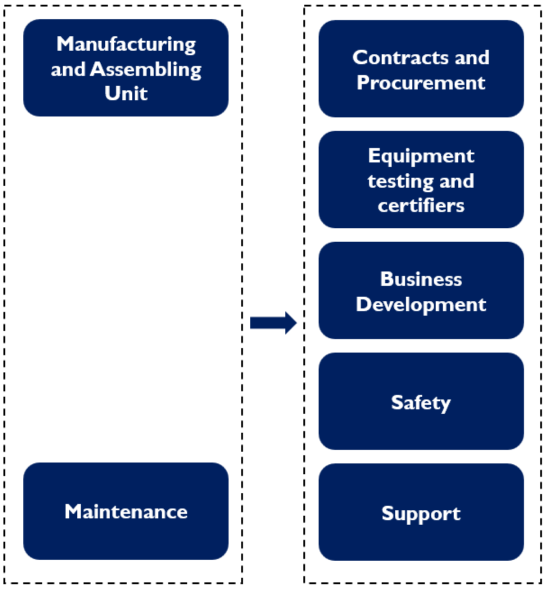

Figure 7.6 Electrolyser Manufacturing

The organizational chart in Figure 7.7 delineates various roles and quantum within the electrolyser manufacturing domain for a plant of typical capacity of 1 GW. Additionally, the 20 workers in the support team comprising of payroll personnel, HR managers, accounts personnel, etc., will be required.

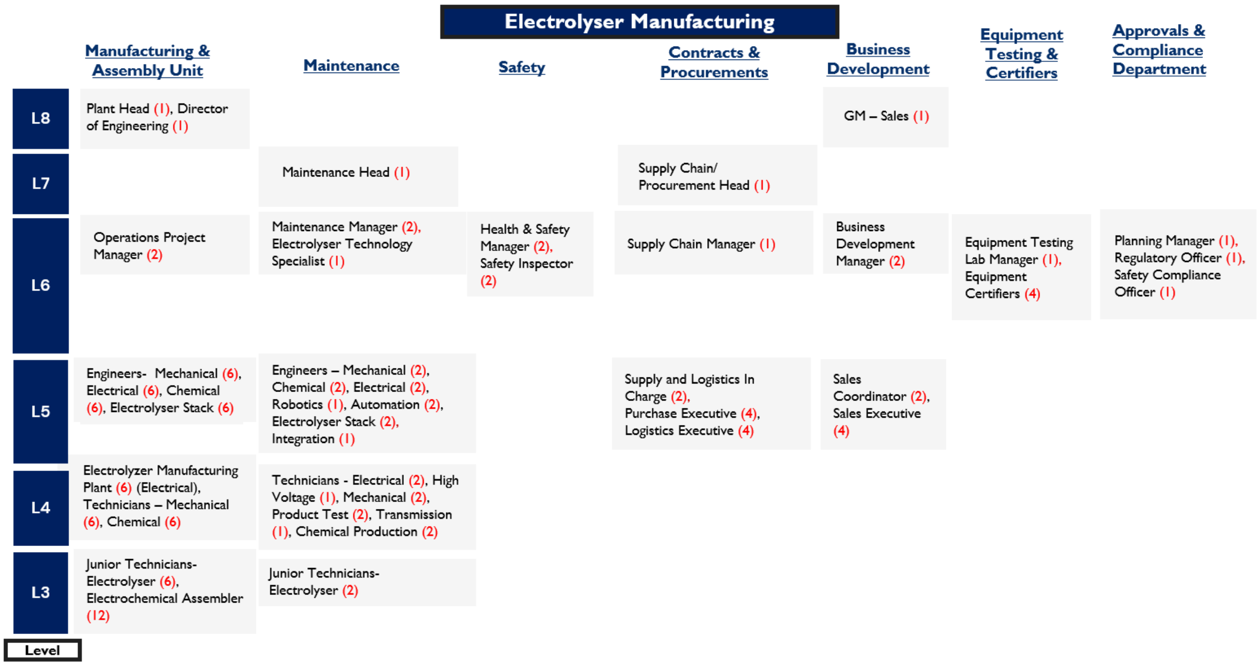

Figure 7.7 Electrolyser Manufacturing Job Roles

7.1.2 ESTIMATION OF JOBS BY 2030

Potential number and type of jobs required have been estimated till 2030 for the green hydrogen value chain with focus on hydrogen production and electrolyser manufacturing.

The main areas of the said verticals are highlighted as below:

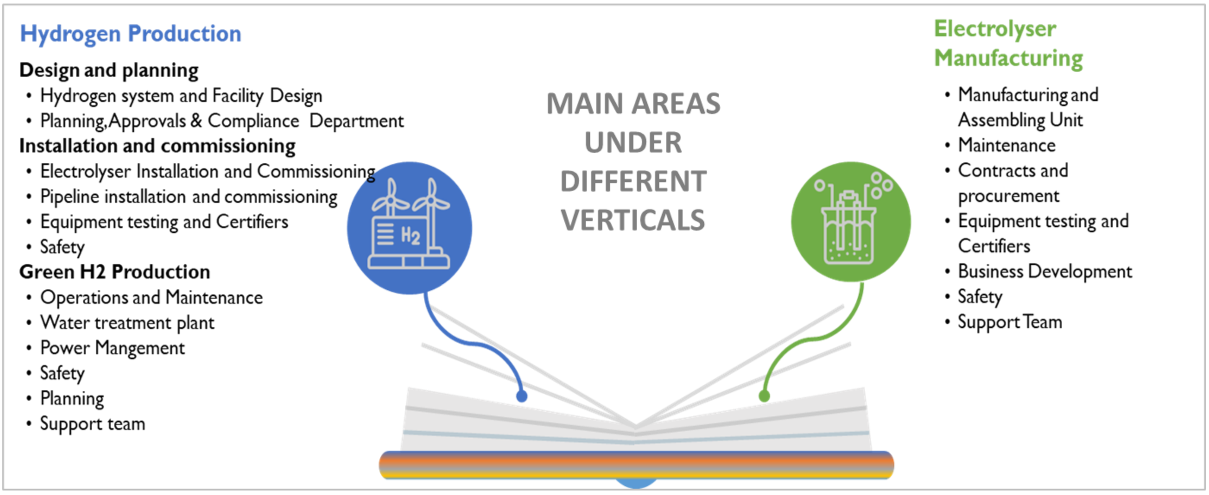

Figure 7.8 Main Areas under Different Hydrogen Verticals

For the accuracy of analysis, the jobs can be broadly categorized into two distinct types: **recurring Job (R) and Non-recurring Job (NR)**

Recurring Jobs	**Non-Recurring Jobs**
Recurring jobs refer to positions or tasks that are part of regular, ongoing operations and are essential for the continuous functioning of a business or industry.	Non-recurring jobs, also known as one-time or temporary jobs, are positions or tasks associated with specific projects, events, or situations and are not part of

Figure 7.9 Recurring and Non-Recurring Jobs Definitions

7.1.2.1 GENERAL ASSUMPTIONS

For the estimation of job roles across the verticals discussed, certain general and vertical specific assumptions are considered. General assumptions are discussed below -

1. Green Hydrogen Capacity

Based on the expected green hydrogen capacity from National Green Hydrogen Mission, the incremental green hydrogen capacity in for year is determined to reach 10 MTPA (including additional 5 MTPA for green hydrogen export) by 2030 as below.[61]

A similar scenario can be built for green hydrogen capacity as per the NITI Aayog's target of 5 MTPA by 2030. The outcome would be 50% of the projections from the National green hydrogen mission.

Table 7.1 Green Hydrogen Capacity Assumption

Year	2025	2026	2027	2028	2029	2030
Cumulative green H2 Capacity (MTPA)	0.20	0.50	2.00	4.00	7.00	10.00

2. Capacity of Plant

For calculation purposes, the market is divided into 3 average capacities of hydrogen production plants.[62]

- **10 MW**
- **100 MW**
- **1000 MW**

Estimation of jobs

[61] As per inputs from discussions, 6 lakh jobs estimated by MNRE are based on 10 MTPA green hydrogen production.
[62] This is based on market analysis as well as stakeholder consultations with ACME, GAIL & other key market players, since a typical commercial electrolyser module has a size of ~2.5 MW, a typical small commercial plant would have size ~10 MW, while medium & large plants have been considered at 10X the previous size for modelling the market capacities. Large green hydrogen plant announcements of 1 GW have already been made by private sector in India (Reliance) and others are expected to be there in future.

This section focuses on estimating the number of jobs in the verticals – renewable energy plant, hydrogen production and electrolyser manufacturing.

1) Renewable energy plant

The NGHM has specified that the Renewable Energy (RE) capacity needed by 2030 is 125 GW. The analysis includes the incremental capacity from 2025 onwards, taking into account the capacities for green hydrogen production. As depicted in the table below, the distribution of solar and wind shares in 2025 is set at 64% and 36%, respectively[63], based on the installed capacity ratio of solar and wind in 2023. This ratio is projected to shift to 70% solar and 30% wind by 2030[64].

Table 7.2 Assumption on RE plant capacity by type

RE Installed Capacity	2025	2026	2027	2028	2029	2030
RE capacity (GW)	3	6	25	50	88	125
Incremental RE capacity (GW)	3	4	19	25	38	38
Solar	64%	65%	66%	67%	68%	70%
Wind	36%	35%	34%	33%	32%	30%

Table 7.3 Number of plants of plant size and type

	2025	2026	2027	2028	2029	2030	Total
Average plant size	63	95	474	634	954	960	3179
Total workforce requirement	6355	9518	47522	63269	94764	94485	3,15,913

Approximately 3.15 lakh job opportunities across various roles in engineering, procurement, commissioning, operations, and maintenance are projected to emerge to meet the demand for a Renewable Energy (RE) capacity of 125 GW by 2030.

2) Hydrogen Production

In hydrogen production facility, the hydrogen production process can be divided into 3 main phases –

1. **Design and Planning -** The design and planning stage is focused on creating a comprehensive blueprint for the hydrogen production facility. This includes conceptualizing the layout, selecting appropriate technologies, and planning for the efficient use of resources.

2. **Installation and Commissioning -** The installation and commissioning stage involves physically setting up the facility and ensuring that all components work together effectively. It includes testing and fine-tuning to prepare the facility for full-scale production.

3. **Green hydrogen production -** This is the operational stage where the facility begins the actual production of green hydrogen. Green hydrogen is typically produced through electrolysis using renewable energy sources, contributing to environmental sustainability.

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[63] https://npp.gov.in/public-reports/cea/monthly/installcap/2023/MAR/capacity1-2023-03.pdf
[64] ICF's Analysis

The type of roles in a hydrogen production facility have been studied for analyzing employment requirement in a plant in the 3 phases of hydrogen production. Number of jobs for a small, medium-sized, and large sized plant are as below:

Table 7.4 Number of Jobs in Hydrogen Production by Plant Size

EMPLOYMENT (per unit)								
Plant Size	**Design & Planning**		**Installation & Commissioning**		**Green H2 Production**		**Total**	
	R	NR	R	NR	R	NR	R	NR
10 MW	5	11	0	34	38	0	**43**	**45**
100 MW	8	19	0	79	73	0	**81**	**98**
1000 MW	12	32	0	134	122	0	**134**	**166**

Projections till 2030

Based on the estimated contribution from the plants of different capacities and the number of plants calculated, the total number of jobs in hydrogen production plants for all the 3 verticals are estimated below:

Table 7.5 Job Estimation in Hydrogen Production

Plant Size (MW)		**2025**	**2026**	**2027**	2028	**2029**	**2030**	**Total**
Design & planning								
Recurring	*10*	195	385	1,915	2,550	3,825	3,825	**12,695**
	100	72	80	384	512	768	768	**2,584**
	1000	-	12	12	24	24	24	**96**
Non - Recurring	*10*	429	847	4,213	5,610	8,415	8,415	**27,929**
	100	171	190	912	1,216	1,824	1,824	**6,137**
	1000	-	32	32	64	64	64	**256**
Installation and commissioning								
Recurring	*10*	-	-	-	-	-	-	**0**
	100	-	-	-	-	-	-	**0**
	1000	-	-	-	-	-	-	**0**
Non-Recurring	*10*	1,326	2,618	13,022	17,340	26,010	26,010	**86,326**
	100	711	790	3,792	5,056	7,584	7,584	**25,517**
	1000	-	134	134	268	268	268	**1,072**
Green Hydrogen Production								
Recurring	*10*	1,482	2,926	14,554	19,380	29,070	29,070	**96,482**
	100	657	730	3,504	4,672	7,008	7,008	**23,579**
	1000	-	143	143	286	286	286	**1,144**
Non-Recurring	*10*	-	-	-	-	-	-	**0**
	100	-	-	-	-	-	-	**0**
	1000	-	-	-	-	-	-	**0**

Total estimated jobs by 2030 from hydrogen production are 2,83,817.

3) Electrolyser Manufacturing

In electrolyser manufacturing, the type of jobs is recurring in nature. The jobs are in departments like manufacturing and assembly unit, operations and maintenance, supply chain management, equipment testing and certifiers, safety team and other support staff.

Projections till 2030

The projections for year 2025 to 2030 based on the estimated number of plants are -

Table 7.6 Electrolyser Manufacturing Jobs Estimation for FY2025-2030

	Plant Size	2025	2026	2027	2028	2029	2030	Total
Electrolyser Manufacturing								
Recurring	*100*	410	369	1,845	820	1,230	1,230	**5,904**
	1000	79	237	869	948	1,422	1,422	**4,977**
	10,000	-	-	-	145	145	145	**435**

Total estimated jobs by 2030 from electrolyser manufacturing are 11,316.

7.1.2.2 TOTAL ESTIMATED JOBS

For estimating the total jobs across the hydrogen value chain - hydrogen production of different average capacities of hydrogen production facility (10 MW, 100 MW & 1 GW) have been considered. Further, assumptions for share of each type of average capacity in the total green hydrogen production & electrolyser manufacturing capacity have been made for each year. The summary of total estimated jobs below depicts the total combined jobs for the two expected green hydrogen market growth scenarios.

Table 7.7 Summary of total estimated jobs

Stage in Value Chain	Phases	2025	2030
Hydrogen Production	*Planning and Design*	867	49,697
	Installation and commissioning	2,037	112,915
	Green H2 production	2,139	121,205
Electrolyser Manufacturing	-	489	11,316

7.1.3 ESTIMATED JOB ROLE-WISE WORKFORCE REQUIREMENT BY 2030

This section categorizes into skill groups, the estimated overall workforce that will be required by 2030.

Hydrogen production

Details of the estimated overall workforce in hydrogen production categorized by skill groups is discussed below:

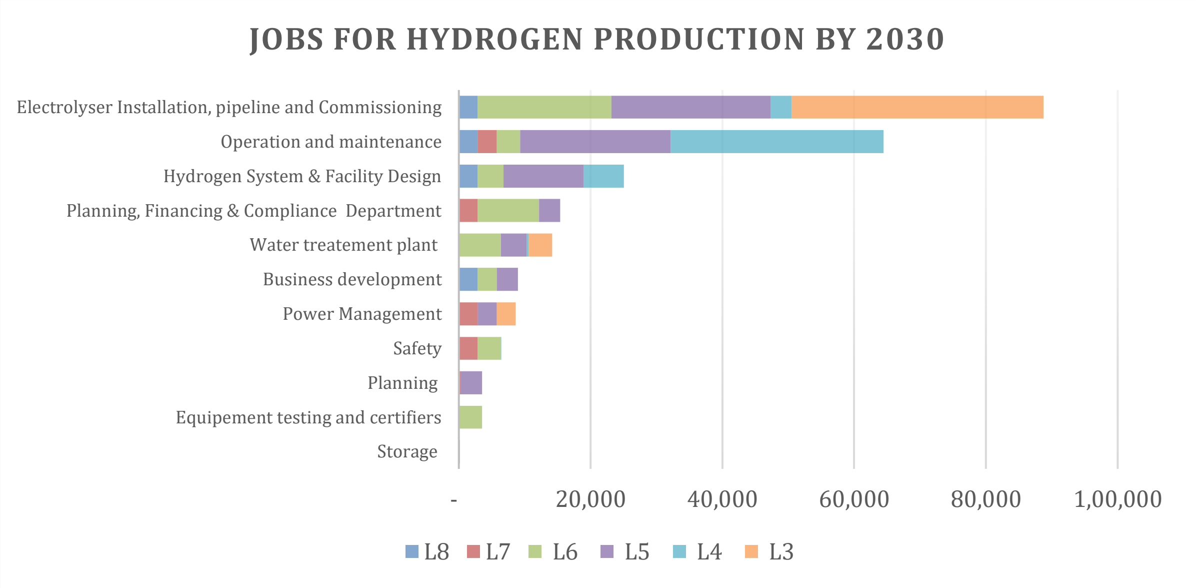

Figure 7.10 Jobs for Hydrogen Production by 2030

A total of **2,83,817** are estimated across all skill groups, of which the largest number are in electrolyser installation and commissioning and pipeline commissioning (88,749 jobs) followed by operations and maintenance (64,474 jobs).

Electrolyser Manufacturing

The major skill groups have been categorized for electrolyser manufacturing and the number of jobs have been estimated till 2030 for each skill group.

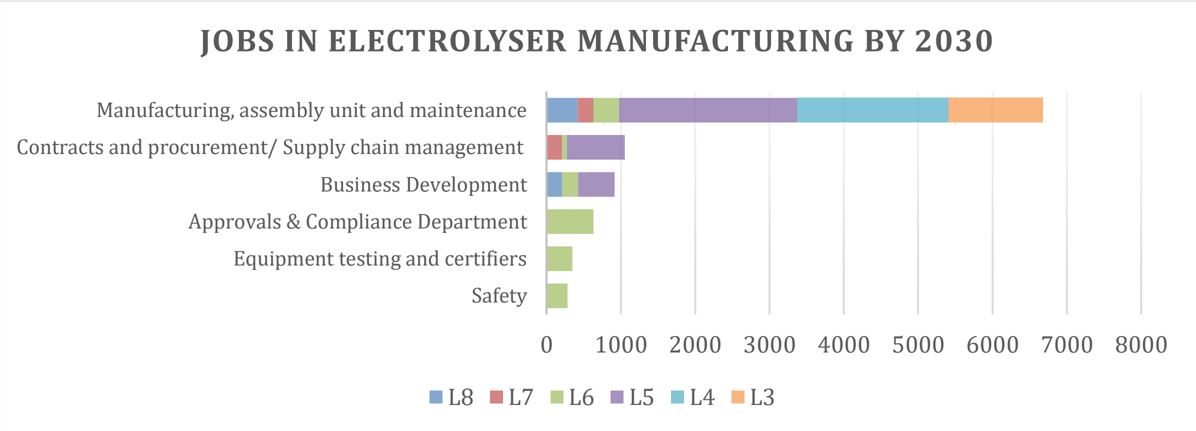

Figure 7.11 Jobs in Electrolyser Manufacturing By 2030

A total of **11,316 jobs** are estimated across all skill groups. The majority of jobs, 6,675, are in the manufacturing assembly unit and its maintenance followed contracts and business development skill group.

Key takeaways –

- In the hydrogen value chain, most jobs are estimated to be for hydrogen production plants.
- The overall number of jobs created across the verticals is estimated to be 2,95,133.

- Among these, the highest number of employment opportunities are anticipated for individuals at levels L6, L5, and L4.
- It is evident that plants with lower capacity require a higher number of jobs per megawatt (MW) in comparison to those with higher capacity. According to the analysis[65] conducted, **a plant with capacity 10 MW, 100 MW, and 1000 MW plant would entail 8.8 jobs, 1.79 jobs, and 0.30 jobs per MW respectively.**
- Considering the scenario outlined, which anticipates a mix of 10 MW, 100 MW, and 1000 MW plants in the proportion as mentioned in annexure - 7.1.2.1, the average estimated employment stands at **4.45 jobs per MW[66]** (jobs for green hydrogen production only).

7.1.4 ANNUAL FRESH EMPLOYMENT REQUIREMENT FOR JOBS TILL 2030

Hydrogen Production

The following figure illustrates the expected annual growth in demand for skilled employees. This demand will be addressed through a combination of retraining the current workforce, recruiting new employees from different industries, and hiring recent graduates. It is challenging to scientifically determine the fraction of jobs undertaken by candidates from each of these three sources. Therefore, the figures below show the total number of fresh jobs created in the sector.

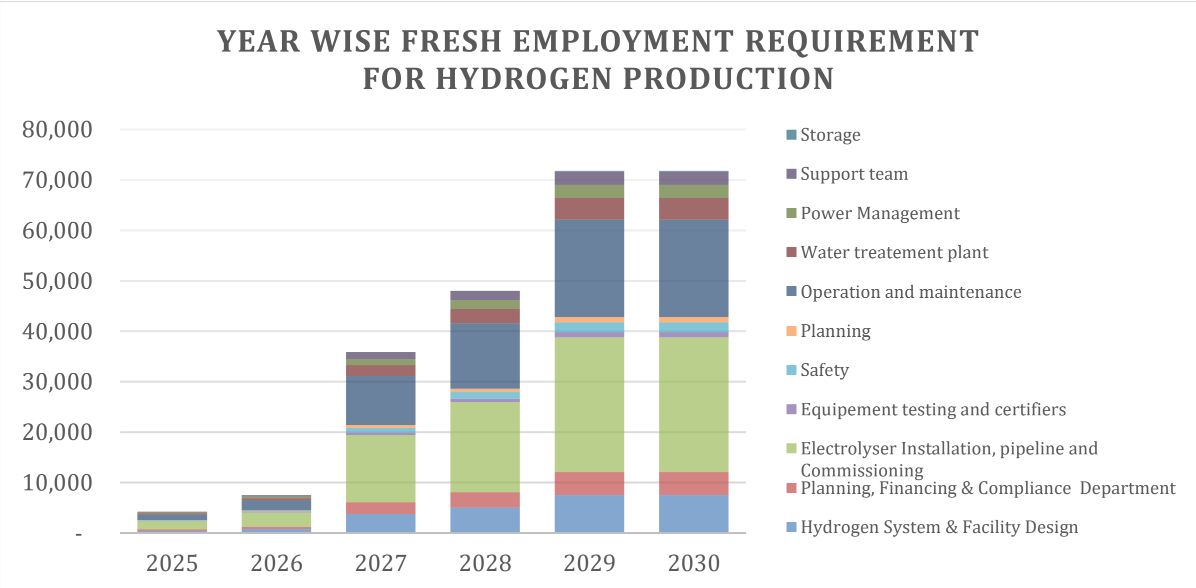

Figure 7.12 Year wise Fresh Employment Requirement for Hydrogen Production [67]

This projects the highest yearly growth in fresh job opportunities at around 8.3% overall CAGR with electrolyser & pipeline installation, and commissioning and operations and management being the main contributors.

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[65] This considers both recurring and non-recurring jobs generated in a plant with mentioned capacity.
[66] 1 MW = 157 TPA or 1 TPA = 6.369 KW
[67] Key in sequence of graph for ease of reading

Electrolyser manufacturing

In electrolyser manufacturing, new jobs created each year are estimated to grow at the rate of 3.66% CAGR from around 456 fresh jobs in 2025 to around 2,650 fresh jobs in 2030.

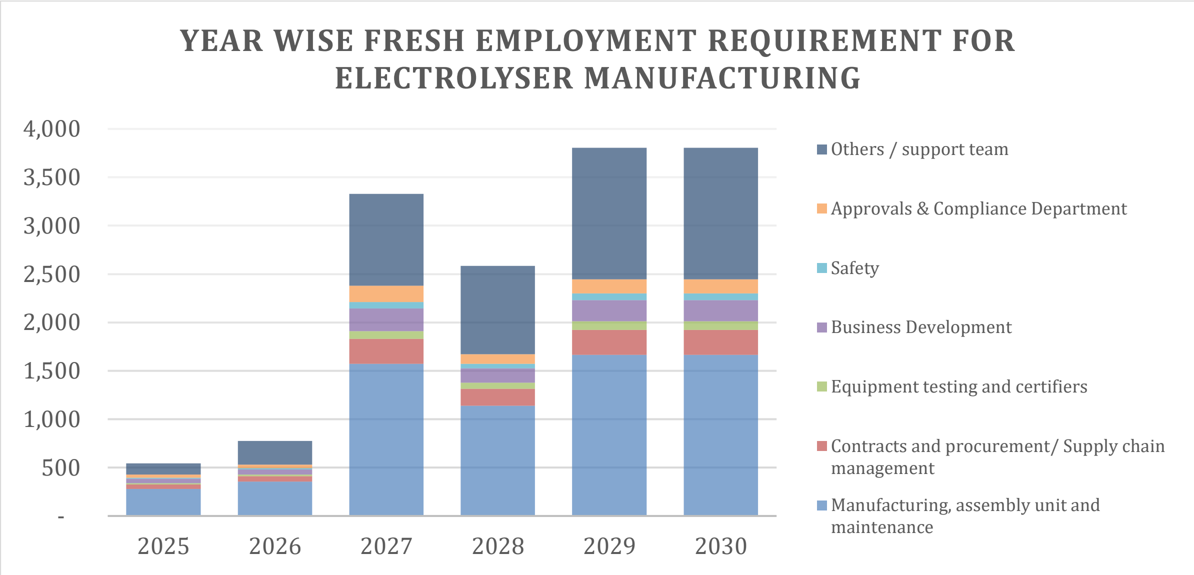


Figure 7.13 Year wise Fresh Employment Requirement for Electrolyser Manufacturing

The highest growth is estimated to be in manufacturing, assembly unit and maintenance at around 3.25% CAGR.

7.1.5 ESTIMATED DEMAND FOR RESKILLING / UPSKILLING TILL 2030

The green hydrogen sector in India is currently in its nascent stage, characterized by ongoing advancements and the swift integration of new technologies across the entire value chain. Annually, there will be a need for reskilling / upskilling across all core skill groups.

In this section we are considering reskilling / upskilling of experienced professionals which are moving to green hydrogen industries from other industries. It is envisaged that in the initial stages of the sector's development, there will be a reliance on seasoned professionals originating from existing industries such as refineries and fertilizer production, among others, to fulfill workforce requirements. However, due to the specialized nature of green hydrogen-related jobs, these individuals will necessitate retraining to align their skill sets with the demands of the sector.

The assumption is that seasoned professionals with advanced competencies will entirely be recruited from the existing talent pool within industries. Also, for positions at the junior to mid-level, a significant proportion of the workforce will necessitate reskilling or upskilling, while some portion will comprise freshly recruited individuals. Thus, the following assumptions are outlined –.

- For Levels 7-8: The assumption is that **all** personnel will necessitate reskilling/upskilling.
- For Levels 5-6: **90%** of the workforce is assumed to require reskilling/upskilling.
- For Levels 3-4: **80%** of the workforce is assumed to require reskilling/upskilling.

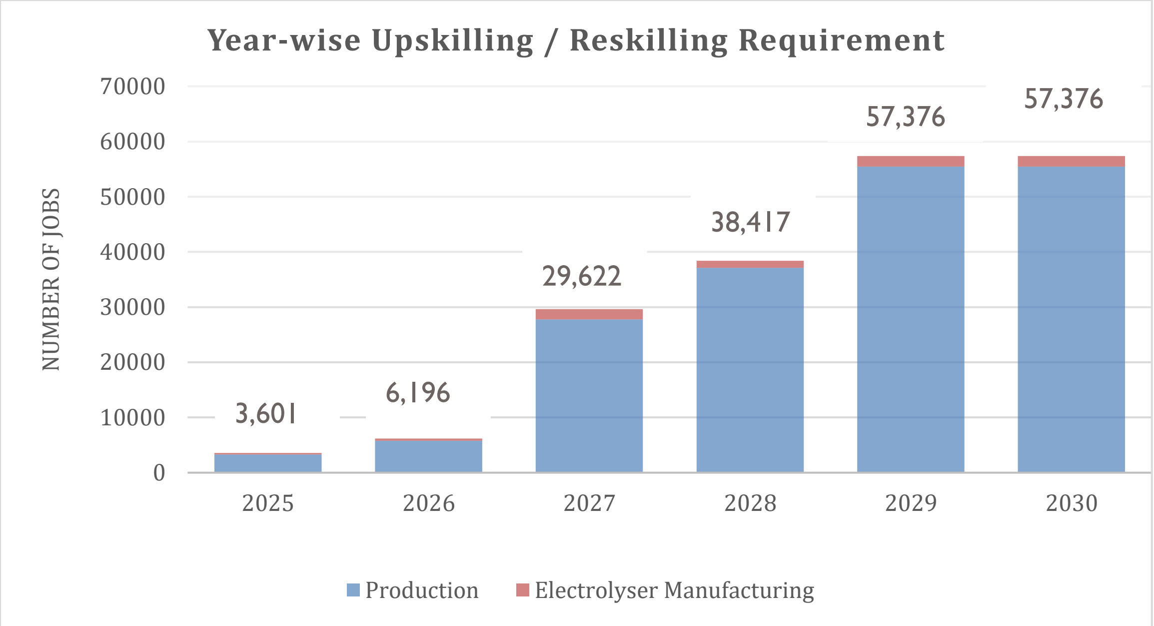


Figure 7.14 Year-wise Upskilling/Reskilling Requirement

Key insights –

- 3 scenarios were considered for estimating the demand for year-wise upskilling / reskilling requirement. Based on the analysis, by 2030, the upskilling / reskilling requirement is estimated to reach the range of **0.5-1.9 lakhs** (Details of other cases is in Annexure- 9.4.3)
- Hydrogen production contributes to around 95% of the total upskilling / reskilling requirement by 2030.

7.2 IDENTIFYING SKILL GAPS

Developing skills for a hydrogen-based economy is a critical consideration that involves tapping into the current skill pool while creating additional job opportunities. Presently, hydrogen production mainly involves grey hydrogen generated by refineries, fertilizer, chlor-alkali, or gas manufacturers. These industries provide a chance to utilize existing industrial knowledge, occupations, and skills present in the labor market. Moreover, individuals with experience in hydrogen usage from these sectors could be enlisted and trained to operate and maintain equipment in hydrogen facilities, including compressors, storage, pipelines, and also adhere to safety protocols.

On the flip side, the demand for skilled engineers and technicians is crucial for the development and operation of green hydrogen systems. These skills can be sourced from sectors such as oil & gas, chemical, petrochemical, power, renewable energy, and manufacturing. However, there is currently a limited pool of skills available for green hydrogen production. Some skills related to green hydrogen can be identified through manufacturers and suppliers of green hydrogen electrolysers and gas. For instance, installation and commissioning experts from gas manufacturing sectors like Linde, INOX, Air Liquide, etc., can be leveraged.

To meet the demands of large-scale production infrastructure, there may be a need for workforce expansion and realignment. Enhancing the readiness of the workforce required for advancing the hydrogen economy involves building on existing expertise. Table 7.8 provides an overview of the existing skills that can be leveraged upon for green hydrogen transition.

Table 7.8: Existing expertise relevant for green hydrogen transition

Sectors (existing source)	Expertise than can be leveraged
Oil & Gas sector	• The professionals working in this sector possess extensive knowledge in gas processing, gas compression, pipeline transmission, truck transportation, and safe handling of gaseous fuels.
Chemical / petrochemical	• Expertise in chemical processes, which is crucial for the production and refinement of hydrogen. • The industry emphasizes process efficiency and optimization, skills that are directly applicable to enhancing the efficiency of green hydrogen production processes. • Knowledge of operating / managing advanced control systems and instrumentation is valuable for ensuring precise monitoring and control in green hydrogen production facilities. • Understanding materials and their properties is important for selecting suitable materials for hydrogen production, storage, and transportation systems.
Processing	• Expertise in designing and optimizing industrial processes, which is crucial for efficient green hydrogen production. • Knowledge of chemical reactions, separation techniques, and purification processes is essential for the production and refinement of hydrogen. • Understanding fluid flow and behavior is important for the design and operation of equipment involved in green hydrogen production, such as reactors and separators. • Knowledge of heat exchange systems is valuable for optimizing temperature conditions in various stages of green hydrogen production
Chlor-alkali (brine-based electrolyser units)	• The skills and knowledge to design, install and operate electrolyser plant and its components such as pressure vessels, valves, piping systems, heating, and cooling systems, etc.
Power/ Renewable Energy	• Expertise in designing and maintaining electrical systems. • Experience in integrating renewable energy sources, such as solar and wind, into the grid. • Skills related to energy storage technologies are relevant for managing intermittent energy sources. • Experience in grid operations and management, which can be applied to optimize the integration of green hydrogen production facilities into the existing power grid.
Machinery/power plant equipment manufacturing	• Professionals in machinery manufacturing often have strong mechanical engineering skills, essential for designing and fabricating equipment used in green hydrogen production, such as compressors and pumps.

Sectors (existing source)	Expertise than can be leveraged
	• Welding and fabrication skills are crucial for constructing and assembling the infrastructure and components required for green hydrogen production facilities
Hydrogen technology providers such as Linde, INOX, Air Liquide	• The skills and knowledge to design, install and operate electrolyser plant and its components such as pressure vessels, valves, piping systems, heating, and cooling systems, etc.
Electrolyser / fuel cell development	• Strong background in electrochemical engineering, essential for understanding and optimizing the electrochemical processes involved in green hydrogen production. • Expertise in identifying and resolving technical issues, ensuring the reliable and continuous operation of electrolysis equipment

The current market's available expertise plays a crucial role in identifying the additional skills required by the sector in the future. The following section conducts an analysis to discern the skill demand, the existing sources supporting the demand, and anticipate the skills that will become essential across various job roles within the green hydrogen technology's supply chain. The analysis focuses on the supply chain aspects of green hydrogen production, and electrolyser manufacturing. It is essential to acknowledge that while the major indispensable elements of the hydrogen value chain have been addressed in this study, it does not encompass certain aspects such as transportation is not a part of the study.

7.2.1 GREEN HYDROGEN PRODUCTION

This segment focuses on identifying the existing skill gaps within various job roles in the context of green hydrogen production. The prevalence of hydrogen-related competencies and current skill gaps associated with each role have been assessed. Table 7.9 outlines the skill prerequisites, enabling a thorough assessment of the potential requirements for upskilling or re-skilling within each job function.

To assess the necessary level of skill augmentation, job roles are categorized on a 3-point scale of low, moderate, and high. Details of the scale used are -

Low – Skill gap	Medium – Skill gap	High – Skill gap
No Task changes, but some domain knowledge may be needed	Some new responsibilities are assumed, up/reskilling needed to address new tasks.	Many new responsibilities, new and unfamiliar areas of expertise and a significant need for up/re-skilling.

A summary of the detailed skill gaps prevailing in the job roles across green hydrogen production value chain is shown in the figures below. The key for the figure is same as mentioned above with green representing a low skill gap, blue for medium skill gap and red for high skill gap.

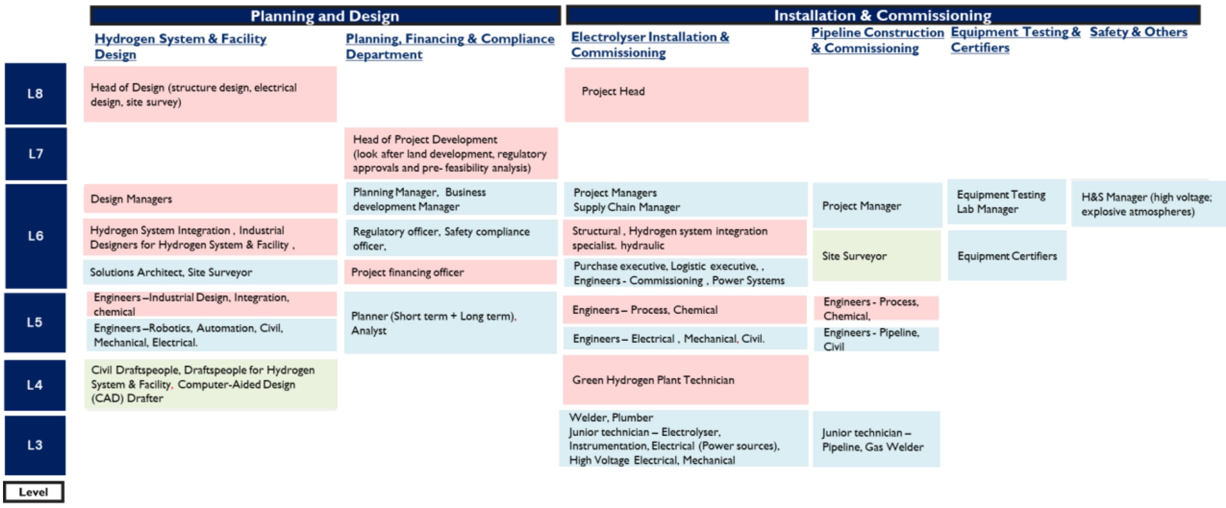


Figure 7.15 Planning & Design and Installation & commissioning

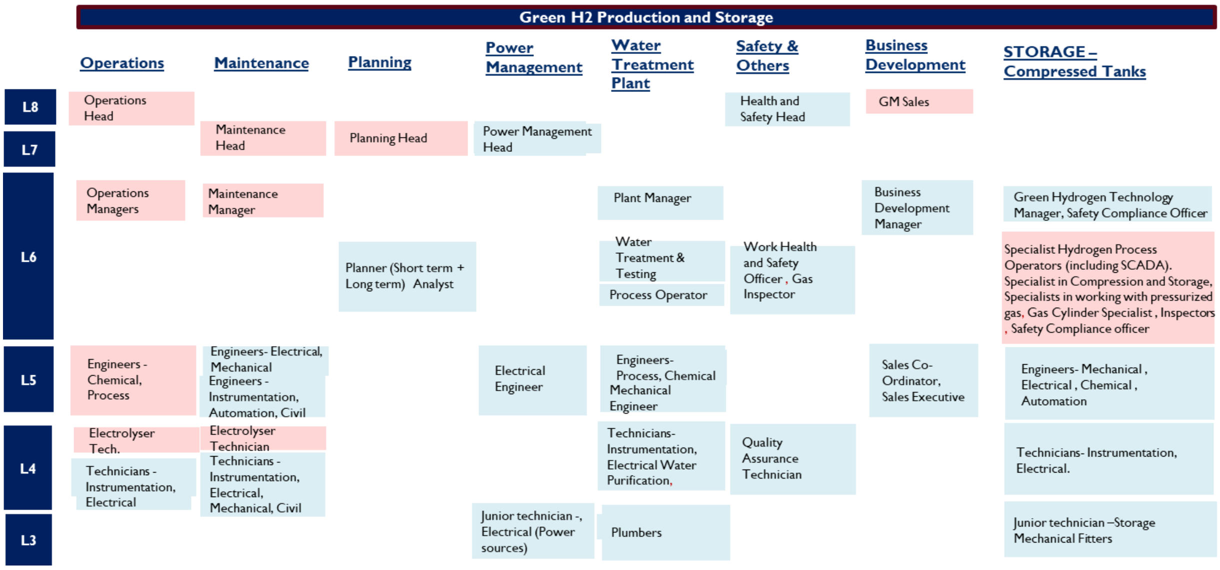
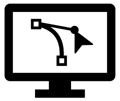
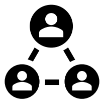
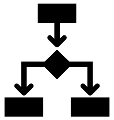
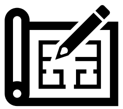


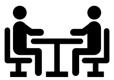
Figure 7.16 Skill Gap Analysis for Green Hydrogen Job Roles

Details of skills gaps identified for each job roles are as below:

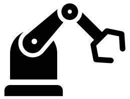
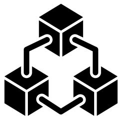
Table 7.9: Capability in demand across hydrogen production job roles

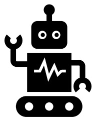
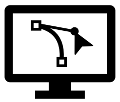
Job roles	Existing source(s) of relevant skills	Skills required for each job role	Skill gaps identified	Required augmentation level
 Head of design	Experience in leading design & engineering functions in Oil & Gas / Process industry	**Expertise in detailed engineering:** Proficiency in detailed engineering, process design calculations, process optimization, sizing and selection of equipment, costing, plant layout. **Project leadership and management:** Manage engineering & technology decisions in the early phases of hydrogen projects, set timelines, allocate resources, and oversee project milestones for successful and timely completion. **Understanding engineering deliverables**: Ability to comprehend engineering deliverables, including drawings and documents such as datasheets for equipment & instruments, piping & instrumentation diagrams.	• Proficiency in technical design aspects for setting up an electrolyser compression and storage facility. • Knowledge of production technologies and best practices to provide economical solutions for green hydrogen production. • Proficiency in design considerations for Integration of RE power & green hydrogen plant.	High
	Experience in designing brine-based electrolyser units in chlor-alkali plants		• Knowledge of production technologies and best practices to provide economical solutions for green hydrogen production. • Proficiency in design considerations for Integration of RE power & green hydrogen plant.	Low
 Project head (Planning)	Experience in thermal and / or renewable energy project development	**Project development:** Proficiency in managing every phase of project development from inception to the start of construction. **Project planning:** Ability to develop and manage project development schedules and budgets. **Site assessment:** Knowledge to carry out environmental studies, surveys, and diligence for selected site.	• Experience with green hydrogen electrolysis facilities and/or industrial process plants. • Knowledge of green hydrogen production technologies. • Ability to identify optimal locations for green hydrogen production	High
Project head (Installation & commissioning)	Experience in plant erection, commissioning, and service supervision in oil & gas, chemical industry	**Establishing erection & commissioning framework**: Define the scope of activities for erection and commissioning in the context of green hydrogen, establish systems, procedures, and best practices. **Commissioning:** Proficiency in commissioning of various utility, process, control, electrical, fire and gas, safety systems, etc.	• Knowledge of activities related to erection and commissioning of electrolyser plants, compressors, and storage facilities. • Knowledge of green hydrogen system integration with RE power plant. • Dealing with cryogenic materials	High

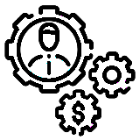
Job roles	Existing source(s) of relevant skills	Skills required for each job role	Skill gaps identified	Required augmentation level
	Experience in installation & commissioning with technology providers such as Linde, INOX, Air Liquide	**Execution:** Knowledge to develop, manage and deliver means & methods of commissioning execution strategy, schedule, and cost.	• Knowledge of green hydrogen system integration with RE power plant.	Low
 Operations & maintenance head	Experience in leading O&M functions in chemical or petrochemical industry	**Formulate and execute O&M strategy**: Create and enact operations and maintenance strategy and plan. **Optimize maintenance and reliability**: Establish preventive and predictive maintenance programs, manage schedules, and enhance equipment reliability & performance. **Budget management and optimization:** Develop and manage the O&M budget, balancing cost-effectiveness with quality and safety standards.	• Knowledge to perform inspection, troubleshooting, repair, and testing of electrolysers, RE power generation units, and other associated infrastructure. • Knowledge of safety standards pertaining to green hydrogen.	High
	Experience in designing brine based electrolyser units in chlor-alkali plants		• Knowledge to perform inspection, troubleshooting, repair, and testing of RE power generation units.	Low
 Planning and Design Manager	Experience in leading design & engineering functions in Oil & Gas/Thermal projects	**Engineering & design**: Proficiency in engineering & design of electrolyser systems, gas compression, and storage. **Proposal development & estimation**: Experience in crafting technical proposals including sizing and selecting piping and instruments, preparing Bill of Material, and estimating project costs. **Technology evaluation**: Evaluate various electrolyser and derivative product technologies to identify optimal solutions.	• Knowledge of engineering, design, and integration of green hydrogen systems including gas compression, and storage • Knowledge of production technologies and best practices to provide economical solutions for green hydrogen production. • Ability to identify optimal locations for green hydrogen production. • Proficiency in design considerations for Integration of RE power & green hydrogen plant.	High

Job roles	Existing source(s) of relevant skills	Skills required for each job role	Skill gaps identified	Required augmentation level
	Experience in designing brine based electrolyser units in chlor-alkali plants	**Planning**: Maintain design schedules and address design issues through the development and acceptance of solutions. **Initiate On-site Logistics and Plans:** Develop and implement initial on-site logistics and utilization plans until the dedicated project team is assigned. Verify the presence of necessary permits to initiate construction.	• Ability to identify optimal locations for green hydrogen production. • Knowledge of production technologies and best practices to provide economical solutions for green hydrogen production. • Proficiency in design considerations for Integration of RE power & green hydrogen plant.	Low
 Business development manager	Experience in heading business development and of chemical/ RE equipment/power industry.	**Market Research and Analysis:** Conduct thorough market research to identify potential business opportunities and trends. Analytical skills to assess market dynamics, competition, and customer needs. **Networking:** Building and maintaining strong relationships with key stakeholders, including government agencies, industry associations, and potential clients. Leveraging industry connections for business development opportunities. **Strategic Planning:** Developing and implementing strategic business plans. Formulating market entry strategies and expansion plans.	• Comprehensive knowledge of green hydrogen production processes and technologies. • Familiarity with industry trends, regulations, and emerging technologies in the renewable energy sector.	Medium
 Supply chain manager	Experience in supply chain management/procurement division in verticals such as machinery manufacturing, power plant equipment, and renewable energy	**Procurement and Negotiation:** Strong negotiation skills for securing favorable terms with suppliers. Experience in procurement processes, vendor management, and contract negotiation. **Risk Management:** Identifying and mitigating risks in the supply chain, including disruptions, delays, and quality issues. Developing contingency plans to address unforeseen challenges	• Familiarity with the technologies and processes involved in green hydrogen production.	Medium

Job roles	Existing source(s) of relevant skills	Skills required for each job role	Skill gaps identified	Required augmentation level
Project / plant manager (Installation & commissioning)	Experience in plant erection, commissioning, and service supervision in oil & gas, chemical industry	**Lead construction activities:** Includes on-site construction activities, including electrolyser plant setup and necessary infrastructure. **Develop comprehensive commissioning plans:** Includes creating schedules, resource needs, and test procedures. **Supervise commissioning:** Includes pre-commissioning, functional & performance testing. **Ensure compliance issues:** Conduct regular inspections and audits to identify potential issues, ensuring adherence to safety standards, and environmental regulations. **Troubleshoot and resolve technical challenges**: Address technical problems during commissioning process.	• Knowledge of activities related to erection and commissioning of electrolyser plants, compressors, and storage facilities. • Knowledge of green hydrogen system integration with RE power plant Dealing with cryogenic materials. • Knowledge of safety standards pertaining to green hydrogen.	Medium
	Experience in installation & commissioning with technology providers such as Linde, INOX, Air Liquide		• Knowledge of green hydrogen system integration with RE power plant.	Low
Operations & maintenance manager	Experience in leading O&M functions in chemical or petrochemical industry	**Supervise daily operations and compliance:** Oversee day-to-day plant operations and monitor process parameters. **Safety and regulatory compliance**: Foster a strong safety culture within the O&M team, ensuring compliance with regulations and permits. **Continuous improvement**: Identify opportunities for process optimization, efficiency improvements, and cost reduction, implementing best practices in O&M.	• Knowledge of operation and troubleshooting of electrolyser system & components and RE power generation units. • Capability to comprehend and interpret safety guidelines, operational and maintenance instructions, procedural manuals, and technical specifications pertaining to green hydrogen.	High
	Experience in designing brine based electrolyser units in chlor-alkali plants		• Knowledge to perform inspection, troubleshooting, repair, and testing of RE power generation units.	Low

Job roles	Existing source(s) of relevant skills	Skills required for each job role	Skill gaps identified	Required augmentation level
 Equipment testing lab manager	Engineering or technology company laboratories	**Manage daily operations**: Supervise daily operations for membrane electrode assembly, Stack, and System testing, which may involve conducting tests continuously, 24/7, or across multiple work shifts. **Monitor lab needs**: Track laboratory necessities, including safety measures, power supply, hydrogen availability, ventilation, compressed air, coolant, purity of reactants and coolant, and adherence to building codes	• Knowledge of safety standards and codes pertaining to green hydrogen. • Expertise in system testing of electrolyser components, storage, and pipeline.	Medium
 Regulatory Officer	Gas industry/ Consultant with expertise in regulatory affairs	Monitor significant policy changes and regulatory advancements within the sector. Ability to map policy & regulatory risks related to green hydrogen in project identification and assessment. Foster connections with pertinent regulatory bodies to obtain necessary clarifications and approvals as and when required.	• Knowledge of policies and regulatory developments in the sector • Knowledge of safety standards and codes pertaining to green hydrogen.	Medium
 Project Financing Specialist / officer	Gas industry / Consultant with expertise in financing projects	**Project finance capabilities -** Expertise in project finance structures and financial modeling, ability to negotiate financing terms and manage financial instruments. **Project due diligence and coordination** **Contracts-** Draft, review, and manage contracts with suppliers and contractors. Resolve contractual disputes effectively. **DPR and third party deliverable preparation -** Develop detailed project reports and documentation. Ensure accuracy and compliance of third-party deliverables.	• Understanding green hydrogen market dynamics, and regulatory frameworks. • Familiarity with environmental regulations, sustainability standards, and carbon pricing mechanisms. • Familiarity with incentive structures, subsidies, and financing mechanisms unique to green hydrogen projects. • Understanding of types of financial risk associated with green hydrogen projects.	High
 Integration engineer	Chemical/Gas processing industry	**System optimization**: Knowledge to optimize various components and processes within the system to ensure seamless and efficient operation. **Efficiency improvement**: Identifying opportunities for improving the overall efficiency of the green hydrogen production process, from feedstock to storage, and implementing measures to enhance performance.	• Understanding of Green H2 equipment and infrastructure, • Knowledge of new and emerging technologies within hydrogen and energy storage. • Understanding of plant performance metrics and monitoring systems.	High

Job roles	Existing source(s) of relevant skills	Skills required for each job role	Skill gaps identified	Required augmentation level
	Degree in chemical Engineering or similar/ Master's in related field	**Develop and implement systems integration test plans**.	• Knowledge of new and emerging technologies within hydrogen and energy storage • Understanding of Green H2 equipment and infrastructure • Knowledge of various components and processes within green hydrogen system.	High
 Instrumentation & Automation engineer	Experience within automation engineering, with special focus on power plants, hydrogen, or Gas/LNG sector	**Comprehensive understanding of execution phases**: Knowledge of all execution phases from early development to construction phase. **Design proficiency in automation systems**: Ability to perform specification and design of automation systems. **Automation systems creation and activation**: Oversee the creation and activation of automation systems for green hydrogen, addressing all technical aspects of the project concerning instrumentation and controls, as well as SCADA. **Ensuring regulatory compliance in green hydrogen**: Guarantee compliance with green hydrogen regulations to meet regulatory standards.	• In depth understanding of Green H2 equipment and infrastructure, • Understanding of plant performance metrics and monitoring systems • Understanding of green hydrogen regulations to meet regulatory standards. • Knowledge of automation systems for green hydrogen, such as SCADA	Medium
	B.Sc./M.Sc. in Electrical engineering, Automation technology, Mechanical engineering or similar		• Knowledge of all execution phases from early development to construction phase • Understanding of green hydrogen regulations to meet regulatory standards. • Knowledge of automation systems for green hydrogen, such as SCADA	Medium
 Industrial design engineer	Experience in Gas Processing plants/Hydrogen Generation plants	**Sizing & selection**: Proficiency in sizing and selection of Piping & instruments of complete system, preparation of Bill of Material, and project cost/estimation **Preparation of various engineering deliverables (Drawings & Documents).** **Technical proposal expertise**: Expertise in technical proposal-making and execution of green hydrogen projects	• Knowledge around Hydrogen/ Green Hydrogen which will be responsible for engineering, design & integration of green hydrogen generation systems, Gas compression, Gas storage, and transportation	High
	Bachelor's/ master's degree in industrial design or in business administration		• In depth understanding of Green H2 equipment and infrastructure, • Knowledge of new and emerging technologies within hydrogen and energy storage	High

Job roles	Existing source(s) of relevant skills	Skills required for each job role	Skill gaps identified	Required augmentation level
			• Knowledge of Computer-aided design (CAD), graphic modelling, design principles etc.	
 Mechanical, & Electrical engineer	Experience in Refinery, Gas, Power, Chlor-alkali industry	**Integration with Other Systems:** Understanding how mechanical systems integrate with other systems in a hydrogen production facility, including electrical, control, and civil engineering components. **High-Pressure Systems:** Expertise in designing and working with high-pressure systems, as hydrogen is often stored and transported under high pressure. **Power Electronics for Electrolysers:** Expertise in power electronics, especially as applied to electrolysers, to control and optimize the electrical input required for hydrogen generation. **Grid Connection and Power Distribution**: Expertise in connecting hydrogen production facilities to the electrical grid and designing power distribution systems within the facility.	• To integrate infrastructure-scale hydrogen technology systems with renewable energy sources. • Familiarity with different storage technologies for hydrogen, such as compressed hydrogen storage and liquid hydrogen storage.	Medium
	Bachelor's degree in mechanical, & electrical engineering		• Understanding the principles and technologies involved in green hydrogen production, including electrolysis and other emerging methods. • Knowledge of compression technologies for handling and transporting hydrogen, considering its gaseous nature and potential high-pressure storage requirements • Understanding the compatibility of materials with hydrogen to avoid issues like embrittlement and selecting appropriate materials for equipment and pipelines. • Knowledge of designing tools such as SLD etc.	Medium
 Civil engineer	Experience in Refinery, Gas, Power, Chlor-alkali industry	**Site planning & design:** Plan and design the layout of the green hydrogen production facility, considering factors such as safety, efficiency, and environmental impact. **Structural Design and Analysis:** Designing and analyzing the structural components of the facility, including foundations, buildings, and supporting	• Understanding the fundamentals of green hydrogen production processes, including electrolysis and other hydrogen generation methods. • Knowledge of different methods of hydrogen storage and their structural requirements, such as underground storage or aboveground tanks.	Medium

Job roles	Existing source(s) of relevant skills	Skills required for each job role	Skill gaps identified	Required augmentation level
	Bachelor's degree in civil engineering	structures, to ensure they meet safety and regulatory standards. **Knowledge of designing tools such as CAD** **Pressure Vessel Design:** Knowledge of pressure vessel design principles, as hydrogen is often stored under high pressure. This includes understanding codes and standards related to pressure vessel construction.	• Awareness of materials that are compatible with hydrogen and those that may react adversely. This is crucial for selecting appropriate construction materials. • Knowledge of different methods of hydrogen storage and their structural requirements, such as underground storage or aboveground tanks. • Understanding the impact of hydrogen on materials and structures, particularly in terms of corrosion, and implementing measures.	Medium
 Process engineer	Experience in hydrogen or gas processing, chemical manufacturing, or refining	**Expertise in mapping plant processes:** Create detailed descriptions of plant processes for green hydrogen production. **Sizing electrolysis sub-systems:** Calculate and size electrolysis sub-systems, such as water purification, and components, including hydrogen and oxygen purification and compression. **Process simulation and modeling:** Proficiency in using process simulation software to model and optimize hydrogen production processes. **Gas Purification:** Expertise in gas purification techniques to remove impurities and contaminants from hydrogen streams.	• Familiarity with catalysts used in hydrogen production processes and their impact on reaction kinetics and efficiency. • Knowledge of materials compatibility with hydrogen to address corrosion and degradation issues in the design and operation of equipment. • Understanding safety protocols specific to hydrogen, including explosion prevention and emergency response procedures.	High
	Bachelor's degree in chemical engineering		• Knowledge of principles and operation of electrolysis technology, which is a key process in green hydrogen production. • Knowledge of water electrolysis processes, including alkaline electrolysis, proton exchange membrane (PEM) electrolysis, and solid oxide electrolysis cells.	High
 Pipeline engineer	Experience in working within process industries such as refining, hydrogen production or other facilities	**Piping installation**: Experience supervising the piping installation and testing during the installation phase. **Troubleshooting**: Ability to troubleshoot problems that may arise and make repairs as necessary. **Knowledge of high-pressure gas systems.**	• Familiarity with the properties of hydrogen	Medium

Job roles	Existing source(s) of relevant skills	Skills required for each job role	Skill gaps identified	Required augmentation level
Hydrogen system integration specialist/ Solution architect	Refinery, Gas, Power, Renewables industry	**Optimization techniques:** Understanding of optimization techniques to determine the optimal size and location of renewable energy sources, as well as the optimal operation of the electrolysis and hydrogen storage systems. **Electrical infrastructure design**: Designing the main electrical infrastructure of applications in the Hydrogen ecosystem, including Medium-and Low Voltage (Power distribution and Motor Control Center) and power automation.	• In depth understanding of Green H2 equipment and infrastructure, • Understanding of plant performance metrics and monitoring systems • Knowledge of new and emerging technologies within hydrogen and energy storage • Dealing with cryogenic materials. • Familiarity with the properties of hydrogen	High
Power systems, Evacuation & commissioning engineers	Power, Renewables industry	**Feasibility analysis:** Assessing grid connection feasibility at substations for green hydrogen projects including Solar & Wind. **Power system understanding**: Shall have good understanding of power systems & knowledge of CTU & STU networks & plans. **Knowledge of high-voltage power electronics** that provide large energy inputs into hydrogen production (e.g., transformers, substations, capacitors)	• Expertise in electrolyser system components, storage, and pipeline technical parameters • Knowledge of high-pressure gas systems and safety standards pertaining to green hydrogen.	Medium
Purchase & logistics executive	Experience in supply chain management/logistics division in verticals such as machinery manufacturing, power plant equipment, and renewable energy	**Procurement expertise:** Ability to source and negotiate contracts for raw materials, equipment, and services related to green hydrogen production. **Supply chain management:** Understanding of the entire supply chain process, from procurement to production to distribution, Efficiently receiving and inspecting incoming materials, verifying received items against purchase orders.	• Basic understanding of electrolyser technologies and parts of electrolysers. • Knowledge of specifications of raw materials, equipment, and services related to green hydrogen production.	Medium
	Oil & Gas, Fertilizer, Chlor-Alkali, Renewable energy Industry	**Familiarity with electrolysis-based production** Encompassing on-site hydrogen storage, process, and occupational safety, **Comprehensive sustainability awareness**: Thorough understanding of comprehensive sustainability	• In depth understanding of Green H2 equipment and infrastructure, • Understanding of plant performance metrics and monitoring systems • Familiarity with the properties of hydrogen	Medium

Job roles	Existing source(s) of relevant skills	Skills required for each job role	Skill gaps identified	Required augmentation level
Equipment Certifiers		considerations, including environmental impacts and water sourcing.		
Water treatment & testing specialist	Mechanical engineers	**Understanding water parameters for green hydrogen production**: Familiarity with the necessary water parameters and quality essential for production of green hydrogen. **Capability to propose test strategies**: Proficiency in identifying and suggesting testing strategies to address issues and concerns associated with water quality.	• Familiarity with the necessary water parameters and quality essential for production of green hydrogen. • Dealing with cryogenic materials. • Familiarity with the properties of hydrogen	Medium
Green Hydrogen Plant Technician / Electrolyser Technician	Power/ Renewable industry	**Cell Stack Operation:** Understanding the operation, maintenance, and troubleshooting of electrolysis cell stacks, which are the core components of electrolysis systems. **Purification:** Knowledge of water purification processes and familiarity with purification systems for separating and purifying hydrogen and oxygen produced during electrolysis. **Pressure management:** Understanding and managing the high-pressure conditions associated with hydrogen production through electrolysis. **Monitoring & control systems:** Operating and maintaining monitoring and control systems for electrolysis processes, ensuring optimal performance and efficiency.	• Understanding of the principles of electrolysis, including the electrochemical processes involved in the production of hydrogen from water. • Knowledge of the components of an electrolysis system, including electrodes, membranes (for PEM electrolysis), and cell stacks • Courses and certifications for handling hydrogen gas.	High
Instrumentation Technician	Power/ Renewable industry	**Pressure & temperature control:** Understanding pressure and temperature control systems as they relate to the various stages of hydrogen production, storage, and transportation. **Preventive maintenance:** Conduct routine preventive maintenance and calibrations on electrical & instrument equipment and components. **Understanding of degradation mechanisms:** Includes factors like vibration, corrosion, and chloride-induced stress corrosion cracking.	• Familiarity with instruments specifically designed for monitoring and controlling hydrogen production processes, including sensors and detectors. • Courses and certifications for handling hydrogen gas. • Knowledge of electrolyser system components, storage, and pipeline technical parameters.	Medium

Job roles	Existing source(s) of relevant skills	Skills required for each job role	Skill gaps identified	Required augmentation level
Gas & Pipeline Technician	Power/ Renewable industry	**Installation & testing**: Piping installation and testing during the installation & maintenance phase. **Pipeline monitoring & control systems**: Proficiency in monitoring and controlling hydrogen pipelines using automation and control systems. **Pipeline integrating management**: Implementing strategies for ensuring the integrity of hydrogen pipelines, including regular inspections, leak detection, and corrosion prevention measures.	• Knowledge of cathodic protection systems to prevent corrosion in pipelines and associated infrastructure. • Courses and certifications for handling hydrogen gas.	Medium
Mechanical & Electrical Technician	Experience in Refinery, Gas, Power, Chlor-alkali industry	**Hydrogen Infrastructure Layout:** Understanding the layout and design principles specific to hydrogen production facilities, including foundations and structural components. **Hydrogen Compression Systems:** Familiarity with systems and equipment used in hydrogen compression, ensuring the safe and efficient storage and transportation of hydrogen. **Pressure Vessel Operations:** Knowledge of operations and maintenance associated with pressure vessels used in hydrogen storage. **Power Electronics for Electrolysers:** Knowledge of power electronics used to control and optimize electrical input for electrolysis processes. **Instrumentation and control systems:** Proficiency in the installation, operation, and maintenance of instrumentation and control systems used in hydrogen production.	• Understanding the electrical components and systems associated with electrolysis, a key process in hydrogen production. • Courses and certifications for handling hydrogen gas.	Medium
Water purification technician	Power/ Renewable industry	• Capability to address issues and concerns associated with water quality.	• Courses and certifications for handling hydrogen gas. • Familiarity with the necessary water parameters and quality essential for the production of green hydrogen.	Medium

Job roles	Existing source(s) of relevant skills	Skills required for each job role	Skill gaps identified	Required augmentation level
Welders (structural, pipes) & Plumbers	Vocational and training institutes	• General knowledge to carry out plumbing and welding activities as required	• Courses and certifications for handling hydrogen gas.	Medium
Health & safety head and manager	Health and safety management/ bachelor's degree in occupational health and safety, Environmental Science, Engineering, or a related field	**Executing HSE initiatives:** Ability to implement and complete HSE initiatives for manufacturing, engineering, and commissioning operations. **Safety regulations awareness:** Understanding of safety regulations and general safety requirements	• Knowledge of emerging health and safety trends, technologies, and best practices, and integrate within green hydrogen industry. • Knowledge of handling green hydrogen systems and the risks associated to conduct inspections of site-activities and monitor the implementation and practical use of EHS measures.	Medium
Gas Inspector	Oil & gas, Chemical industry, or a related field	**Safety compliance:** Inspecting and ensuring compliance with safety regulations in the handling, production, and transportation of hydrogen. **Equipment Inspection:** Conducting inspections of equipment, pipelines, and storage facilities to ensure they meet safety and environmental standards.	• Courses and certifications for handling hydrogen gas. • Knowledge of chemical properties of hydrogen and its reactions with other materials of machinery, storage infrastructure etc.	Medium
Quality assurance technician	Power, Renewables industry, Vocational and training institutes	• Knowledgeable about compliance with industry standards, regulations, and environmental requirements.	• Familiarity with safety protocols and guidelines concerning renewable energy systems and green hydrogen facilities.	Medium

Key Takeaways –

1 High level of augmentation –

- Design professionals- Transitioning from design and engineering verticals of oil & gas/thermal projects, design professionals would lack proficiency in technical aspects of gas compression, storage, and integration with renewable energy for green hydrogen production. Additionally, specialized knowledge will be needed to devise economical solutions, identify optimal locations, and engineer green hydrogen systems.
- O&M professionals – With experience in chemical and petrochemical industry, O&M professionals would need additional skills in inspecting, troubleshooting, and maintaining electrolysers and RE power units for green hydrogen production. Professionals with experience in designing brine-based electrolyser units in chlor-alkali plants will require a low level of skill augmentation.
- System integrators – With limited/no prior experience of hydrogen storage and hydrogen systems from gas/power/renewables industry, integration experts would need to stay abreast of emerging technologies in hydrogen for effective system integration.
- Electrolyser technician - Renewable energy/power industry-sourced electrolyser technicians must understand electrolysis principles, components (electrodes, membranes), and be certified for safe hydrogen gas handling.

2 Medium level of augmentation –

- Professionals working in project and plant management, equipment testing, mechanical / electrical power system engineers and technicians, equipment certifiers, health and safety managers, inspection, and quality assurance would require a medium level of skill augmentation. They are comparatively less critical job roles which would require upskilling / reskilling on certain areas related to hydrogen gas, its effect on materials and safety issues.

7.2.2 ELECTROLYSER MANUFACTURING

This section delves into the requisite skills across diverse job roles within electrolyser manufacturing, evaluating the necessity of specific hydrogen-related proficiencies and current skill gaps for each role. The table below details the skill requirements, enabling a comprehensive understanding of the potential need for upskilling or re-skilling within each job role.

In India, the electrolyser manufacturing industry is in its nascent stage, capable of assembling of imported components. This emerging sector is experiencing gradual growth, primarily in the integration of foreign-sourced parts.

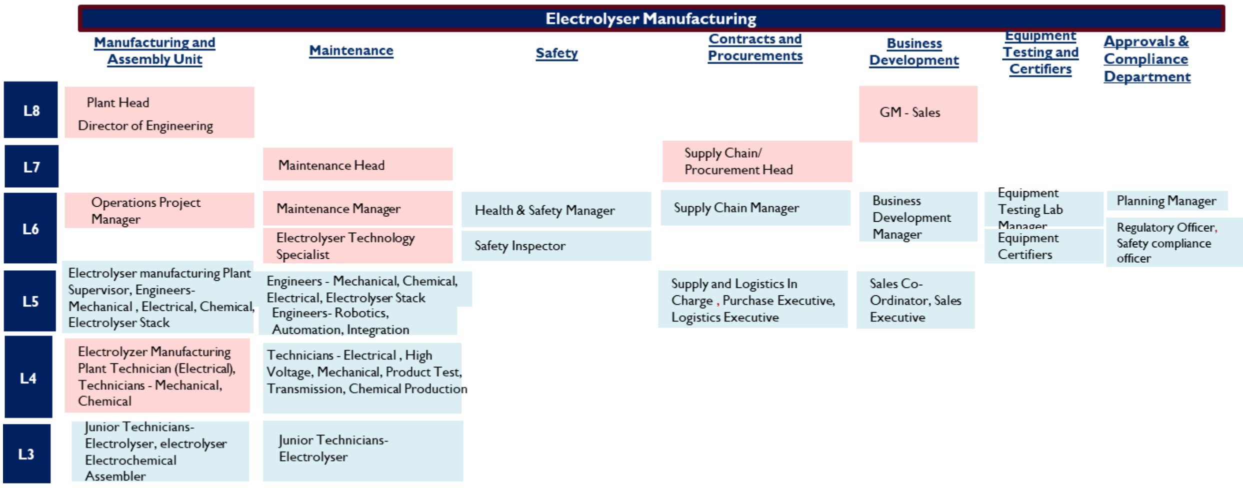
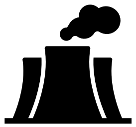
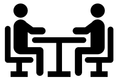
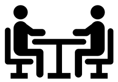


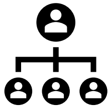
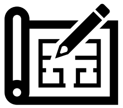
Figure 7.17 Skill Gap Analysis for Electrolyser Manufacturing Job Roles

The following are the details of skills gaps identified pertaining to each job roles associated with the current responsibilities of the workforce in the industry:

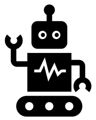
Table 7.10: Capability in demand across electrolyser manufacturing job roles

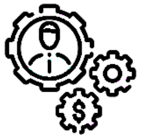
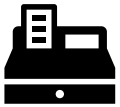
Job roles	Existing source(s) of relevant skills	Capability / skills required for each job role	Skill gaps identified	Required augmentation level
 Plant Head	Experience with hydrogen electrolysers and/or fuel cell development or heading production & operations in chemical industry	**Production optimization:** Oversee the production planning and execution, focusing on optimizing hydrogen electrolyser manufacturing processes for efficiency and scalability. **Plant Operations:** Responsible for overseeing electrolyser manufacturing processes and related systems. Possess knowledge of production equipment, machines, plant design, plant operation, quality controls, supply chain management, production management. **Budget management**: Skills in managing budgets effectively, optimizing resource allocation.	• Demonstrate in-depth knowledge of electrolyser technology, hydrogen production processes, and associated equipment. • Knowledge of compliance requirements and standards & specifications of electrolyser parts	High
 Director of Engineering	Experience with hydrogen electrolysers and/or fuel cell development	**Technical Domain Knowledge:** Proficiency in mechanical design and engineering principles related to the construction of electrolysis equipment and assembling of electrolyser parts. **Design optimization for cost-effective manufacturing:** Work with the electrolyser design team to suggest improvements for cost-effective manufacturability. **Operational expertise**: Engage in component specification, selection, vendor, and partner selection, and procure pre-production materials for electrolyser system development.	• Knowledge of the stack, balance of plant equipment, and components in electrolyser systems • Assembly of electrolyser components in the manufacturing process. • Knowledge of materials used in electrolyser manufacturing, including proficiency in materials selection, corrosion resistance, and durability working with hydrogen.	High
 Maintenance head	Experience with hydrogen electrolysers and/or fuel cell development or heading production	**Optimize maintenance:** Expertise in maintaining and troubleshooting faults in electrolyser components and related machinery. **Process expertise**: Understanding the principles and intricacies of different electrolysis technologies and their processes.	• Knowledge of the stack, balance of plant equipment, and components in electrolyser systems.	High

Job roles	Existing source(s) of relevant skills	Capability / skills required for each job role	Skill gaps identified	Required augmentation level
	& operations in chemical industry			
 Supply chain / procurement head	Experience in heading supply chain management in verticals such as machinery manufacturing, power plant equipment, and renewable energy.	**Supply Chain Management:** Expertise in overseeing the entire supply chain, from sourcing raw materials and part of electrolyser to delivering in timely manner. **Vendor Management:** Proficiency in drafting, reviewing, and managing contracts with suppliers, ensuring compliance with legal and regulatory requirements. Ability to negotiate favorable terms, pricing, and contracts with suppliers.	• Awareness of international electrolyser components supply chain dynamics, including specification compliance, logistics challenges, and global market trends for materials sourcing. • Familiarity with import and export market of electrolyser raw material. • Understanding the specifications and requirements for electrolyser manufacturing to facilitate accurate sourcing.	High
 Business development head	Experience in heading business development and of chemical/ RE equipment/ power industry.	Understanding of Electrolyser technology, proficiency in business case development **Project Management:** Coordinating and managing business development projects to ensure timely and successful implementation. **Cost management:** Budgeting, financial analysis, and cost management to ensure profitable business development strategies. Strong sales skills for promoting electrolyser products and negotiating contracts with clients and partners.	• Technical know-how about electrolyser with ability to build strategic partnerships and alliances with key players in the hydrogen sector. • Requirement to stay updated on the latest trends, innovations, and market dynamics related to electrolyser technology, renewable energy, and hydrogen markets.	High
 BD Manager	Experience in heading business development and of chemical/ RE equipment/power industry.	**Sales Forecasting:** Work with the sales team to develop accurate sales forecasts. Adjust strategies based on market trends and sales performance. **Cross-Functional Collaboration:** Capability to **c**ollaborate with technical, production, and other internal teams to align business development strategies with operational capabilities.	• Proficiency to monitor trends in the production and adoption of green hydrogen. Develop strategies that align with the growing demand for electrolysers. •	Medium

Job roles	Existing source(s) of relevant skills	Capability / skills required for each job role	Skill gaps identified	Required augmentation level
 Operations & maintenance manager	Experience with hydrogen electrolysers and/or fuel cell development or production & operations in chemical industry	**Project Management:** oversee maintenance of projects, upgrades, or modifications, ensuring timely and cost-effective implementation. Capability in implementing maintenance strategies, including preventive and predictive maintenance. **Technical Proficiency:** In-depth knowledge of electrolysis technology, hydrogen production processes, and the specifications of equipment used in the electrolyser plant.	• In depth knowledge of the impact of hydrogen on materials and equipment, with a focus on corrosion prevention and material compatibility. • In depth knowledge of electrolyser manufacturing/assembly process.	High
 Supply chain manager	Experience in supply chain management/procurement division in verticals such as machinery manufacturing, power plant equipment, and renewable energy	**Supply Chain Management:** Expertise in overseeing the entire supply chain, from sourcing raw materials to delivering finished products, to ensure seamless manufacturing processes. Ability to integrate digital technologies, such as IoT sensors to enhance transparency, traceability, and efficiency in the supply chain. **Cost Analysis and Management:** Skill in conducting cost analysis, identifying cost-saving opportunities, and implementing effective cost management strategies.	• Knowledge of specifications and requirements for electrolyser manufacturing to facilitate accurate sourcing.	Medium
 Equipment testing lab manager	Experience in managing equipment testing in a manufacturing plant.	**Laboratory Testing Expertise:** Proficient in designing and conducting various tests to validate the performance, reliability, and safety of electrolyser. **Instrumentation and Measurement:** Proficiency in using a variety of testing instruments and equipment for accurate measurement, calibration, and analysis of electrolysis equipment. Experience in calibrating testing equipment regularly to maintain accuracy and reliability in measurement results. **Data Analysis and Interpretation:** Strong analytical skills to interpret test results, identify deviations from specifications, and make data-driven decisions.	• Knowledge of industry standards and specification related to hydrogen equipment testing to ensure compliance with safety and quality requirements. • Competence in implementing hydrogen leak detection methods and technologies within the testing lab.	Medium

Job roles	Existing source(s) of relevant skills	Capability / skills required for each job role	Skill gaps identified	Required augmentation level
Health & Safety manager	Experience in managing H&S in a manufacturing plant.	**Compliance management:** In-depth knowledge of local, regional, and national health and safety regulations applicable to the manufacturing and handling hydrogen and electrolysers. **Risk assessment and management**: capability to conduct assessments to identify potential hazards associated with the manufacturing, installation, and operation of electrolysis systems. **Emergency response planning:** expertise to develop comprehensive emergency response protocols tailored to potential incidents in an electrolyser manufacturing environment, capability to Conduct regular emergency response training sessions for all employees.	• Develop protocols for responding to hydrogen leaks, including evacuation procedures and communication measures. • Capability to incorporate specific measures for dealing with hydrogen-related fires, considering the unique characteristics of hydrogen flames specially for testing labs.	Medium
Electrolyser technology specialist	Experience in chemical/ RE equipment/ electrolysers and/or fuel cell development	**Technical expertise:** Knowledge of design, engineering, and performance aspects of electrolysis systems. **Troubleshooting:** Troubleshooting technical issues and proposing solutions for improvement. Optimizing electrolysis processes for efficiency, cost-effectiveness, and reliability.	• In-depth knowledge of the electrolyser technologies – PEM/alkaline, including chemical reactions and electrochemical processes. • Understanding the properties and selection of electrode materials and coatings for durability, catalytic activity, and resistance to corrosion. • Understanding the principles of pressure management within electrolyser systems for safe and efficient hydrogen production.	High
Equipment Certifiers	Experience in manufacturing industry	**Standards:** Develop and maintain a comprehensive understanding of relevant industry standards and local/national and international codes for hydrogen electrolysers and parts. **Review and Audits:** Capability to review design specifications and manufacturing processes to ensure compliance with standards. Capability to conduct inspections and audits to verify that equipment meets certification criteria. Issuing certification for electrolysis equipment that meets safety and quality standards.	• In-depth knowledge of national and international standards governing hydrogen equipment, ensuring that the manufactured electrolysis equipment complies with these standards. • Knowledge of relevant certification standards for hydrogen equipment and the ability to apply them to the certification process.	Medium

Job roles	Existing source(s) of relevant skills	Capability / skills required for each job role	Skill gaps identified	Required augmentation level
 Safety Inspector	Experience in managing safety in a manufacturing plant.	**Hazard Management:** Ensuring a safe working environment in the electrolyser manufacturing plant. **Compliance management:** Conduct safety testing and evaluation activities to verify compliance standards and specifications.	• Proficiency in developing safety protocols and checklists for the process of manufacturing/ assembling electrolyser technology.	Medium
 Mechanical/ electrical/ chemical engineer/electrolyser stack engineer	Engineering, experience with manufacturing plants/electrolyser plants/R&D at research institutes.	**Technology expertise:** In-depth understanding of different electrolysis technologies. Proficiency in mechanical design and engineering principles related to the construction of electrolysis equipment and understanding of electrical systems, controls, and instrumentation integral to electrolyser operation. **Troubleshooting and Problem-Solving :** Ability to analyze and resolve technical issues that may arise during manufacturing processes.	• In-depth knowledge of materials used in electrolyser manufacturing, including materials selection, corrosion resistance, and durability. • Understanding hydrogen's flammability and ignition factors will also be important to manufacturing.	Medium
 Robotics/Automation engineers/ Integration	Experience in control system design for industrial automation (specifically in electrolyser, fuel cell, and dispenser systems). Degree in robotic and automation.	**Robotics :** Develop and optimize robotic systems for tasks such as material handling, assembly, and quality control within the manufacturing process **Automated control systems :** Design automated quality control systems to inspect and validate components and final products, ensuring adherence to quality standards **Programming and Coding :** Develop and maintain the software code for programmable logic controllers (PLCs) and other automation systems used in manufacturing. **System Integration :** Design and implement automation systems to integrate various components of the electrolysis system, ensuring seamless operation.	• Proficiency in programming and coding for automation systems used in electrolysis manufacturing, considering the unique requirements of hydrogen production. • Integrating hydrogen sensors and detection systems into automated processes to monitor and ensure safe hydrogen handling.	Medium

Job roles	Existing source(s) of relevant skills	Capability / skills required for each job role	Skill gaps identified	Required augmentation level
 Supply and Logistics in charge	Experience in supply chain management/logistics division in verticals such as machinery manufacturing, power plant equipment, and renewable energy	**Inventory Management:** Proficiency in managing inventory levels, optimizing stock levels, and implementing efficient inventory control measures. **Logistics and Transportation:** Knowledge of logistics principles, transportation management, and coordination of shipments to optimize delivery times and reduce costs. **Technology Proficiency:** Familiarity with supply chain management software, Enterprise Resource Planning (ERP) systems, and other relevant technologies for efficient logistics operations.	• In depth knowledge of specifications and requirements for electrolyser manufacturing parts. • Proficiency of handling electrolyser parts and machinery.	Medium
 Sales Co-ordinator/Sales Executives	Degree in marketing, sales, or a related field.	**Technical Sales Acumen:** Providing technical consultation to clients, understanding their specific needs, and recommending suitable solutions. **Quotation and Proposal Preparation:** Ability to prepare accurate and comprehensive sales quotations and proposals for potential clients based on their requirements.	• Possessing an understanding of electrolysis technology and the ability to articulate technical details to clients.	Medium
 Purchase and Logistics executive	Experience in supply chain management/logistics division in verticals such as machinery manufacturing, power plant equipment, and renewable energy	**Procurement Skills:** Executing procurement processes efficiently, organizing and maintaining an orderly procurement process, coordinating with vendors for timely deliveries. **Material handling:** Efficiently receiving and inspecting incoming materials, verifying received items against purchase orders, maintaining accurate documentation of received materials.	• Basic understanding of electrolyser technologies and parts of electrolysers. • Knowledge of specifications of various electrolyser parts.	Medium

Job roles	Existing source(s) of relevant skills	Capability / skills required for each job role	Skill gaps identified	Required augmentation level
Mechanical / Electrical / High voltage / electromechanical technician	Experience in electrolyser assembly unit, manufacturing plant, gas, chlor-alkali, chemical & water treatment plant	**Technical Expertise:** Mechanical assembly and troubleshooting, technical drawing interpretation, knowledge of power tools, familiarity with electrical systems and components. Mechanical and electrical assembly skills, familiarity with blueprint interpretation, ability to use assembly tools.	• Understanding of materials compatibility in hydrogen systems • Knowledge of hydrogen sensor technologies • Familiarity with hydrogen system integration	Medium
Electrolyser technician	Experience in electrolyser assembly unit, manufacturing plant, gas, chlor-alkali, chemical & water treatment plant	**Electrolyser assembly**: Detailed examination of electrolyser components. Quality control measures during assembly. Integration of components within the electrolyser system. Proper alignment and coupling of system parts. Integration of sensors and control instruments. **Compression and storage**: Overview of compression technologies Various methods of hydrogen storage Hydrogen Compression Technologies; Centrifugal Compressors, Dynamic Compressors, etc. Compression-related hazards and safety protocols Emergency shutdown procedures **Plant operation & maintenance**: Predictive maintenance techniques, Leakage detection, Troubleshooting techniques.	• Understanding of hydrogen & its properties. • Hydrogen production technologies • Electrolyser system overview • Familiarity with hydrogen system integration • Hydrogen Safety	High
Product test technician	Experience in product testing in electrolyser assembly unit	**Testing:** Knowledge of quality control procedures, Data collection and analysis, Equipment calibration knowledge.	• Familiarity with hydrogen-specific testing protocols • Understanding of hydrogen sensor technologies in electrolysers.	Medium

Key Takeaways –

1 High level of augmentation –

- O&M professionals – With experience in chemical and petrochemical industry, O&M professionals would need in-depth knowledge of knowledge of electrolyser manufacturing/assembly process as well as additional skills in inspecting, troubleshooting, and maintaining electrolyser plant.
- Electrolyser technology specialist – A professional transitioning from a chemical/ RE equipment/ electrolysers and/or fuel cell development industry would require high level of upskilling for working as an electrolyser technology specialist. They would require enhancing their knowledge of PEM / alkaline electrolyser technologies, electrode material selection, and pressure management principles for safe and efficient hydrogen production.
- Electrolyser technician - Renewable energy/power industry-sourced electrolyser technicians must understand electrolysis principles, components (electrodes, membranes), electrolyser assembly techniques and hold certifications for safe hydrogen gas handling.

2 Medium level of augmentation –

Professionals in engineering and maintenance, including mechanical, electrical, electrolyser stack and chemical engineers, as well as those in equipment testing and certification, would benefit from a medium level of skill augmentation. This reskilling / upskilling requirement primarily involves enhancing their understanding of electrolyser components and gaining proficiency in standards and specifications related to their respective fields.

7.3 KEY PRIORITY JOB ROLES

This segment focuses on the identification of priority job roles derived from the comprehensive analysis conducted for skilling requirement across the green hydrogen value chain. The objective is to discern and prioritize key job roles crucial from the perspective of skilling requirements.

Methodology

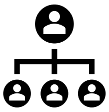
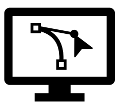
In previous sections, skill gaps across different facets of a hydrogen production plant and electrolyser manufacturing plant have been identified. This involved highlighting the current demands for specific job roles and outlining the existing skill gaps. These job roles have been categorized into high, medium, and low levels based on the extent of skilling augmentation required.

To identify the key priority job roles, the consolidated list of job roles that require high level of skilling is rated based on three parameters –

Availability	Criticality	Demand
Assessment of the current availability of skilled professionals for each job role, considering the pool of talent within the industry.	Evaluation of the impact and significance of each high-priority job role in the overall operational efficiency and success of the plants.	Job roles which are likely to be required in higher numbers by 2030 have been rated high
	Rating Criteria	
1 to 3 = High to not available	1 to 3 = Low to High	1 to 3 = Low to High

Rating of job roles - The rating of the job roles based on the above parameters is as follows:

Table 7.11 Rating of job roles

S.I	Job roles (High skilling requirement)	Rating				Remarks
		Availability	Criticality	Demand	Overall	
Hydrogen Production						
1	 Planning and Design head / manager	1	2	1	**4**	**Availability**: International consultants can be hired for this; however, currently available domestic skill may be limited **Criticality**: Required for medium / large plants; may not be required for smaller plants. **Demand:** Medium / large plants are likely to be set up later than smaller plants.
2	 Operations & maintenance head / manager	2	3	2	**7**	**Availability:** Some skilled workforce is available from Chemical & petrochemical plants (incl. brine-based electrolysis) **Criticality:** Key activities required for all sizes of green hydrogen production plant. **Demand:** required in less number (1 each per 1 GW plant capacity)
3	 Integration engineer/ Hydrogen system integration specialist / Solution architect	1	3	1	**5**	**Availability:** Activities like those performed by electrical engineers can be drawn upon and utilized from existing resources. **Criticality:** Responsible for overall system, process, and control system integration for small, medium, and large-scale projects. **Demand:** required across design and installation & commissioning.
4	 Project Financing Specialist/officer	1	2	1	**4**	**Availability:** Existing project financing personnel can be utilized to some extent **Criticality:** Important for financial arrangements but not as central as technical roles. **Demand:** required in less number (2 per 1 GW plant capacity)
5	 Industrial design engineer	1	2	1	**4**	**Availability:** Existing Industrial design engineers can be utilized to some extent **Criticality:** Plant system construction and integration are dependent on design. Required for medium / large plants; may not be required for smaller plants.

S.I	Job roles (High skilling requirement)	Rating				Remarks
		Availability	Criticality	Demand	Overall	
						Demand: Medium / large plants are likely to be set-up later than smaller plants
6	 Process engineer	2	3	3	**8**	**Availability**: Some skilled workforce is available from Chemical & Petrochemical plants (incl. brine-based electrolysis) **Criticality:** The role is responsible for assessing & optimizing the entire process plant throughout its operational lifetime **Demand:** Required to across each shift to manage electrolyser operations.
7	 Green Hydrogen Plant Technician	3	3	3	**9**	**Availability:** Minimal due to the limited installation of electrolyser plants. **Criticality:** Managing day-to-day operations of electrolysers, including troubleshooting issues related to electrolyser components, across various plant sizes. **Demand:** Required to across each shift to manage electrolyser operations and maintenance.
Electrolyser Manufacturing						
8	 Electrolyser technology specialist	3	2	2	**7**	**Availability:** Minimal due to the limited electrolyser manufacturing/assembly plants. **Criticality:** During the construction/setup phase of the plant, it might not be necessary as it could be managed by the technology provider. However, there will be an urgent requirement to address day-to-day operational challenges. **Demand:** Required in less number (1 per 1 GW plant capacity), mostly to provide technology specific supervision.

7.3.1 TOP 5 PRIORITY JOB ROLES

The priority job roles identified through the rating matrix are key positions deemed essential for skilling. They are enumerated below:

01 **Green Hydrogen Plant Technician**
Green hydrogen production*

02 **Process engineer**
Green hydrogen production

03 **Electrolyser technology specialist**
Electrolyser manufacturing and assembly

04 **Operations & maintenance head / manager**
Green hydrogen production

05 **Integration engineer / Hydrogen system integration specialist / Solution architect**
Green hydrogen production

**Electrolyser technician job role is also a priority job role in an electrolyser manufacturing and assembly unit/plant which could benefit from similar skilling curriculum*

Figure 7.18 Top 5 Priority Job Roles

The priority job roles outlined above are expected to require significant augmentation over the available skill set in the labor market. These job roles are prioritized based on their combined ratings in three criteria - criticality, demand & availability.

These priority job roles are expected to be required for all major upcoming green hydrogen production / electrolyser manufacturing plants. Most of these roles are expected to be consistently engaged in day-to-day activities throughout the operational lifespan of the green hydrogen production / electrolyser manufacturing plant. Moreover, with advancement in the sector, hydrogen fuel cell technology is likely to be an area that might be important in future from a skilling point of view- considering the expected development in the end-use application of the fuel cells.

Currently, there is a pool of skilled workforce available from professionals in the chemical, petrochemical (including brine-based electrolysis), and power sector. However, the demand for these skills is anticipated to increase significantly with the increase in planned, under-construction and installed green hydrogen production plants. Thus, it might be prudent to develop structured skilling programs to ensure availability of required skilled resources especially for these priority job roles.

8 RECOMMENDATION - TRAINING CURRICULUM & WAY FORWARD

8.1 BROAD TRAINING CURRICULUM FOR THE 5 PRIORITY JOB ROLES

This segment outlines the appropriate broad training curriculum for the five priority job roles identified in previous sections of this report.

8.1.1 GREEN HYDROGEN PLANT TECHNICIAN (ELECTROLYSER TECHNICIAN) – GREEN HYDROGEN PRODUCTION[68]

The role of the electrolyser technician (Green Hydrogen Plant Technician) is pivotal in both the manufacturing / assembly unit of electrolyser and the production unit for green hydrogen. Their primary duties involve manufacturing and assembling electrolyser units in accordance with engineering drawings. They are also tasked with testing the assembled units under operational conditions.

Furthermore, the Green Hydrogen Plant Technician is responsible for the installation of electrolysers, including the integration of mechanical and electrical equipment within a green hydrogen plant. Additionally, the technician assists in conducting pre-commissioning tests, contributing to the commissioning of the electrolyser unit and other subsystems in a green hydrogen plant. The scope of the role extends to the operation and troubleshooting of the electrolyser unit.

The broad curriculum outlined for this position aims to facilitate the acquisition of knowledge and skills essential for performing these activities effectively.

Table 8.1 Curriculum for Green Hydrogen Plant Technician (Electrolyser Technician)

Course name	Green Hydrogen Plant Technician (Electrolyser technician)
NSQF Level	L4
Course duration	390 hours (Theory duration: 195 hours, Practical duration: 135 hours and remaining 60 hours for industry training)
Minimum Eligibility Criteria (Educational and/ or Technical Qualification)	10th pass with ITI / Diploma in Electrical, Electronics, Civil or Mechanical Engineering, Fitter, or Instrumentation is a prerequisite that will provide a solid foundation for learning the practical aspects of electrolyser operation and maintenance.
Minimum Entry Age for course	18-20 years

[68] Electrolyser technician job role is also a priority job role in an electrolyser manufacturing and assembly unit/plant which could benefit from similar skilling curriculum

Modules			
Module name	**Key Learning Outcomes**	**Course duration (hr)**	
		Theory	**Practical**
Module 1: Introduction to hydrogen & its properties	• Hydrogen and its colors • Characteristics of hydrogen • Physical & chemical properties of hydrogen • Green hydrogen value chain • Green hydrogen applications • Hydrogen safety hazards	15	0
Module 2: Hydrogen production technologies	• Types of green hydrogen production technologies systems (proton-exchange membrane, alkaline, and others), capacity, and sizes. • Various existing methods of hydrogen production globally and in India. • Technology readiness of each production technology in India. • Electrochemical reactions related to each technology. • Key parameters of electrolysis: current density, work pressure, operating temperature, hydrogen purity, volume, and weight. • Advantages and disadvantages of each technology. • Key manufacturers of each technology and understanding the standard equipment specifications across industry. • Understanding different job roles & responsibilities across a green hydrogen plant • 1 day visit to green hydrogen production plant (PEM / AE) to understand the fundamental working principle, layout of the plant, the applicable codes, standards, and protocols.	30	15
Module 3: Electrolyser system overview	• Overview of entire electrolyser system • Electrolyser Stack: Structure and Function • Electrolyser Cell Operation • Gas collector • Electrolyte Materials and Membranes • Catalysts and Electrodes • Gas Handling and Separation • Pressure categories of systems • 1 day visit to green hydrogen production plant (PEM/AE) to understand the key components and it's functioning as per plant layout diagrams,	30	15

<table>
<tr><td></td><td>the protection devices used, fundamental working principle of each component, etc.</td><td></td><td></td></tr>
<tr><td>Module 4: Electrolyser installation and assembly</td><td>Overview of the installation process and procedure
Safety considerations during installation.
Detailed examination of electrolyser components.
Quality control measures during assembly.
Integration of components within the electrolyser system
Proper alignment and coupling of system parts.
Integration of sensors and control instruments
Procedures for quality assurance during installation
Pre-installation checks and tests
Systematic testing of assembled electrolyser units
Overview of commissioning in electrolyser installation
Pre-commissioning checks and procedures
Systematic commissioning of electrolyser units
Importance of documentation in installation
Record-keeping and reporting protocols
Compliance with industry standards
One week training in electrolyser manufacturing / assembly plant and lab / facility to understand step by step process for assembly/installation of electrolyser plant and for hands-on training in the assembly of electrolyser units.</td><td>30</td><td>30</td></tr>
<tr><td>Module 5: Regulations and standards</td><td>Introduction to regulatory frameworks
Safety standards and protocols
Hydrogen safety codes
Hydrogen transportation regulations
Other national & international regulations related to production, handling & distribution of green hydrogen</td><td>15</td><td>0</td></tr>
<tr><td>Module 6: Plant operation & maintenance</td><td>Importance of systematic operation for efficiency
Role of technicians in plant operations
Step-by-step procedures for starting up electrolyser plants.
Safe and efficient shut-down protocols
Emergency procedures during start-up and shutdown.
Monitoring and controlling critical operational parameters.</td><td>30</td><td>30</td></tr>
</table>

	• Importance of regular inspections • Inspection procedures for electrolyser plant components • Documentation and reporting of inspection findings • Predictive maintenance techniques • Leakage detection • Troubleshooting techniques		
Module 7: Hydrogen Safety	• Key Properties of Hydrogen • Risks of Working with Hydrogen • Compliance and Hazardous Zones • Pressure Tests and Leak Testing • Intro to Plant & Fire Safety	15	15
Module 8: Communications in the Workplace	• Role of communication in professional success • Overview of communication challenges in the workplace • Precision in written communication • Technical writing for reports and documentation • Recognizing and navigating cultural differences • Building inclusive communication practices • Effective communication in diverse workplace environments	30	30

8.1.2 PROCESS ENGINEER – GREEN HYDROGEN PRODUCTION

The responsibilities of a process engineer encompass the development, design, control, safety, and optimization of systems involved in hydrogen production. The broad curriculum outlined for this position aims to facilitate the acquisition of knowledge and skills essential for performing these activities effectively.

Table 8.2 Curriculum for Process Engineer

Course name	Process Engineer
NSQF level	L5
Course duration	510 hours (Theory duration: 245 hours, Practical duration: 145 hours and remaining 120 hours for industry training)
Minimum Eligibility Criteria (Educational and / or Technical Qualification)	Bachelor's degree in chemical engineering or process engineering with experience in technical department of a Refinery / Petrochemical / Fertilizer / Chemical plant.

Minimum Entry Age for course	20-23 years		
Modules			
Module name	**Key Learning Outcomes**	**Course duration (hr)**	
		Theory	**Practical**
Module 1: Introduction to hydrogen & its properties	• Hydrogen and its colors • Characteristics of hydrogen • Physical & chemical properties of hydrogen • Green hydrogen value chain • Green hydrogen applications • Hydrogen safety hazards	15	0
Module 2: Hydrogen production technologies	• Types of green hydrogen production technologies systems (proton-exchange membrane, alkaline, and others), capacity, and sizes. • Electrolyser / green hydrogen plant designs • Understanding of electrochemical reactions, processes and hydrogen production using PEM / AE electrolysers. • Key parameters of electrolysis: current density, work pressure, operating temperature, hydrogen purity, volume, and weight. • Advantages and disadvantages of each technology. • Key manufacturers of each technology and understanding the standard equipment specifications across industry. • Understanding different job roles & responsibilities across a green hydrogen plant. • 1 day visit to green hydrogen production plant (PEM/AE) to understand the fundamental working principle, electrolyser hydrogen production plant control systems and advanced control systems for process optimization.	30	15
Module 3: Electrolyser system overview	• Overview of entire electrolyser system • Electrolyser stack: structure and function • Electrolyser cell operation	30	0

	• Stack designs & safety • Electrolyte materials and membranes • Catalysts and electrodes • Gas handling and separation • Pressure categories of systems		
Module 4: Design and development	• Process control design • Design of heat exchangers, pumps specifications, hydraulics calculations for integration of the electrolyser unit with Balance of Plant. • Development of new processes and methods. • Thermal and hydraulic design. • Calculation and sizing of electrolysis sub-systems • Preparation of equipment specifications, plant schedules, technical risk assessments, commissioning strategies, and cost and program estimations	30	15
Module 5: Process and project management	• Project management and disciplines such as piping, layout, static and rotating equipment, electrical and automation disciplines • Mass- and energy balance calculations • Process flow diagrams, Piping, and Instrumentation diagram • Emission data management - effluent, heat, noise, gas, etc. • Identify areas for process improvement and optimization, aiming for enhanced energy efficiency and reduced environmental impact. • Formulate and execute experiments to validate process performance, address operational issues, and fine-tune process parameters. • Employ process simulations and modeling to evaluate the efficiency, feasibility, and safety of different components within hydrogen systems.	30	15
Module 6: Water Purification System	• Water filtration techniques. • Reverse osmosis principles and applications. • Deionization and ion exchange processes. • Distillation and other purification methods • Filtration technologies and equipment.	15	15

	• Demineralization and Ion Exchange		
Module 7: Hydrogen Purification	• Hydrogen Water Separation • Temperature Swing Gas Dryer Operation- Principles of temperature swing adsorption, Dryer operation for hydrogen purification. • Pressure Control on Hydrogen System – importance and Pressure regulation methods	15	15
Module 8: Compression and storage	• Energy Storage Systems - Basics of energy storage for grid integration. • Overview of compression methods for hydrogen • Design and operation of compressors • High-pressure compression technologies • Types of hydrogen storage systems • Materials used in hydrogen storage. • Safety measures in hydrogen storage • Advanced storage systems and emerging technologies	15	15
Module 9: Process Simulation Software	• Training in Simulation Tools like – Aspen Plus – Aspen HYSYS – gPROMS – UniSim – ProSim Plus – Modellica	15	15

Module 10: Safety & Risk assessments	• Key Properties of Hydrogen
	• Risks of Working with Hydrogen
	• Compliance and Hazardous Zones
	• Pressure Tests and Leak Testing
	• Intro to Plant & Fire Safety
	• Training on potential hazards and their assessment tools like –
	  • FMECA (Failure Modes, Effects, and Criticality Analysis)
	  • HAZOP (Hazard and Operability Study)
	  • LOPA (Layer of Protection Analysis)
		15	15

Module 11: Regulations & standards	• Introduction to regulatory frameworks • Safety standards and protocols • Hydrogen safety codes • Hydrogen transportation regulations	30	0

	• Other national & international regulations related to production, handling & distribution of green hydrogen		
Module 12: Professional Development and Industry Practices	• Communication skills • Teamwork and collaboration • Time management and project coordination • Ethical considerations in electrolyser process management • Exposure to industry best practices • Compliance with safety and environmental regulations	15	15

8.1.3 ELECTROLYSER TECHNOLOGY SPECIALIST – ELECTROLYSER MANUFACTURING & ASSEMBLY

The role of the electrolyser technology specialist involves overseeing and optimizing electrolysis processes for hydrogen production. Responsibilities include maintaining and troubleshooting electrolyser systems, ensuring safety protocols, and staying updated on industry advancements.

The broad curriculum outlined for this position aims to facilitate the acquisition of knowledge and skills essential for performing these activities effectively.

Table 8.3 Curriculum for Electrolyser Technology Specialist

Course name	Electrolyser technology specialist		
NSQF level	L6		
Course duration	630 hours (Theory duration: 330 hours, Practical duration: 180 hours and remaining 120 hours for industry training)		
Minimum Eligibility Criteria (Educational and/ or Technical Qualification)	A bachelor's degree in a relevant field such as engineering or chemistry. Basic knowledge of physics, chemistry, and engineering principles.		
Minimum Entry Age for course	20-23 years		
Modules			
Module name	**Key Learning Outcomes**	**Course duration (hr)**	
		Theory	**Practical**

Module 1: Introduction to hydrogen & its properties	• Hydrogen and its colors • Characteristics of hydrogen • Physical & chemical properties of hydrogen • Green hydrogen value chain • Green hydrogen applications • Hydrogen safety hazards	15	0
Module 2: Hydrogen production technologies	• Types of green hydrogen production technologies systems (proton-exchange membrane, alkaline, and others), capacity, and sizes. • Various existing methods of hydrogen production globally and in India. • Technology readiness of each production technology in India. • Electrochemical reactions happening inside each technology. • Key parameters of electrolysis: current density, work pressure, operating temperature, hydrogen purity, volume, and weight. • Advantages and disadvantages of each technology. • Key manufacturers of each technology and understanding the standard equipment specifications across industry. • Understanding different job roles & responsibilities across a green hydrogen plant. • 1 day visit to green hydrogen production plant (PEM/AE) to understand the fundamental working principle, layout of the plant, the applicable codes, standards, and protocols of the plant.	30	15
Module 3: Electrolyser system overview	• Overview of entire electrolyser system • Electrolyser stack: structure and function • Electrolyser cell operation • Stack designs & safety • Electrolyte materials and membranes • Catalysts and electrodes • Gas handling and separation • Pressure categories of systems	30	15
Module 4: Process control	• Basics of process control in electrolysis • Importance of process control in electrolyser operations • Overview of control loops and feedback systems	45	30

	• Different types of sensors used in electrolyser systems. • Instrumentation for measuring temperature, pressure, and flow. • Calibration and maintenance of control instruments • Process Diagrams		
Module 5: Material science for electrolysis	• Material compatibility and design considerations for hydrogen systems. • Materials used in electrolyser components. • Corrosion prevention and materials selection • Impact of materials on electrolyser performance	30	0

Module 6: Electrolyser assembly techniques	• Hands-on experience in assembling electrolyser units
	  ○ Positioning, and stacking of the cells.
	  ○ Gasket connections
	  ○ Compress and tensioning of the stack
	  ○ Testing for leaks
	• Assembly procedures for various electrolyser technologies
	• Quality control during cell assembly
	• Safety considerations during installation.
	• 30-45 days certification training from electrolyser manufacturing/assembly plant.
		45	30

Module 7: Research and development in assembly techniques	• Current research trends in electrolyser assembly. • Evolving technological trends and their impact on hydrogen production. • Innovation in assembly processes.	15	15
Module 8: Regulations & standards	• Introduction to regulatory frameworks • Safety standards and protocols • Hydrogen safety codes • Hydrogen transportation regulations • Other national & international regulations related to production, handling & distribution of green hydrogen	30	0
Module 9: Plant operation & maintenance	• Optimization of plant operations • Developing plans and protocols to test component performance, durability, accelerated stress testing for new materials and technology.	45	45

	• Monitoring and controlling critical parameters. • Adapting to varying demand and load conditions • Development and implementation of preventive maintenance schedules • Fault diagnosis and troubleshooting in plant operations. • Predictive maintenance techniques for plant equipment.		
Module 10: Hydrogen Safety	• Key Properties of Hydrogen • Risks of Working with Hydrogen • Safety Compliance and Hazardous Zones • Pressure Tests and Leak Testing • Intro to Plant & Fire Safety	30	15
Module 11: Professional Development and Industry Practices	• Communication skills • Teamwork and collaboration • Time management and project coordination • Ethical considerations in electrolyser assembly • Exposure to industry best practices • Compliance with safety and environmental regulations	15	15

8.1.4 OPERATIONS & MAINTENANCE HEAD / MANAGER – GREEN HYDROGEN PRODUCTION

The key responsibility of the Operations and Maintenance (O&M) Head / Manager is to ensure smooth continuous operations of the plant. This role entails ensuring efficient and safe plant operations and optimizing maintenance processes. The broad curriculum outlined for this position aims to facilitate the acquisition of knowledge and skills essential for performing these activities effectively.

Table 8.4 Curriculum for Operations & Maintenance Head/ Manager

Course name	Operations & Maintenance Head / Manager
NSQF level	L7
Course duration	690 hours (Theory duration: 330 hours, Practical duration: 210 hours and remaining 150 hours for industry training)
Minimum Eligibility Criteria (Educational and/ or Technical Qualification)	B.Tech./B.E. in Civil/Mechanical/Electrical Engineering or equivalent with more than 3 years experience in leading O&M functions in chemical, petrochemical, or relevant industry.

Minimum Entry Age for course	23-25 years		
Modules			
Module name	**Key Learning Outcomes**	**Course duration (hr)**	
		Theory	**Practical**
Module 1: Introduction to green hydrogen	• Hydrogen and its colors • Characteristics of hydrogen • Physical & chemical properties of hydrogen • Green hydrogen Value chain • Green hydrogen Applications • Hydrogen safety hazards	15	0
Module 2: Hydrogen production technologies	• Types of green hydrogen production technologies systems (proton-exchange membrane, alkaline, and others), capacity, and sizes. • Various existing methods of hydrogen production globally and in India. • Technology readiness of each production technology in India. • Electrochemical reactions related to each technology. • Key parameters of electrolysis: current density, work pressure, operating temperature, hydrogen purity, volume, and weight. • Advantages and disadvantages of each technology. • Key manufacturers of each technology and understanding the standard equipment specifications across industry. • 1 day visit to green hydrogen production plant (PEM / AE) to understand the fundamental working principle, layout of the plant, the applicable codes, standards, and protocols.	30	15
Module 3: Electrolyser plant integration with grid	• Integrating renewable energy with electrolyser plant • Integration of backup power such as pumped hydro or storage with electrolyser plant • Integrating electrolyser plant with other sub-components.	30	15

	• Electrical transmission and distribution systems. • Power factor, power curtailment, voltage/frequency range and power quality		
Module 4: Instrumentation and Control Systems	• Types of Instruments • Control Elements • Distributed Control Systems (DCS) and Programmable Logic Controllers (PLC). • DCS Architecture and Configuration. • PLC Programming • Remote Monitoring Systems. • Human-Machine Interface (HMI)	30	30

Module 5: Operation & maintenance strategies development & its implementation	• Project management & maintenance techniques (including but not limited to)
	  ◦ Quality Assurance and Operational Excellence - Continuous improvement initiatives and cost optimization
	  ◦ Instrumentation and Control Maintenance
	  ◦ Quality Control Maintenance
	  ◦ Predictive and Preventive Maintenance
	  ◦ Testing and maintenance of emergency shutdown systems
	  ◦ Sustainability and Energy Efficiency
	  ◦ Inventory management
	• Strategic Planning procedures for a green hydrogen plant
	• Procedure of developing and implementing operational, maintenance, emergency and quality plans and policies for a green hydrogen plant
	• Effective methods for environmental management and sustainability
		45	0

Module 6: Operations & maintenance	• Monitoring process parameters • Monitoring key performance indicators (KPIs) for plant operations and maintenance. • Optimizing equipment reliability and performance. • Safety, environmental, and regulatory standards. • Green hydrogen production equipment (incl. electrolyser) operation	30	15

	• Inspection techniques - membrane and Electrode • Electrical components maintenance • Sensor calibration and maintenance • Electrolyte solutions		
Module 7: Perform cost optimization activities	• Budget preparation and management process. • Data analysis of, financial statements, sales reports, performance data etc. • Techniques to control the cost. • Setting the prices or credit terms for goods or services, based on forecasts of customer demand. • State the importance of optimizing the production cost as per demand and supply and best utilization of installed capacity. • Cost-effective plant operation. • Inventory or cost control programs	30	15
Module 8: Manage Human Resources	• Job roles & responsibilities across a green hydrogen plant. • Human resource management and team management procedures. • Procedure and importance of preparing the work schedule for the team members. • Effective handling of resources for optimal results. • Effective ways of conflict management and sharing a trusting relationship with workgroup and manage and develop plant staff	15	15
Module 9: Manage administrative activities	• Procedure and importance of forecasting the customer demand for the plant. • Quality control and assurance methods. • Importance of meeting the contractual obligations against the relevant operational subcontractors. • Procedure of preparing the compliance and measurement report. • Importance of coordinating the business or departmental activities with the production, pricing, sales, or distribution of green hydrogen	15	15
Module 10: Promote gender & PwD	• Standard policies and practices related to gender and PwD sensitivity at workplace. • Importance of promoting equal treatment for all genders at the workplace and	15	15

sensitivity at the workplace	ensuring the team is educated about their rights at the workplace. • POSH (Prevention of Sexual Harassment) policy guidelines and importance of proper implementation of the same to prevent both physical and verbal sexual harassment. • Importance of training and treating the PwD without bias at the workplace		

Module 11: HSE and compliance management	• Health, Safety, and Environment (HSE) – Audit requirement, safety protocol, environmental regulations.
	• Emergency Response and Contingency Planning
	• Safety Instrumented Systems (SIS)
	  • Introduction to SIS
	  • Functional Safety and SIL (Safety Integrity Level)
	  • Emergency Shutdown Systems (ESD)
		15	15

Module 12: Hydrogen Safety & Risk assessments	• Risks of Working with Hydrogen
	• Compliance and Hazardous Zones
	• Pressure Tests and Leak Testing
	• Training on potential hazards and their assessment tools like –
	  • FMECA (Failure Modes, Effects, and Criticality Analysis)
	  • HAZOP (Hazard and Operability Study)
	  • LOPA (Layer of Protection Analysis)
		15	30

Module 13: Regulations & Standards	• Introduction to regulatory frameworks • Safety standards and protocols • Hydrogen safety codes • Hydrogen transportation regulations • Other national & international regulations related to production, handling & distribution of green hydrogen	15	0
Module 14: Ensure Compliance with applicable Statutory Laws, Policies and Procedures	• Functioning of local corporations / authorities that have a bearing on the particular business process along with policies and procedures that impact the business process. • Importance of building and maintaining relationships with key people to ensure smooth functioning of business. • Various legal formalities applicable for the particular business.	15	15

	• Various benefits to the company due to the practice of these procedures. • Importance of having an ethical and value-based approach to governance and knowledge of processes involved in the business. • Country specific regulations for the green hydrogen sector and their importance. • Standard reporting procedure in case of any deviations		
Module 15: Professional development and Industry practices	• Communication skills • Teamwork and collaboration • Time management and project coordination • Ethical considerations in plant O&M management • Exposure to industry best practices	15	15

8.1.5 HYDROGEN SYSTEM INTEGRATION SPECIALIST – GREEN HYDROGEN PRODUCTION

The hydrogen integration specialist is tasked with overseeing the integration of one or multiple renewable energy power plants and electrolyser plants (as well as other components) at a single site or across various locations with the grid. The broad curriculum outlined for this position aims to facilitate the acquisition of knowledge and skills essential for performing these activities effectively.

Table 8.5 Curriculum for Hydrogen System Integration Specialist

Course name	**Hydrogen system integration specialist**		
NSQF level	L6		
Course duration	630 (Theory duration: 300 hours, Practical duration: 180 hours and remaining 150 hours for industry training)		
Minimum Eligibility Criteria (Educational and/ or Technical Qualification)	Bachelor's degree in electrical engineering and experience with renewable energy is preferrable including knowledge of associated codes and standards.		
Minimum Entry Age for course	20-23 years		
Modules			
Module name	**Key Learning Outcomes**	**Course duration (hr)**	
		Theory	**Practical**
Module 1: Understanding	• Various sources of renewable power, and its variability.	15	0

renewable energy as an electrical input	• Advantages and challenges of each source. • Understanding of the modes of power supply in the market such as intra-state, inter-state, short-term etc. (including solar, wind, hybrid, etc.) • Technology selection criteria based on sizing, plant load factor, etc. • Available banking facilities and its working principle		
Module 2: Introduction to hydrogen & its properties	• Hydrogen and its colors • Characteristics of hydrogen • Physical & chemical properties of hydrogen • Green hydrogen value chain • Green hydrogen applications • Hydrogen safety hazards	15	0
Module 3: Hydrogen production technologies	• Types of green hydrogen production technologies systems (proton-exchange membrane, alkaline, and others), capacity, and sizes. • Key parameters of electrolysis: current density, and operating voltage. • Key manufacturers of each technology and understanding the standard equipment specifications across industry. • Understanding different job roles & responsibilities across a green hydrogen plant. • 1 day visit to green hydrogen production plant (PEM/AE) to understand the fundamental working principle, integration of the grid with electrolyser plant and other components, the applicable codes, standards, and protocols.	30	15
Module 4: Electrolyser system overview	• Overview of entire electrolyser system • Electrolyser Stack: Structure and Function • Electrolyser Cell Operation • Stack interconnection & its impact on current and voltage dynamics • Stack designs & safety	30	0
Module 5: System design and modelling	• Infrastructure requirement for grid interconnection such as substations, transmission & distribution system. • Knowledge of key high power electrical equipment and interconnection applications associated with renewable	45	45

	electricity powered electrolyser produced hydrogen. • Direct integration considerations such as connection points, components, and the grid. • Sizing of electrolyser and renewable power capacity. • Design and manage interconnection of renewable generation sites to electrolyser production plant. • Conduct computer modeling to ensure stable power flow.		
Module 6: System integration & grid flexibility	• Approach of integrating renewable energy with electrolyser plant • Integration of backup power such as pumped hydro or storage with electrolyser plant • Electrical transmission and distribution systems. • Power factor, power curtailment, voltage/frequency range and power quality • Review of grid codes with respect to renewable energy power, banking, and hydrogen. • Need of power electronic equipment in grid integration, converter, inverter, chopper, and ac regulator for AC/DC conversion	60	60
Module 7: Compression and storage	• Overview of compression methods for hydrogen • Types of hydrogen storage systems • Interconnection of compressors and storage with electrolyser plant. • Safety measures in hydrogen storage	30	30
Module 8: Regulations and Standards	• Introduction to regulatory frameworks related to power flow within state as well as interstate. • Introduction to regulatory frameworks related to banking provisions, scheduling & despatch, etc. • Introduction to regulatory frameworks related to green hydrogen. • Safety standards and protocols • Hydrogen safety codes • Hydrogen transportation regulations	45	0

	• Other national & international regulations related to production, handling & distribution of green hydrogen		
Module 9: Hydrogen Safety	• Risks of Working with Hydrogen • Compliance and Hazardous Zones • Pressure Tests and Leak Testing • Intro to Plant & Fire Safety	15	15
Module 10: Professional Development and Industry Practices	• Communication skills • Teamwork and collaboration • Time management and project coordination • Exposure to industry best practices • Compliance with safety and environmental regulations	15	15

8.2 RECENT SKILLING INITIATIVES

Skill interventions in green hydrogen are crucial for cultivating a proficient workforce capable of propelling the growth of this nascent but transformative sector in the country. Ministry of Skills Development and Entrepreneurship (MSDE) is anchoring skill initiatives under the National Green Hydrogen Mission aimed at skilling, reskilling and upskilling the workforce across the green hydrogen value chain. SCGJ with the support from the World Bank and industry has undertaken a series of skill interventions in Green Hydrogen, which include the development of 10 nationally approved qualifications catering to various stakeholders such as Junior Technicians, Technicians, Supervisors, Entrepreneurs, Process Engineers, and more. These interventions encompass diverse training programs aimed at familiarizing participants to the core principles of green hydrogen production, storage, and utilization. Key topics covered in these training programs range from electrolysis processes, renewable energy integration, policy and investment landscapes, to cost economics, hydrogen fuel cells, safety protocols, and regulatory frameworks, etc. By imparting this knowledge, individuals are better equipped to contribute effectively to the development and implementation of green hydrogen projects nationwide. Moreover, there is a focus on upskilling initiatives targeted at enhancing the capabilities of the existing workforce to meet the evolving requirements of the green hydrogen sector.

MNRE NOTIFIES SKILL DEVELOPMENT SCHEME FOR GREEN HYDROGEN SECTOR

- FY2023-24 to FY2029-30, total outlay Rs. 35 crores.
- To meet the required skillsets for the NGHM, the scheme undertakes the following activities:
  - Short-term training (STT).
  - Up-skilling along with recognition of prior learning (RPL).
  - Creation of centres of Excellence (CoEs) at identified institutions.
  - Enabling curriculum based long duration training at schools, ITI's, polytechnics and Higher Education Institutions (HEIs).
- The scheme will be implemented by MNRE through Implementation Agency (IAs) (to be notified) – responsible for creation of STT, certification of trainers, review and monitor training facilities, update curriculum, post training tracked for one year after training.
- For STT training centres may include Pradhan Mantri Kaushal Kendras (PMKKs), ITIs, Polytechnics, HEIs, Schools, etc. For RPL up-skilling, industrial enterprises (PSUs, autonomous bodies, industry associations) included as training centres.
- Certification: trainers must be certified by awarding bodies (SSCs, universities, school boards)

USAID through SAREP has also been providing capacity buildings in areas related to green hydrogen. SAREP has curated training programs on techno-economic considerations for the Design of Green Hydrogen Projects as well as specific training for financing institutions on green hydrogen. SAREP also organized a 3-series master class on 'Financing Green Hydrogen in South Asia. Further, SAREP published a report on "Investment Landscape of Green Hydrogen in India" which provides a comprehensive guide for investments into India's green hydrogen ecosystem, seeking to demystify the fundamentals, and provide a perspective on investment. Additionally, efforts are also being made by other Sector Skill Councils/Awarding bodies including Hydrocarbon Sector Skill Council (HSSC), Power Sector Skill Council (PSC) along with Logistics Sector Skill Council (LSC) to develop new qualifications and implement various training programs to facilitate cross-disciplinary collaborations and knowledge exchange among youth & professionals from varied backgrounds.

Figure 8.1 10 nationally approved qualifications developed by SCGJ

8.3 FINAL RECOMMENDATION

The adoption of hydrogen skilling necessitates systemic intervention across all levels. Achieving substantial change requires the formulation of actionable interventions, outlining priorities, and involving key stakeholders. These actionable areas can be grouped into four overarching categories as discussed below.

Table 8.6 Final Recommendation: Key Actionable Areas and Interventions

Sl. No.	Actionable areas	Actionable interventions	Priority	Stakeholder
1	Creating demand for certified skills	Mandatory certification in industries: Mandate employment of certified personnel for critical roles such as Electrolyser technician, Operations & Maintenance Manager, etc.	High	MNRE
		Mandatory certification for Govt. tenders & PLI schemes: Include certified professionals in production & manufacturing facilities to ensure the safe handling of operations involving hydrogen.	High	MNRE
		Establish scholarship programs to attract talented individuals to pursue careers in green hydrogen-related fields.	Medium	Institutes / Industry
		Industry sponsored / stipend entrepreneurial / business courses on hydrogen sector.	Medium	SCGJ
		Skill council to empanel end-use industries for specific short-term technical trainings (will ensure job opportunities)	Medium	SCGJ
		Organize skill competitions for professionals in the green hydrogen sector (similar to skill competitions like solar skill competition).	Low	SCGJ
		Conduct regular workshops / knowledge sharing initiative for industry professionals	Low	SCGJ / CII
2	Designing training programs suiting the market demand	Create short-term bridge courses (with practical & on the job exposure) for the priority job roles identified to be developed	High	SCGJ/Institutes
		Create a set of micro-credentials, created collaboratively with industry subject matter experts, to bridge the immediate skills gaps while formal training packages are being developed. Importantly, this initiative can enhance awareness among industry workers in	High	SCGJ

Sl. No.	Actionable areas	Actionable interventions	Priority	Stakeholder
		various sectors. The topics covered should encompass Hydrogen fundamentals, diverse production technologies, components of electrolyser plants, the integration of renewable energy power with green hydrogen plants, and adherence to hydrogen safety regulations and norms.		
		Introduce online short-term courses for topics like Hydrogen production technologies, Electrolyser system overview, Electrolyser assembly techniques, Compression and storage, Regulations & standards, Plant operation & maintenance, and Hydrogen Safety.	High	Private
		Introducing hydrogen as an elective for engineering students for instance chemical engineering, mechanical engineering etc.	High	Institutes
		Develop evaluation format to certify "Recognition of prior learning" in experienced professionals.	High	SCGJ
		Initiate collaboration between Institutes and Department of Science and Technology / other R&D institutes / Hydrogen Valley to establish Center of Excellence. The Center will serve as a facilitator for partnerships and act as a pivotal link, bringing together researcher, innovators, and academics to foster knowledge exchange.	High	Institutes
		Build industry partnerships to conduct capacity-building trainings on topics such as current market trends across various technologies, operational learnings etc. for enhancing employability.	Medium	Institutes
		Access to laboratory facilities & innovation centers to support training initiatives further contributes to the practical education of individuals involved in the programs	Medium	GoI / MNRE / SCGJ
		Foster collaboration with industries by providing apprenticeship / internship opportunities that allow trainers / trainees to	Medium	GoI / MNRE

Sl. No.	Actionable areas	Actionable interventions	Priority	Stakeholder
		gain practical experience within the green hydrogen industry.		
3	Availability of trained trainers to disseminate right skill sets	Establish training-of-trainer programs to educate faculty members at institutes and companies actively involved in research and development, such as IOCL, BPCL, ONGC, CSIR, by international experts specializing in electrolyser component manufacturing and the safe handling of green hydrogen.	High	SCGJ / Training institutes
		Fund training institutions to operationalize trainings till demand increases; provide trainings on pilot basis across few major centers and expand later based on industry response	High	MNRE / SCGJ / / International financial institutions
		Introduce post-training assessment & subsequent yearly assessments of trainers to align their skill sets with market demand	Medium	SCGJ / Training institutes
		Incentivize skills upgradation training for existing instructors	Medium	SCGJ / Training institutes
		Enticing trainers, by offering a possibility of a permanent position after completing two years and subsidizing accommodation for those from remote locations.	Low	SCGJ / Training institutes
4	Ensuring inclusivity	Promoting the establishment of training centers or knowledge hubs at the community level gives women easy access to knowledge, training, and capacity-building necessary for network deployment and operations.	High	SCGJ
		Promote inclusion of women with percentage-based reservation for women in training programs.	High	SCGJ
		Adapt project sites to accommodate women, establish guidelines for flexible work arrangements, and address immediate safety risks through specific actions such as improving transportation, enhancing lighting, and encouraging work in pairs. Implement innovative measures to overcome challenges associated with fieldwork for	High	Industries

Sl. No.	Actionable areas	Actionable interventions	Priority	Stakeholder
		instance standardizing installation work can reduce dependence on individual workers		
		Appoint women as trainers with permanent roles in training institutes to fostering a gender-inclusive training environment.	High	SCGJ
		Offer incentives like stipends, free accommodation, and food to attract individuals from low-income or socio-cultural minority groups, making skill development programs more accessible and appealing to a wider range of individuals.	High	MNRE / SCGJ / International financial institutions
		Enhance inclusiveness and reach of skill development programs by creating learning materials in multiple formats accessible to those with visual or auditory impairments	High	SCGJ
		Customize learning approaches to meet the specific needs of diverse groups with, flexible schedules, online learning options, and training materials in multiple languages	Medium	SCGJ
		Provide guaranteed placements for the top 10% of qualified women with transparent pay scales to encourage women's participation	Medium	SCGJ/Industries

9 ANNEXURE

9.1 INDIA'S TECHNOLOGY AND R&D LANDSCAPE - FUTURE (IDENTIFIED BY MNRE)

9.1.1 HYDROGEN PRODUCTION

Short Term R&D Priority areas for India

R&D priority areas proposed by MNRE towards achieving short-term impact (0 to 5-year) focuses on early-stage research efforts as follows:

1. Advancement of catalysts and electrodes with lower Platinum Group Metal (PGM) content to enhance the cost-effectiveness, performance, and durability of PEM electrolysers.
2. Development of AEM electrocatalysts with improved Oxygen Evolution Reaction (OER) kinetics and catalytic activity.
3. Progress in the creation of Solid Oxide Electrolyser Cells (SOEC).
4. Innovation in feedstock-agnostic technology for biomass gasification to facilitate hydrogen production.

IMPACT ON SKILLING – The key short-term focus in green hydrogen production in India is to improve electrolyser technology's cost-effectiveness and performance. Thus, highly skilled workforce focused on specific electrolyser technologies are likely to be required to carry out these R&D activities, Further, these R&D activities would impact which electrolyser technologies emerge superior in terms of cost-effectiveness and performance and gain traction in terms of commercial adoption. Thus, skilling requirements would change in line with change in commercial adoption of different electrolyser technologies & any subsequent technology changes/ improvements in them.

Medium Term Priority Areas for India

Proposals by MNRE aimed at fostering mid-term impact (0 to 8 years) are as follows:

1. Advancement of AEM electrolysis technology.
2. Development of power-to-gas and co-electrolysis technology utilizing SOEC.
3. Implementation of demonstrations for hydrogen generation via biomass gasification.
4. Furthering development of compact bio-methane reformers for decentralized hydrogen production.
5. Creation of integrated, cost-effective, net carbon-negative solutions for hydrogen production using indigenous technologies.

IMPACT ON SKILLING – In the medium term, the focus will be on both improving the electrolyser technologies & advancement of alternative green hydrogen production technologies like biomass gasification and biomethane reformers. Thus, skilled workforce requirement for these alternate hydrogen generation technologies may increase in medium term. Further, since the focus is to create indigenous technologies Thus, there will be an added requirement for personnel for manufacturing, installation, commissioning & operation of these indigenous technologies.

Long Term Priority Areas for India

Long-term initiatives (0 to 15 years) will be pursued with a strong emphasis on building global intellectual property (IP) and bolstering the competitive edge of the Indian industrial sector. The suggested projects by MNRE for consideration include:

1. Utilizing seawater electrolysis to produce hydrogen.
2. Employing photoelectrochemical processes to split water into hydrogen and oxygen.
3. Exploring thermochemical water splitting and its incorporation with nuclear or solar heat sources.
4. Advancing microbial electrolysis systems for the generation of hydrogen.
5. Pioneering novel methods for converting biomass into hydrogen.
6. Harnessing bio-methane pyrolysis to produce hydrogen.
7. Transforming waste materials into hydrogen.

IMPACT ON SKILLING – R&D initiatives for these novel hydrogen production technologies would require highly skilled personnel focused on these technologies.

9.1.2 HYDROGEN STORAGE

Short Term Priority areas for India (0-5 years)

As recommended by MNRE:

1. The development of easily recyclable durable materials capable of storing 4-5 wt.% of hydrogen at near-ambient temperatures and moderate pressure conditions, and safety handling rapid hydrogenation / dehydrogenation cycles.
2. Employing abundant, domestically available elements to reduce costs for synthesizing alloys using industrial-grade materials.
3. Establishment of domestic manufacturing units for materials-based hydrogen storage canisters, accompanied by demonstrations for various applications.
4. Utilization of artificial intelligence and machine learning to identify high-performing materials and optimize canister designs, reducing the time and cost of experimentation.
5. Demonstration of the developed materials and systems, particularly emphasizing higher volumetric density for applications where weight is less critical, such as submarines, construction equipment,

mining vehicles, forklifts, freight vehicles, and stationary applications like heating and cooling, thermal energy storage, hydrogen compression, and purification.
6. Domestic production of Type III tanks.
7. Development of standards and regulations for compressed hydrogen tanks and materials-based storage.

IMPACT ON SKILLING – This phase is focused on establishment of domestic manufacturing of hydrogen storage canisters & Type III tanks and is thus likely to boost requirement for skilled & semi-skilled workforce in manufacturing. Further, the focus will be on improving performance & cost-effectiveness of materials used for hydrogen storage, which will require research and development professionals in material science and related fields.

Medium Term Priority areas for India

MNRE's medium term priorities focus on promoting startups in hydrogen industry. Projects recommended by MNRE for this stage are:

1. Developing facilities and infrastructure to enable the scaled production of required alloys and materials within India.
2. Encouraging startups and industries to establish facilities for the manufacture of solid-state hydrogen storage canisters.
3. Large-scale production of these canisters to facilitate commercialization and reap the benefits of economies of scale.
4. Exploring methods to reduce boil-off losses and harnessing the hydrogen that would otherwise be lost in the case of liquid state storage.
5. Domestic manufacturing of liners, carbon fibers, valves, and TPD (Thermal Pressure Relief Devices) for Type III and Type IV tanks.
6. Establishing indigenous manufacturing capabilities for Type IV tanks.

IMPACT ON SKILLING – In medium term, the R&D priority is aimed at building large scale production for storage technologies expected to be relatively mature at that time. Focusing on domestic manufacturing will create opportunities for employment at all levels.

Long Term Priority areas for India

The following projects are recommended by MNRE-

1. Research into novel materials with a potential to offer higher gravimetric capacity, reduced cost, reduced weight, faster kinetics, and excellent reversibility.
2. Widespread deployment of materials-based hydrogen storage systems across various sectors, including industrial, urban residential, and rural areas, for both stationary and vehicular applications.
3. Development of advanced, high-strength materials and cost-effective for compressed hydrogen tanks.
4. Domestic manufacturing of Type V tanks with all components produced within India.

5. Establishment of indigenous manufacturing capabilities for Type IV cylinders.
6. Creation of a national testing facility dedicated to Type IV cylinders.

IMPACT ON SKILLING – The long-term priorities include research into novel technologies and manufacturing & testing of established storage technologies. Thus, broad areas likely to require skilling for long-term are expected to be aligned with short & medium-term requirement. However, skilling needs will evolve in tandem with shifts in the widespread adoption of various storage technologies and any subsequent advancements or improvements in these technologies.

9.1.3 HYDROGEN END USE

Short Term Priority areas for India

The following projects are recommended for industry by MNRE:

1. Rapid increase in mandatory utilization of green hydrogen in sectors like petroleum refineries, fertilizers, and ammonia production.
2. Development and deployment of hydrogen-based internal combustion engines (ICE) for electric vehicle applications, including the advancement of light vehicle powertrains and pilot implementations.
3. Efficient generation of green hydrogen through distributed-scale electrolysers operating at around 1.8V or lower, coupled with solar photovoltaic (PV) plants, and integration with the evolving hydrogen infrastructure.
4. Advancement in high-pressure hydrogen storage technologies, including Type III to Type IV composite cylinders with pressure ranges of 350 to 750 bar, compressor systems, and hydrogen piping networks suitable for decentralized on-site power generation and hydrogen filling for vehicles. Prioritizing multipurpose technologies is essential.
5. Deployment of distributed power plants:
   a) Implementation of hydrogen-based power plants using PEMFC or Phosphoric Acid Fuel Cells (PAFC) with power outputs in the range of 100kW to 500kW and linking these facilities with the partially developed hydrogen infrastructure.
   b) Establishment of power plants with power outputs in the range of 250kW to 1MW using CNG reforming and PAFC or PEMFC technologies, making use of the available compressed natural gas (CNG) infrastructure.

IMPACT ON SKILLING – Along with developments in electrolyser manufacturing and storage infrastructure, there is a need for complimentary infrastructure in industries. Areas of skilling in end-use segment would include workforce for infrastructure upgrade like piping and new technology areas like manufacturing & maintenance of hydrogen vehicles. Upskilling of the current workforce at these industries would also be required, along with additional workforce for new job roles.

Medium Term Priority areas for India

In the context of mid-term objectives spanning 0 to 8 years, with a focus on demonstration actions to promote the growth of startups and industries, the following projects are recommended for industry by MNRE:

1. Expanding and enhancing the hydrogen infrastructure, by incorporating improvements such as high-efficiency hydrogen compressors and enhanced safety measures.
2. Increasing green hydrogen generation using improved electrolysers operating at around 1.6V.
3. Deploying marine vessels powered by onboard hydrogen storage, CNG, dimethyl ether (DME), methanol reforming, and fuel cell systems, utilizing low platinum (Pt) catalysts.
4. Implementing mini hydrogen-powered power plants, including:
   a. Distributed power generation systems based on gas turbines with extended capacity, operating at several megawatts.
   b. SOFC or gasifier-reformer power plants producing over 100 kilowatts, and capable of using various feedstocks such as biomass and CNG.
5. Introduction of hydrogen-powered locomotives, utilizing stored hydrogen, onboard reformers, CNG (LNG), or methanol/DME reformers.
6. Development of low Pt fuel cell-based light vehicles equipped with onboard hydrogen storage, with a target of less than 5 grams of Pt per vehicle.
7. Utilization of evaporated hydrogen from cryo-cooled hydrogen tanks for long-distance marine hydrogen shipments, supported by a suitable combination of fuel cells and electrolysers.

IMPACT ON SKILLING – This phase focuses on deployment and implementation activities. Hence, the skilled workforce requirement in sectors like marine transportation, power and locomotives utilizing stored hydrogen is likely to increase.

Long Term Priority areas for India

The following projects are recommended for industry by MNRE:

1. A comprehensive extension of the hydrogen infrastructure, to cover at least 80% of India, with on-site power generation capability and mobility solutions for road, railway, and marine transportation.
2. Establishing an end-to-end network for the hydrogen infrastructure, seamlessly integrated with solar, wind, and other renewable energy sources, and connected to end-user points to complete the hydrogen grid. This network may also include connections to fossil fuel or other hydrogen generation sources for efficient hydrogen grid management.
3. Development of high-efficiency hydrogen-bromine fuel cells combined with electrolysers for gigawatt-hour (GWh) energy storage.
4. Strategic deployment of hydrogen ICE and hydrogen fuel cell-based light vehicles, considering their competitiveness against other battery-driven electric vehicles. Additionally, exploring the use of indirect hydrogen-based fuel cell technology for heavy vehicles via onboard multi-fuel processors.
5. Deployment of high-efficiency hydrogen gas turbines and fuel cell-based on-site and centralized power stations with power outputs ranging from several hundred kilowatts to 50-100 megawatts. These facilities are expected to achieve high round-trip efficiency in the long term.
6. Implementation of marine hydrogen fuel cell-based ships and larger vessels powered by hydrogen gas turbines.

IMPACT ON SKILLING – This phase will witness the expansion of hydrogen infrastructure. Growth in skilled workforce will be required for seamless integration processes. The long-term priorities include research into novel technologies. Thus, broad areas in which skilling is likely to be required for long-term is expected to be in line with short & medium-term requirement. However, skilling requirements would change in line with any subsequent change in technology.

9.2 TECHNOLOGY IN GREEN HYDROGEN - INTERNATIONAL

9.2.1 AUSTRALIA

Australia is making substantial investments in demonstration projects, emerging technologies, and the establishment of 'hydrogen hubs' to position itself favourably in the anticipated global market expansion between 2030 and 2050. By late 2021, globally, Australia ranked second[69] in terms of the number of zero-carbon hydrogen projects in development. The private sector in Australia has also announced around A$127[70] billion in the pipeline invested in the in the hydrogen sector in 2023. Up until 2022, there were approximately 85 documented[71] projects related to various electrolyser technologies, about 37 projects associated with storage and supply, and ~60 projects pertaining to diverse end-use applications, as indicated in the figure below. Currently, 480[72] tons of green hydrogen is produced per year from operational projects in the country. Additionally, there are 95 clean hydrogen projects in various stages of development, with a total capacity of approximately 7 million metric tons per year.

Figure 9.1 Number of Projects for Clean Hydrogen in Australia

Source: HyResource Projects Database, August 2022.[73]

"Seizing Australia's Hydrogen Opportunity by 2040" report 2023.[74], assessed the technological readiness levels (TRLs) of key hydrogen technology, and the opportunities for further development in Australia. **Error! Reference source not found.**9.2.1 outlines the equipment TRL ranking for each of the clean hydrogen supply chains.

[69] Hydrogen report_V4_Final Report_24 October 2022 (energycentral.com)
[70] Green Hydrogen in Asia: A Brief Survey of Existing Programmes and Projects (orrick.com)
[71] The documented projects include projects at all stage – feasibility studies, demonstrations, and commercial projects as documented in the HyResource Projects Database, August 2022
[72] https://www.iea.org/reports/hydrogen-projects-database
[73] https://explore.mission-innovation.net/wp-content/uploads/2023/03/H2RDD-Australia-FINAL.pdf
[74] https://www.nera.org.au/Publications-and-insights/Attachment?Action=Download&Attachment_id=392

Table 9.1 TRL ranking

Supply chain	Equipment	TRL Equipment Rating	TRL Rating Concept
Renewable energy generation	Solar panels, Wind turbines, BESS, Inverters, Rectifiers, Transformers	11	Proof of stability reached
Electrolysis	PEM electrolyser, Alkaline electrolyser	10	Integration needed at scale
	Solid oxide electrolyser	7	Pre-commercial demonstration
	Anion exchange membrane electrolyser	6	Full prototype at scale
	Capillary fed electrolyser	4	Early prototype
Anaerobic digestion or gasification	Anaerobic digestor	10	Integration needed at scale
	Biomass gasification/pyrolysis	6	Full prototype at scale
Natural gas reforming and carbon capture and storage	Steam Methane Reforming	11	Proof of stability reached
	Carbon capture, transport, and storage	8	First of a kind commercial
Hydrogen compression	Hydrogen compressor	11	Proof of stability reached
Hydrogen storage	MCH tank	10	Integration needed at scale
	Pressure vessels	11	Proof of stability reached
	Liquid hydrogen tanks, Salt cavern	9	Commercial operation in relevant environment
Hydrogen fuel cell	Fuel cell	10	Integration needed at scale
Hydrogen liquefaction	Hydrogen liquefaction plant	9	Commercial operation in relevant environment
	Heat exchangers	11	Proof of stability reached

Supply chain	Equipment	TRL Equipment Rating	TRL Rating Concept
Alternative carrier production	Ammonia synthesis technology, Haber-Bosch catalysts, Air separation unit, Haber-Bosch reactors	11	Proof of stability reached
	MCH conversion technology	6	Full prototype at scale
Hydrogen combustion systems	Hydrogen-integrated process equipment	8	First of a kind commercial
	Hydrogen-compatible components (burners, valves, flame arresters, instruments)	11	Proof of stability reached
Dispensing / refueling	Metering systems	11	Proof of stability reached
	Hydrogen safety systems	9	Commercial operation in relevant environment
	Hydrogen refueling and dispensing	10	Integration needed at scale
Distribution	Piping, Ammonia tanker, MCH/solvent tanker	11	Proof of stability reached
	Liquid hydrogen tanker	7	Pre-commercial demonstration
	Compressed hydrogen tube trailer	10	Integration needed at scale
Water treatment	Sewage treatment, Reverse osmosis treatment, UV treatment, Ultrafiltration	11	Proof of stability reached

A TRL of 9 or higher indicates readiness for commercial scalability. PEM and alkaline electrolysers have already reached TRL 10, indicating they are ready for commercial deployment. Solid oxide electrolyser technology, at TRL 7, offers high electrical efficiency (around 90%) without relying on rare earth materials, providing a supply chain advantage. Hydrogen fuel cells are at TRL 10, employing existing technologies, while Australia is developing solid oxide fuel cells. For hydrogen storage (TRL 9-11), emerging equipment requires further development, thereby presenting opportunities for Australian suppliers. In distribution (TRL 7-11), local companies can manufacture specialized tanks, but large-scale MCH use faces plant size limitations.

The information on technology readiness of the hydrogen industry offers valuable insights for skilling the workforce:

- **Electrolysis:** Skilling the workforce in the operation and maintenance of PEM and alkaline electrolysers is a priority, as these technologies are commercially ready. Additionally, training in solid oxide electrolyser technology is crucial, given its potential for higher electrical efficiency and reduced reliance on rare earth materials. Investment in this area can foster innovation and competition driven growth.

- **Fuel Cell:** Workforce development should focus on training in various fuel cell technologies, including phosphoric acid, PEM, and alkaline fuel cells, which are already commercially available. However, to gear up for likely future advancements, training in emerging technologies like solid oxide fuel cells, is also necessary. The workforce needs to be prepared to handle their development, manufacturing, and operation.

- **Hydrogen Storage:** With hydrogen storage technologies ranging from TRL 9 to 11, there's a compelling need for skilled professionals in this field. Workforce training should encompass the design, manufacturing, and operation of hydrogen storage equipment. Given the nascent stage of long-duration and large-scale storage technologies, there's an opportunity for innovation, and development of competing ideas and approaches that the workforce can capitalize on.

- **Distribution:** Distribution, with TRL levels varying from 7 to 11, demands a skilled workforce. This should include manufacturing specialists capable of producing specialized tank containers, road tankers, and aerospace tanks. While Australian companies have the capability, addressing the limitations of large-scale MCH use, such as plant size, requires workforce expertise in plant operation and management.

9.2.2 UNITED STATES OF AMERICA

The US Government has demonstrated a robust commitment to advancing technologies aimed at promoting an efficient and sustainable hydrogen and fuel cell industry. The country recently unveiled a significant investment of $35 billion to achieve groundbreaking advancements in renewable energy technology, with the goal of addressing the climate crisis, driving innovation in clean energy technology, and fostering growth in the clean energy workforce. The figure below includes projects in operation in 2010, and those that are expected to be in operation by 2030. Furthermore, the numbers include projects in various stages of development, such as feasibility study, final investment decision, demonstration and, operational. Up until 2021, there were approximately 30 documented[75] projects related to various electrolyser technologies, about 42 projects associated with storage and supply, and ~30 projects pertaining to diverse end-use applications, as indicated in 9.2.2 Currently, there are 0.12.[76] million metric tons per year of operational green hydrogen projects in the country. Additionally, there are 11 green hydrogen projects in various stages of development, with a total capacity of approximately 2.2 million metric tons per year.

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[75] Projects listed IEA Hydrogen Projects Database, as of October 2021 at all stage levels -Operational, feasibility study, concept, under construction etc.
76 https://www.iea.org/reports/hydrogen-projects-database

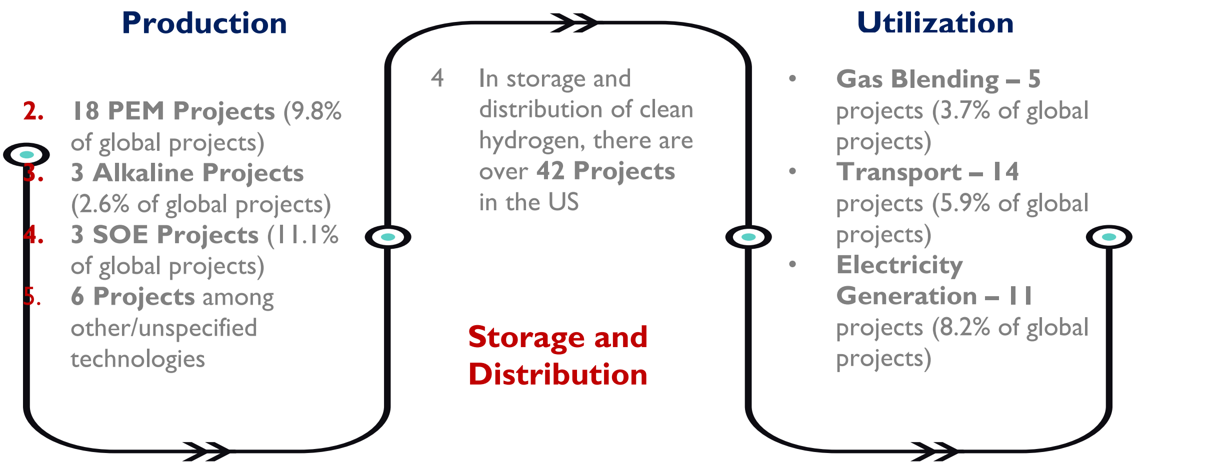

Figure 9.2 Number of Projects for Clean Hydrogen in the US

Source: IEA Hydrogen Projects Database, as of October 2021.[77]

The execution of proposed clean hydrogen production capabilities hinge on a nation's technological preparedness in various production and storage methods. This segment provides an overview of the hydrogen technology and its expected progress through 2036.

The U.S. National Clean Hydrogen Strategy and Roadmap for 2022[78] delineates a strategic plan, for near-term (2023), mid-term (2028), and long-term (2036) initiatives, aimed at advancing the development and implementation of clean hydrogen technologies. These actions involve committing $1 billion from fiscal year 2022 to fiscal year 2026 for expanding research, development, and demonstration of electrolysis technology, with the objective of producing hydrogen at $2 per kilogram via electrolysis. Additionally, $500 million is allocated for research and development in manufacturing and recycling of clean hydrogen technologies. The key targets encompass three value chains viz production, infrastructure & supply chains and end-use as depicted in 9.2.2.

Table 9.2: Key strategy & roadmap Targets 2022-2036

Value chain	2022-2023	2024-2028	2029-2036
• Production	• 10,000 hours of high temperature electrolyser testing • 1.25 MW of electrolysers integrated with nuclear for H2 production	• 10 or more demos with renewables (including offshore wind), nuclear, and waste/fossil with CCS. • 51 kWh/kg efficiency; 80,000-hr life; and $250/kW	• 10 MMT per year by 2030 • 46 kWh/kg efficiency; 80,000-hr life; $100/kW uninstalled cost for low temperature electrolysers. • 80,000-hr life & $200/kW cost for

[77] https://explore.mission-innovation.net/wp-content/uploads/2023/03/H2RDD-US-FINAL.pdf
[78] https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf

Value chain	2022-2023	2024-2028	2029-2036
		for low temperature electrolysers • 44 kWh/kg efficiency; 60,000-hr life; and $300/kW for high temperature electrolysers	high temperature electrolysers while maintaining or improving efficiency
• Infrastructure & Supply Chains	• 10 kg/min average H2 fueling rate for heavy-duty applications. • 40% reduction in footprint of liquid H2 fueling stations vs. current (2016) code. • 400 kg/hr. high-pressure compressors • 5% or better accuracy for H2 flow meters at up to 20 kg/min flow	• 7 kWh/kg efficiency for H2 liquefaction • 50% cost reduction of carbon fiber for H2 storage vessels (vs. 2020) • 3 GW or more electrolyser manufacturing capacity in the US	• $4/kg H2 cost at scale (including production, delivery, and dispensing at fueling stations)
• End-Use and Enablers	• $170/kW heavy-duty truck fuel cell cost vs. $200/kW baseline • 18,000-hr fuel cell durability for buses. • 1.5 MW or more of H2 fuel cells for data center resilience • 1 MW scale electrolyser and fueling marine applications. • 15 fuel cell delivery trucks operating in disadvantaged communities. • 1 or more integrated H2 for ammonia production demonstration	• $140/kW heavy-duty truck fuel cell cost • 1 ton/week reduction of iron with H2 and pathway to 5,000 tons/day • 4 or more Regional Clean Hydrogen Hubs using diverse resources and for multiple strategic end-uses	• $80/kW heavy-duty truck fuel cell cost while also meeting durability and performance • $900/kW and 40,000-hr durability fuel-flexible stationary fuel cells or more end-use demos (e.g., steel, ammonia, storage) at scale • 10 MMT per year or more of clean H2 used in strategic markets at scale aligned with the National Hydrogen Strategy goal

Key insights for skilling

- Workforce training programs should focus on specialized skills for conducting high temperature electrolyser testing. Skilling is essential for integrating electrolysers with nuclear facilities for hydrogen production, to ensure adherence to safety protocols and operational procedures.
- Skilled professionals will be needed to plan, execute, and oversee demonstrations involving renewables (e.g., offshore wind), nuclear, and waste/fossil energy with carbon capture and storage (CCS).
- Workforce capabilities need to be developed to cater to usage of clean hydrogen in strategic markets at scale, which includes end-use sectors like steel, ammonia, and storage.
- Training programs should cater to the installation and operation of hydrogen fuel cells in heavy-duty trucks, buses, data centers, marine applications, and delivery trucks. Training is also needed for integrated hydrogen use in ammonia production and iron reduction processes.

9.2.3 GERMANY

Germany's hydrogen strategy aims to foster scientific development and mobilize a skilled labor workforce around it. To facilitate the scaling up of hydrogen production, the government aims to support research companies and institutes. Thus, there is a push to train, recruit and develop scientists and newly skilled staff. To this end, Germany is focusing on education and training capacity in regions working with hydrogen.

Currently, around 8 KTPA[79] of green hydrogen is produced by operational projects in the country. The entire technological landscape of hydrogen projects in Germany, has been split into hydrogen production, hydrogen supply and distribution, and hydrogen utilization, which has been outlined in the figure shown below.

[79] IEA Project Database, as of October 2021

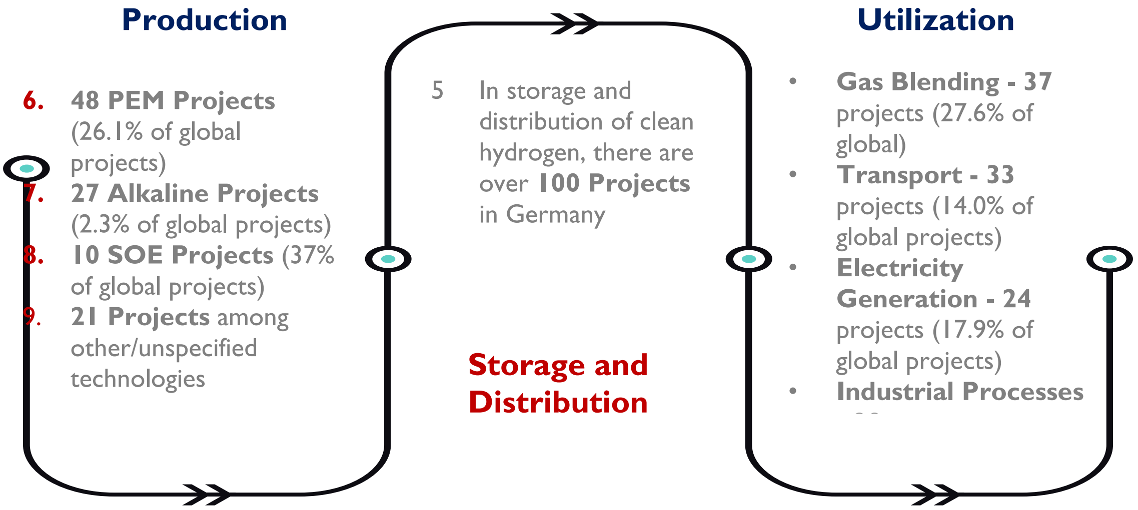

Figure 9.3. Number of Projects for Clean Hydrogen in Germany

Source: IEA Project Database, as of October 2021.[80]

The above figure includes projects in operation in 2010, and those that are expected to be in operation by 2030. Furthermore, the numbers include the projects that are at various stages of development, including feasibility study, final investment decision, demonstration and, operational.

9.2.3 presents an overview of Germany's research, development, and demonstration (RD&D) focal points throughout the hydrogen value chain. This table delineates sub-technology domains recognized by Germany, along with the associated primary RD&D emphasis within each domain.

Table 9.3 Overview of Germany's RD&D

Supply Chain Area	Sub-Technology Areas	Germany's Key RD&D priorities
Production	Electrolysis	Reduce cost to less than EUR 500 per kilowatt via RD&D, economies of scale, and automation. Optimize energy demand in flexible and dynamic operation. Energy and cost optimization of peripheral system components such as power electronics (rectifiers and transformers) and gas processing (gas analysis, drying, compression). Quality assurance and certification for electrolysis components. • Alkaline: Adapting cell materials to increase power density, efficiency, and service life for alkaline electrolysis.

[80] https://explore.mission-innovation.net/wp-content/uploads/2023/03/H2RDD-Germany-FINAL.pdf

Supply Chain Area	Sub-Technology Areas	Germany's Key RD&D priorities
		• PEM: Alternative membrane materials in PEM electrolysis for higher operating temperatures. Non-precious metals catalysts (e.g., iridium, platinum), and developing suitable recycling. Increasing the size and service life of large-scale PEM stacks in the MW class. Development of competitive high-pressure electrolysers for decentralized applications. • Chlor-alkali: Adapting previously operated facilities at base load to renewable energies. • Other: Germany is also interested in anion exchange membrane (AEM) and solid oxide electrolysis (SOE).
	Fossil fuel conversion	While fossil fuel conversion continues to be a RD&D priority for major industrial players, the German government places a higher emphasis on hydrogen generated from renewable sources rather than fossil fuel conversion with CCUS. Key RD&D priorities within the realm of fossil fuel conversion encompass: • Utilizing methane pyrolysis for hydrogen production, with a focus on industrial applications. • Supplying carbon dioxide (CO2) feedstock through either CCUS or Direct Air Capture (DAC).
Storage and Distribution	Compression and liquefaction	Conducting research, development, and demonstrations to achieve cost reductions in transportation technologies, specifically focusing on cryogenic storage, high-pressure vessels, and liquid hydrogen transport. This includes efforts to decrease the expenses associated with high-pressure tanks constructed from carbon fiber, which may involve enhancements in the carbon fiber manufacturing process.
	Hydrogen carriers	Lower the cost of hydrogen carriers: ammonia, methanol, liquid organic hydrogen carriers (LOHCs).
	Gas networks	Existing pipelines (conversion) and new pipelines.
Utilization	Industry	Developing plants capable of flexible operation to accommodate fluctuations in feedstock and volume flow rates, along with the modularizing processes for the refinery and chemical industry. Additionally, designing ammonia engines and turbines, while simultaneously reducing nitrous oxide (NOx) emissions, are key research and development priorities.
	Steel	• Dynamic steel plants (reduction process and varying natural gas-hydrogen ratios, while improving steel product quality). • Large scale-demonstration.

Supply Chain Area	Sub-Technology Areas	Germany's Key RD&D priorities
	Power generation	• Pure hydrogen gas turbines: cost reduction, increased tolerance ranges, larger scale, and improved operational performance.
	Chemical and refinery	• RD&D of hydrogen utilization from renewable sources for chemical recycling, focusing on the synthesis of liquid fuel products from plastic pyrolysis. • Integration of pyrolysis and gasification processes with dynamic operation modes, along with advancements in catalysts. • Development of new production processes incorporating optimized catalysts. • Exploration of techniques for recovering, separating, and capturing CO2 during synthesis processes. • Investigation of power-to-liquid e-fuels (PtL), particularly Methanol synthesis, with greater flexibility in feedstock and flow rate, as well as integration with electrolysis. • Progress in developing processes with closed carbon cycles. • Analysis of the impacts of changing feedstock on inter-industrial material flows. • Large-scale demonstration of industry-related projects that incorporate PtX (Power-to-X) processes into existing industrial infrastructure.
	Mobility	Achieving commercialization of fuel cell vehicles, including buses, cars, trains, and trucks by the year 2025. Fuel Cells: • Working towards cost reduction and increased lifespan of fuel cells, particularly for trucks and buses, but also extending the lifespan of fuel cells for trains and ships. • Advancing the development of fuel cell powertrains. Materials: • Striving to reduce the reliance on precious metals, such as platinum, in fuel cells, while maintaining power density and efficiency. • Increasing the longevity of fuel cells by stabilizing catalytic converters and catalytic converter carriers and reducing sensitivity to contamination. • Optimizing the coating of bipolar plates to enhance their durability. • Simplifying system components.

Supply Chain Area	Sub-Technology Areas	Germany's Key RD&D priorities
		• Developing manufacturing processes that enable high-speed, high-throughput production along with quality assurance. Circular Economy: • Pursuing strategies to lower the cost of fuel cell materials while also reducing the expense of recycling. Other: • Scaling up the refueling infrastructure, through the establishment of heavy-duty gas station networks. • Developing hydrogen refueling stations capable of processing cryogenic hydrogen, methanol, ammonia, or LOHC.
Cross-cutting	International standards	Internationally recognized certified standards for hydrogen-based energy sources and chemicals.
	International supply chains	Research (e.g., feasibility studies into trade partnerships). System analysis on business models for global supply chains.
	Testing	Analysis of location, value chain technology options, and sustainability of potential suppliers (including Australia).
	Modeling	Concepts for market-oriented production technologies (regarding upscaling electrolyser production and the performance of individual electrolysis systems).

Key takeaways for skilling –

- **In production –** Skilling in Automation, energy optimization, quality assurance, and certification of electrolysis components would be required to meet the rising demand. Also, operating Methane pyrolysis and CCUS related technology will require skilled, trained professionals.
- **In Storage -** Apart from experts in equipment operation and maintenance, upskilling for knowledge of hydrogen carrier production processes will be needed.
- **In Industries –** More skilled professionals with knowledge of chemical recycling and catalyst development, steel plant operators with knowledge of dynamic processes and a bigger workforce with expertise in infrastructure development and station operation will be required.

9.2.4 JAPAN

Japan was the first nation to introduce a hydrogen framework in 2017. The country has committed to achieving net zero target and carbon neutrality by 2050. Each year, Japanese government give subsidies to the tune of Yen 40 – 70 billion ($305 – 534 million) for building hydrogen infrastructure. In March

2022, the number of fuel cell electric vehicles in Japan crossed 7000[14], up from less than 200.[81] in 2015. Currently, there exist about 150 hydrogen refueling stations in the country, and the goal is to establish 1000 by 2030.[82]. The heavy-duty fuel cell electric trucks.[83] (FCETs), powered by hydrogen participating in the on-the-road trials launched in May 2023 were the first heavy-duty FCETs to operate in Japan.

Japan's technological strengths lie in hydrogen fuel cells, for which it has the world's largest number of patents, and in marine transportation. Japan announced the development of 80 hydrogen refueling stations by the end of 2022. To gain insights into the technological landscape, a comprehensive evaluation has been conducted for both currently operational hydrogen projects and those scheduled to become operational by the year 2030. Additionally, the planned projects encompass a spectrum of developmental stages, ranging from feasibility studies, final investment decisions, demonstrations, to fully operational initiatives.

Japan currently has an only 1.8 KTPA[84] of hydrogen production capacity, but it also imports significant quantities of it. The entirety of these projects has been categorized into three primary segments, namely hydrogen production, hydrogen supply and distribution, and hydrogen utilization, as represented in 9.2.4.

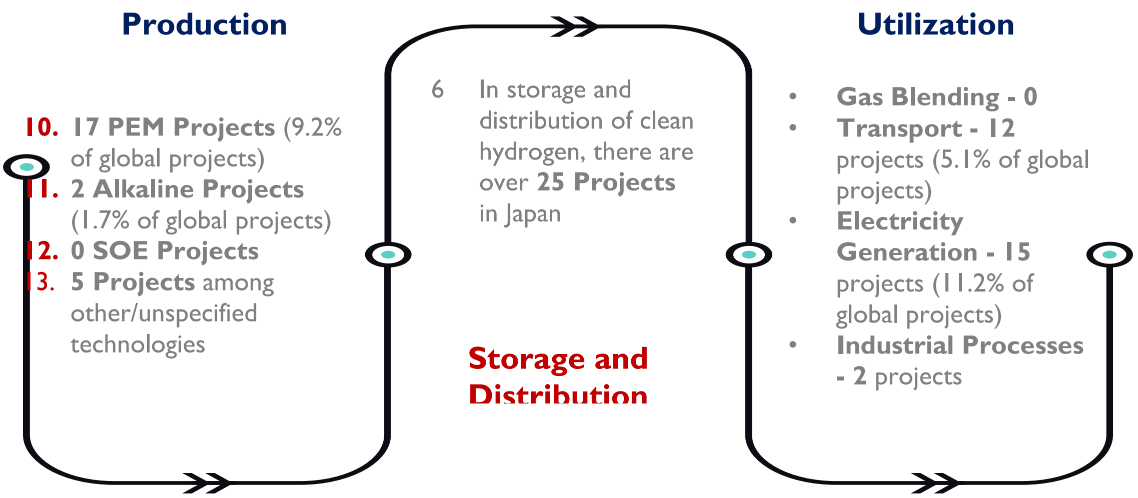

Figure 9.4. Number of Projects for Clean Hydrogen in Japan

Source: IEA Hydrogen Projects Database, as of October 2021.[85]

The overall number of projects in Japan are comparatively low as compared to other major countries in the report. This indicates that Japan might be adopting a more focused and selective strategy concerning hydrogen-related initiatives, potentially concentrating on certain aspects of the hydrogen

[81] https://www.statista.com/statistics/1252727/japan-fuel-cell-electric-vehicles-in-use/#:~:text=As%20of%20March%2031%2C%202022,primarily%20hydrogen%2Dfueled%20passenger%20cars.
[82] https://asia.nikkei.com/Economy/Japan-targets-1-000-hydrogen-stations-by-end-of-decade
[83] https://www.asahigroup-holdings.com/en/pressroom/2023/0517.html
[84] IEA Hydrogen Projects Database, as of October 2021
[85] https://explore.mission-innovation.net/wp-content/uploads/2023/04/H2RDD-Japan-FINAL.pdf

economy, or leaning on strategic partnerships and cooperative efforts with other countries to accomplish its hydrogen-related goals.

Technology

To fulfill the objectives outlined in its national hydrogen strategy, Japan is directing investments towards RD&D efforts across several key domains, which encompass Production, Storage and Distribution, Utilization, and Cross-cutting areas.

Within the sphere of hydrogen production, efforts are concentrated on advancing technologies like solid oxide electrolysis, anion exchange membrane electrolysis, coal gasification combined with carbon capture and storage (CCS), as well as innovative photochemical and photocatalytic production methods.

Regarding storage and distribution, the emphasis is on enhancing compression and liquefaction techniques, investigating chemical storage solutions like ammonia, liquid organic hydrogen carriers, and synthetic fuels.

In terms of hydrogen utilization, the priority areas include the development of gas separation technologies for effective gas blending, advancements in fuel cell technology and the establishment of refueling stations for the transport sector. Furthermore, Japan is exploring hydrogen turbines, ammonia turbines, various types of fuel cells such as PEM and Solid Oxide Fuel Cells (SOFC), applications in steel processing, synthetic fuel production, and methanol production.

In the cross-cutting category, efforts are focused on comprehensive life cycle and supply chain analysis, the establishment of international standards and regulations, and the optimization of rare metals processing and manufacturing.

Table 9.4 Overview of Japan's RD&D

Supply chain area	Sub-technology areas	Japan's key RD&D priorities
Production	Electrolysis	Improve efficiency, cost, durability, and scale of water electrolysis systems. Expand demonstrations in designated regions. Components related to hydrogen production at high temperature (nuclear).
	CCS	Reduce the cost of CO2 capture, collection, and storage. Reach demonstration stage of CO2 storage technology. Establish monitoring technology for CCS.
	Brown coal gasification	Increase scale and efficiency of brown coal gasification (including CO2 separation and collection).

Supply chain area	Sub-technology areas	Japan's key RD&D priorities
	Emerging hydrogen production technologies	Employ highly efficient water electrolysis (e.g., SOE), and photocatalysis, reversible systems, and permeable membranes to improve the purity of hydrogen.
Storage and distribution	Liquid hydrogen	Scaling-up of liquid hydrogen tanks and improving thermal insulation properties. Large-capacity liquid hydrogen loading systems. Large-capacity liquid hydrogen vaporizers, boosting pumps, piping, and joints. Practical use, commercialization, and cost reduction of liquid hydrogen. Improvements in the efficiency of hydrogen liquefaction (liquefier structure, non-contact bearings). Reducing the amount of carbon fiber in hydrogen storage systems in mobility applications.
	Hydrogen carriers	Practical use, commercialization, and cost reduction of energy carriers such as LOHCs, ammonia and synthetic methane.
		Dehydrogenation of energy carriers (e.g., process optimization utilizing waste heat). Driving down cost of the methanation processes. Cost reduction of LOHC supply chain and reducing the loss rate of toluene.
	Compressed gas	Developing technology to reduce carbon fiber content of hydrogen storage systems in mobility applications.
Utilization	Gas turbines	Feasibility studies on limited mixture co-firing rates for hydrogen power generation (development of burners, boilers, and turbines). Priority for co-firing ammonia and coal in the short term, and ammonia for gas turbines in the mid- term. Combustion improvements (increased efficiency of combustors, tackling high combustion temperatures, reducing NOx emissions, improving flame propagation velocity, flame quenching distance). Next generation, high efficiency thermal power via hydrogen co-firing. Burners and large-size, high performance boilers designed for hydrogen combustion.
	Industrial use	Investigation of availability and utilization of CO2-free hydrogen in industry (including steelmaking and oil refining). Practical application of carbon recycling technology.

Supply chain area	Sub-technology areas	Japan's key RD&D priorities
	Fuel cells	Automotive fuel cells – increasing performance of membranes for cost reduction in fuel cell vehicles; reducing the amount of platinum used in electrode catalysts. Stationary fuel cells – achieving grid parity in commercial and industrial use; higher efficiency and power density; eliminating causes of degradation; increased power generation efficiency for SOFC and fuel heat utilization factor for PEMFC (polymer electrolyte membrane fuel cell). This includes pure hydrogen fuel cells. Auxiliary machines and tank related systems.
	Hydrogen refueling stations	Reducing the cost of compressors and high-pressure vessels (e.g., using polymer materials, life-extension methods for ground storage vessels, higher temperature refueling methods). Low-cost equipment for ultra-high pressure hydrogen stations.
Cross-cutting	Lifecycle/supply chain analysis	Reducing CO2 emissions
	International standards and regulation	Promote international standardization in the fields of CO2 separation, collection, transportation, and storage. Promote international collaboration on safety (standards and technical improvements). Formulation of international rules for marine transportation of liquid hydrogen in the International Maritime Organization.
	Rare metals processing and manufacturing	Mass production techniques for rare metals used as catalysts

Key takeaways for skilling –

- **In production –** Advanced training for system optimization and advanced materials. Transitioning from traditional hydrogen production to advanced methods like solid oxide electrolysis, photocatalysis, and membrane technologies would require reskilling of the existing staff, so upcoming projects could generate employment opportunities.
- **In Industries –** Adapting industrial processes to utilize clean hydrogen would require skilling efforts focused on training in carbon recycling technologies.

9.2.5 SAUDI ARABIA

Saudi Arabia's official strategy or roadmap is in the process of development. While a comprehensive framework of priorities, policies, specific targets, and timelines is not yet fully established, the statements made by political leaders and corporate executives offer valuable insights into Saudi Arabia's potential approaches to hydrogen deployment. Additionally, the extent and thoroughness of the hydrogen strategy are closely intertwined with the kingdom's CCUS strategy, as the rate of CO2 utilization beyond enhanced oil recovery (EOR) advances can significantly impact the commercial viability of blue hydrogen production.

The current primary focus is on securing a substantial market share in blue hydrogen, with a particular emphasis on blue ammonia production within the coming decade. Blue ammonia refers to ammonia generated by ammonia synthesis along with hydrocarbon CCUS.

Key developments –

Some of the key developments in Saudi Arabia, that demonstrate their inclination towards cleaner hydrogen are listed below-

- Saudi Arabia is collaborating with South Korea, as exemplified by the Memorandum of Understanding between Aramco and Korea's Hyundai Oil Bank Co. This agreement requires Korea's Hyundai Oil Bank Co. to convert liquefied petroleum gas (LPG) cargoes from Saudi Aramco into hydrogen and return the captured CO2 emissions to Saudi Arabia.

- A notable milestone occurred in September 2020 when Saudi Aramco, the state oil company, successfully shipped 40 tons of blue ammonia from Saudi Arabia to Japan. This marked the world's first demonstration of blue ammonia supply chains, encompassing the entire process from production to international maritime transportation.

- The focus on renewables-based hydrogen is a pivotal aspect of technological and economic experiments within the visionary city of Neom. **Neom** is at the center of a substantial $5 billion green hydrogen project, which is a joint venture between Neom, ACWA Power in Riyadh, and Air Products based in Pennsylvania. This project, anticipated to come online in 2025, will have 4 GW renewable energy capacity, making it the world's largest renewable hydrogen-to-ammonia conversion facility. It is expected to produce 1.2 million tons per year of green hydrogen, roughly equivalent to the energy obtained from 5 million barrels of oil per year. (For comparison, Saudi Arabia's annual crude oil production volume stands at approximately 12 million barrels per day.)

- **End use**
  On the consumption front, Saudi Arabia is exploring the integration of hydrogen in the **transportation sector.** This endeavor began with the establishment of its **first hydrogen fueling station in 2019.**
    - The country has conducted successful tests of Toyota Motor's Mirai sedan-style FCEVs at the Air Product's Technology Center within the Dhahran Techno Valley Science Park, affirming their suitability for the kingdom.
    - Hyundai Motor of South Korea exported FCEVs to Saudi Arabia for the first time in September 2020, marking the debut of Korea's crossover utility vehicle-style FCEVs (NEXO) and FCEV buses (Elec City) in the Middle East.

Companies from North America and Europe are exploring the possibility of collaborating with Saudi Arabia to establish FCEV-related manufacturing facilities in Saudi Arabia. This includes partnerships with New York-based Hyzon Motors to establish an assembly plant for fuel cell trucks and with France-based Gaussin to set up a manufacturing facility for on-road and off-road FCEVs.

Key Takeaways for skilling –

- Develop specialized training programs for engineers and technicians to operate and maintain hydrogen production facilities, especially for blue hydrogen and ammonia production. Focus on training experts in renewable hydrogen production.
- The workforce will require specialized training programs to operate and maintain renewable energy facilities, like wind and solar farms, which are crucial for green hydrogen production.

As evident from the analysis of the technology landscape across these 5 countries – Australia, USA, Germany, Japan & Saudi Arabia, each country has distinct technological priorities and technology readiness levels.

Accordingly, their skilling requirements differ across the hydrogen value chain. However, not all countries have prepared a specific workforce skilling plan to support the growth of the green hydrogen sector. Australia & USA are leading the pack in-terms of planning workforce skilling with the growth of the green hydrogen sector. Section on "Global insights in skilling and jobs in green hydrogen" elaborates the current training & skilling initiatives in these countries.

9.3 CASE STUDIES – EXISITING HYDROGEN PRODUCING / CONSUMING INDUSTRIES

9.3.1 REFINERIES

9.3.1.1 PROCESS

Refineries use hydrogen to lower the sulfur content of diesel fuel. For this purpose, hydrogen is produced either via steam methane reforming process of natural gas or naphtha, or as a by-product from the Catalytic Reforming Unit. The hydrogen is utilized for processes such as hydrotreating and hydrocracking within the refinery.

a) Distillation:

- Crude oil is heated, and its vapors are passed through a distillation tower, where its components are separated based on their boiling points by the process of fractional distillation. These components include gases, naphtha, kerosene, diesel, and heavy residues.

b) Catalytic Reforming Unit (CRU):

- The naphtha obtained from distillation, is sent to the CRU.
- In the CRU, naphtha is subjected to catalytic reforming. This process involves the use of heat and catalysts to convert low-octane hydrocarbons into higher-octane products. Naphtha is converted into reformate, which is a high-octane gasoline blending component.
- Hydrogen is a byproduct of dehydrogenation reactions during catalytic reforming.

c) Hydrogen Generation Unit (HGU):

- The hydrogen generated in the CRU is typically insufficient to meet the refinery's demand for hydrogen. Mainly, HGU is responsible for the large-scale production of high-purity hydrogen.
- Hydrogen is generated in the HGU primarily through processes like SMR or other methods that involve the reaction of hydrocarbons with steam.
- Then the hydrogen is purified and compressed for distribution to various refinery units.

d) Hydrotreating (HT):

- Naphtha, other feedstocks and, certain intermediate products, often contain impurities like sulfur and nitrogen, which need to be removed to produce cleaner and environmentally friendly fuels.
- Feedstocks react with high-purity hydrogen, supplied from the HGU, during the process of hydrotreating.
- Hydrogenation reactions convert or remove impurities, resulting in cleaner products.

e) Hydrocracking:

- Hydrocracking is used to convert heavy hydrocarbons into lighter, more valuable products like gasoline and diesel.
- Heavy feedstocks, such as vacuum gas oil, are subjected to high-pressure and high-temperature conditions in the presence of a catalyst.
- High-purity hydrogen from the HGU is used to break down complex hydrocarbons in hydrocracking reactions.

f) Additional Units:

- Refineries have several other units and processes to further refine and treat various products, including desulfurization units, isomerization units, and more. Some of them are mentioned in brief below:

Hydrodesulphurization:	**Hydro-isomerization:**	**De-aromatization:**
Sulphur compounds are hydrogenated to hydrogen sulfide as feed for Claus plants.	Normal paraffins are converted into iso-paraffins to improve the product properties.	Aromatics are hydrogenated to cyclo-paraffins or alkanes.

Hydrogen as Fuel for Heating: Refineries use various fuels for direct heating, including natural gas, furnace oil. As the cost of producing hydrogen decreases, it may be adopted for heating in refineries, potentially increasing the demand for hydrogen in this sector. The hydrogen demand in a refinery is estimated by considering its use inside the hydrotreater and hydrocracker units. If adopted as a fuel for heating, this demand will have to be additionally considered while calculating the demand from large industries.

Change in Process with Green Hydrogen

Presently, hydrogen is predominantly produced in the HGU through Steam Methane Reforming (SMR) of natural gas or naphtha. The introduction of electrolysers to produce green hydrogen will entail the elimination of the SMR process.

Typically, most electrolysers consume around 50 kWh to produce 1 kilogram of hydrogen[86]. To set up a refinery plant with green hydrogen, approximately 40% more power would be required. Additionally, the refinery might have to incorporate process changes to manage renewable energy variability.

9.3.1.2 DRIVERS

The drivers for the refinery industry have been classified into pushing and pulling drivers. Pushing drivers refer to the factors which will help in growing the overall demand for hydrogen in the industry. On the other hand, pulling drivers refer to the factors which will curb the growth of hydrogen demand.

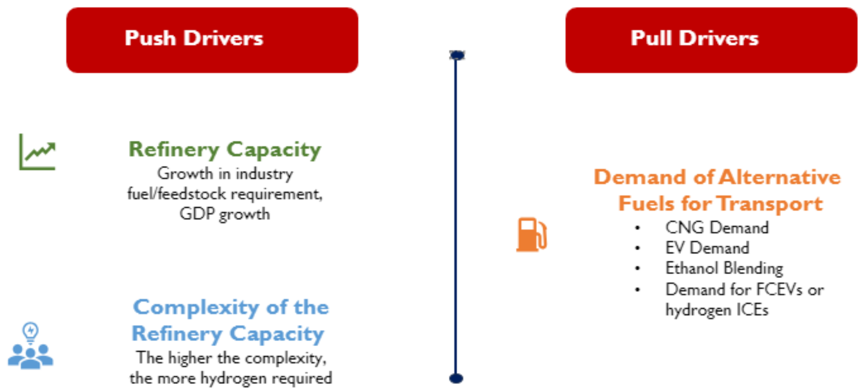

Figure 9.5 Drivers for Refinery

Push Drivers for Refinery Industry

- **Refinery Capacity Growth:** Hydrogen demand in the refinery sector is directly linked to the overall refining capacity in the country.
- **Complexity of the Refinery Capacity:** Complex refineries which process high sulphur crude oil require more hydrogen than refineries that process low sulphur crude oil.
- **Net Zero Targets / Policy:** By adopting green hydrogen, the Indian refinery industry will be prepared for the inevitable transition towards low-carbon and renewable energy sources. the government introducing green hydrogen consumption obligation (GHCO) for the refineries, would significantly drive up the green hydrogen demand in this sector.

Pull Drivers for Refinery Industry

- **Demand for Alternative Fuels for Transport:** The increasing demand of alternates like CNG, Electric Vehicle (EV), FCEVs etc. would impact the demand for refinery products including petrol & diesel. Thus, the increase in demand for these alternate fuels is likely to reduce the demand for conventional fossil fuels & refinery capacity.

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[86] https://www.sciencedirect.com/science/article/pii/S2666821121000880

Major Challenges:

Some challenges include the high cost of green hydrogen, large renewable power requirement & managing the variability of renewable power. Wind and solar power generation can be intermittent, leading to fluctuations in hydrogen production. Refineries must implement energy storage solutions and grid management strategies to ensure a continuous and stable supply of green hydrogen, which adds to the complexity and cost of the transition.

9.3.1.3 REFINERY - CASE STUDY - INDIAN OIL CORPORATION LIMITED (IOCL)

Indian Oil is a 'Maharatna' company with approximately a 35% share of India's refining capacity. It performs a wide variety of operations including refining, pipeline transportation, petroleum product marketing, exploring, and producing crude oil and gas. Additionally, IOCL specializes in natural gas marketing and petrochemicals.

Plans for Green Hydrogen and Scaling Up

Indian Oil has taken several steps to establish a presence in India's emerging Green Hydrogen sector.

- The company has solidified a partnership with ReNew Power Private Limited and Larson & Toubro Limited (L&T) to enter the Green Hydrogen business.
- Their Panipat refinery is currently developing a notable 7,000 tons per annum (TPA) of Green Hydrogen production capacity. Also, the refinery is increasing its current capacity of 15 MTPA by 10 MTPA by 2025 which will require an additional workforce.
- A hydrogen dispensing demonstration facility has been installed at their Gujarat refinery, using hydrogen sourced from the refinery unit.
- Indian Oil's Research and Development Centre is working to advance low-carbon technologies and products, emphasizing their comprehensive approach to green energy innovation.

IOCL Organogram – Hydrogen Generation Unit (HGU)

IOCL's Mathura plant has a HGU capacity of ~94 KTPA. The plant operates 24X7 with 3 working shifts. Through stakeholder consultation, a tentative layout of workforce utilization to run the HGU has been drawn up. However, the employees are shared resources over many processes in the refinery with none dedicated to HGU operation. Figure below illustrates the current organogram to manage an HGU.

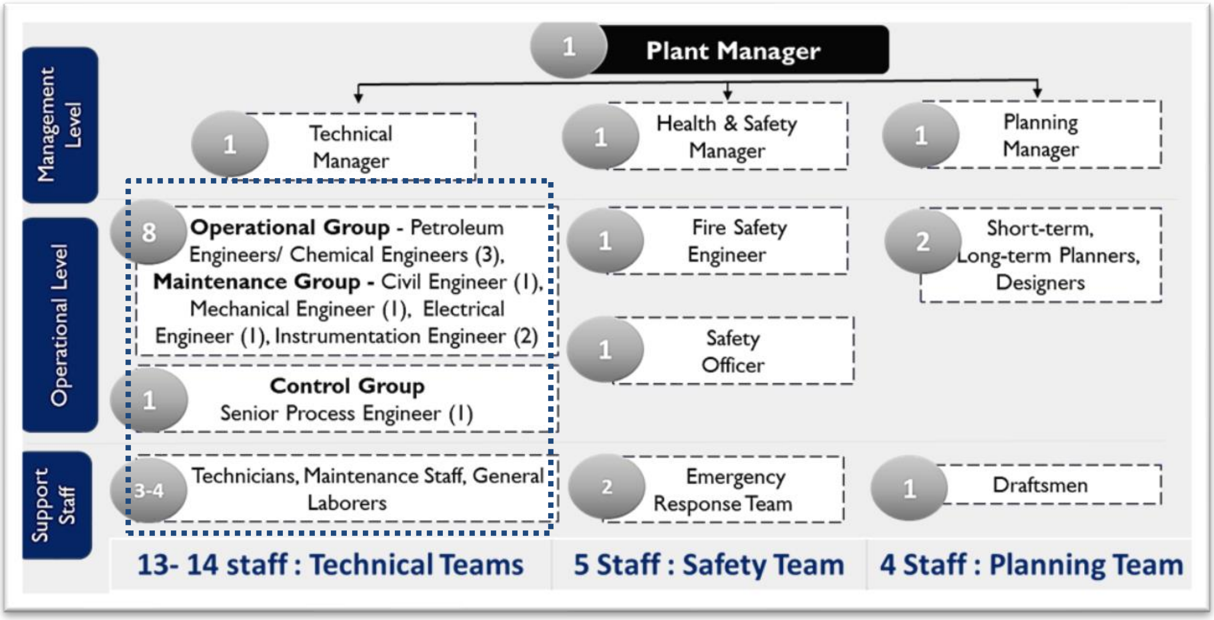


Figure 9.6 IOCL Organogram- HGU unit

Source: ICF Analysis and Stakeholder Discussions

The respondent from IOCL shared that the key job responsibilities required today are -

- Technical staff, that includes engineers in various fields for operating the plant processes.
- Safety department personnel, including emergency response teams and fire safety personnel.
- Short-term & long-term planners

In 2008, training for hydrogen generation and associated activities in Refineries was provided by Center for High Technology. Now most of the training happens 'on the job'.

In future, with introduction of green hydrogen, additional workforce / job roles may be required including –

- A separate green hydrogen production unit with a dedicated workforce for hydrogen production processes.
- An operations group managed by the hydrogen production unit mainly comprising of engineers – chemical, electrical and instrumentation.
- A dedicated process engineer.
- Dedicated operational staff like technicians, maintenance personnel etc.

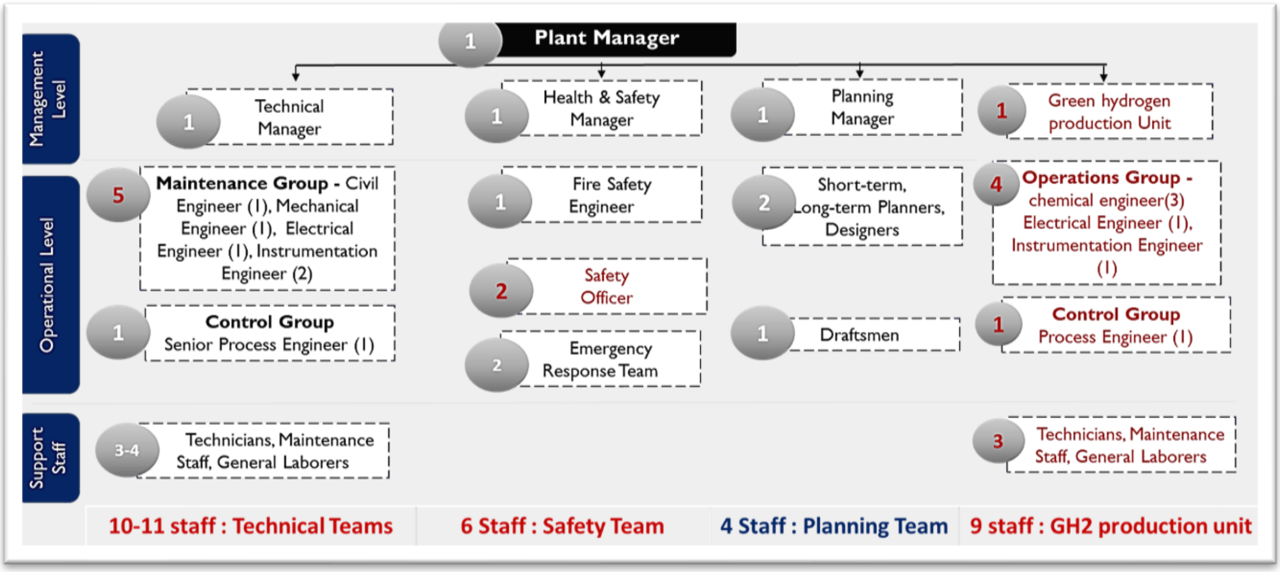


Figure 9.7 Refinery - Expected Organogram

Critical training areas –

- Managing electrolyser operations for the O&M workforce.
- Power management team including electrical engineers to manage the increased Renewable Energy (RE) power requirement & its variability.
- Storage is not possible in refineries at present. The need for storage might arise when shifting to green hydrogen, to manage the variability of renewable energy. Then skilling will be required for managing a storage facility.

9.3.2 FERTILIZERS

9.3.2.1 PROCESS

A typical nitrogen-based fertilizer industry uses ammonia to produce urea-based and non-urea-based fertilizers such as DAP (Diammonium Phosphate), among others. Many of these fertilizer units produce synthetic ammonia in-house, using hydrogen & nitrogen as key inputs via the Haber-Bosch process, which directly synthesizes ammonia from hydrogen and nitrogen. The hydrogen utilized in the production of ammonia is produced in-house, typically via steam methane reforming of natural gas.

Thus, like refineries, many fertilizer production units produce grey hydrogen for captive consumption.

Change in Process with Green hydrogen.

With the shift to green hydrogen the following changes will be required in a fertilizer plant -

Pressure Swing Adsorption (PSA) Unit for Nitrogen Extraction: In traditional ammonia production, nitrogen is sourced from the air through an air separation unit. With the shift to

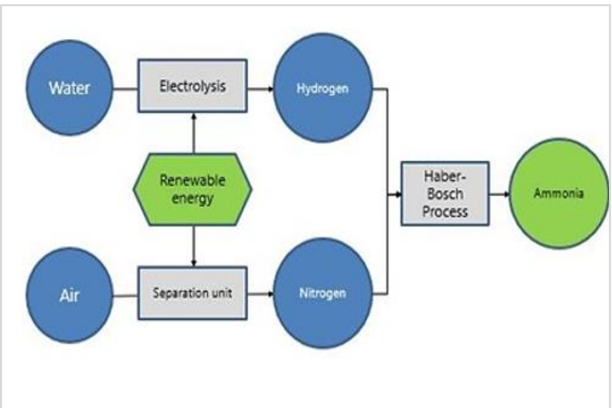


Figure 9.8 Green Ammonia production process

green hydrogen, a Pressure Swing Adsorption (PSA) unit may be needed to extract nitrogen from the air. This unit separates nitrogen from other gases, ensuring a pure nitrogen stream for the ammonia synthesis process.

Ammonia Synthesis Reaction: The redesign will focus on adjusting the synthesis loop for ammonia production to accommodate green hydrogen and nitrogen extracted through the PSA unit. The correct balance of hydrogen and nitrogen in the synthesis gas is crucial for optimal ammonia production.

External CO2 Requirement: Traditional ammonia production utilizes carbon dioxide generated within the process of hydrogen production. With green hydrogen, additional external sources of carbon dioxide may be required for the synthesis of certain fertilizers. This can be sourced from other industrial processes, biogenic sources, or direct air capture.

Hydrogen Storage and Distribution: If the fertilizer plant does not produce green hydrogen on-site, the green hydrogen storage and distribution infrastructure will need modification. This may involve adjusting pipelines, storage tanks, and distribution systems.

9.3.2.2 DRIVERS

The various factors that boost the demand of fertilizer industry and those that pose as a challenge are discussed here –

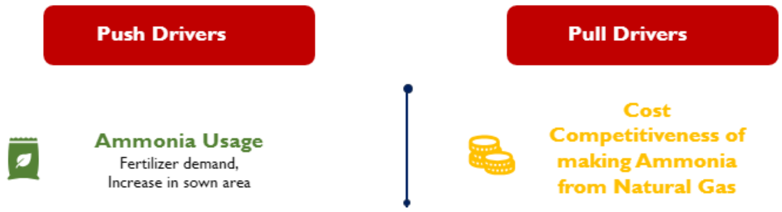


Figure 9.9 Drivers for Fertilizer

Push Drivers for Fertilizer Industry

- **Ammonia Usage**: Fertilizer plants produce ammonia as an intermediary product, which apart from being converted into fertilizer is also sold for other industrial uses. Thus, increase in ammonia demand either for fertilizer production, or for industrial usage, increases the hydrogen demand in the sector.
- **Net Zero Targets/Policy –** The government introducing green hydrogen consumption obligation (GHCO) for the fertilizer sector, would drive up the green hydrogen demand.

Pull Drivers for Fertilizer Industry

- **Cost Competitiveness of Making Ammonia from Natural Gas**: Current production costs for new green ammonia plants are in the range of $ 720 – 1,400 per ton, about six times higher than that of traditional ammonia (natural gas-based ammonia and coal-based ammonia), which is in the range of USD 110-340 per tonne.[87]

Major Challenges

- Fertilizer plants have a fixed profitability; thus, the transition should take place gradually, keeping the costs low.
- Conventional imported ammonia currently costs around INR 50-60,000 per metric ton. Cost of green ammonia is around INR 1,00,000 per metric ton. Unless the government mandates a minimum of 5-6% use of green ammonia (not likely in Urea sector), the industry will be reluctant to transition to high-cost green ammonia.

9.3.2.3 FERTILIZERS - CASE STUDY – IFFCO FERTILIZERS

Indian Farmers Fertilizer Cooperative Limited (IFFCO), is a multi-state cooperative society. IFFCO is wholly owned by Cooperative Societies of India. The cooperative is engaged in the business of manufacturing and marketing of fertilizers. Its primary purpose is to supply fertilizers, agricultural products, and services to support agricultural productivity in India.

Plans for Green Hydrogen and Scaling Up

IFFCO has taken several steps to establish its presence in India's emerging Green Hydrogen sector.

- It is planning to expand the manufacturing facility at Paradeep to 30 lakh tons a year. The total project cost is estimated at INR 5000 million.
- It is likely to start producing nano-di ammonia phosphate (DAP) at its Paradeep plant in Odisha before proceeding to other units.
- IFFCO, is the first Indian company to use low carbon ammonia for fertilizer production because of its partnership with SABIC AN.

Organogram IFFCO - Hydrogen Generation Unit Only

The organogram given below is for a 6,000 MT/day capacity plant. Like refineries, this plant also operates 24X7 in three different shifts. The key job roles identified by the respondent are -

- Production staff & process engineers.
- Fire and Safety Department with 3 staff members.
- The Laboratory Department has a unit head and analysts working on design.

However, none of the job roles are dedicated to the process and are shared across the unit. Details of each department related to hydrogen handling is shown in the figure below:

[87] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/May/IRENA_Innovation_Outlook_Ammonia_2022.pdf

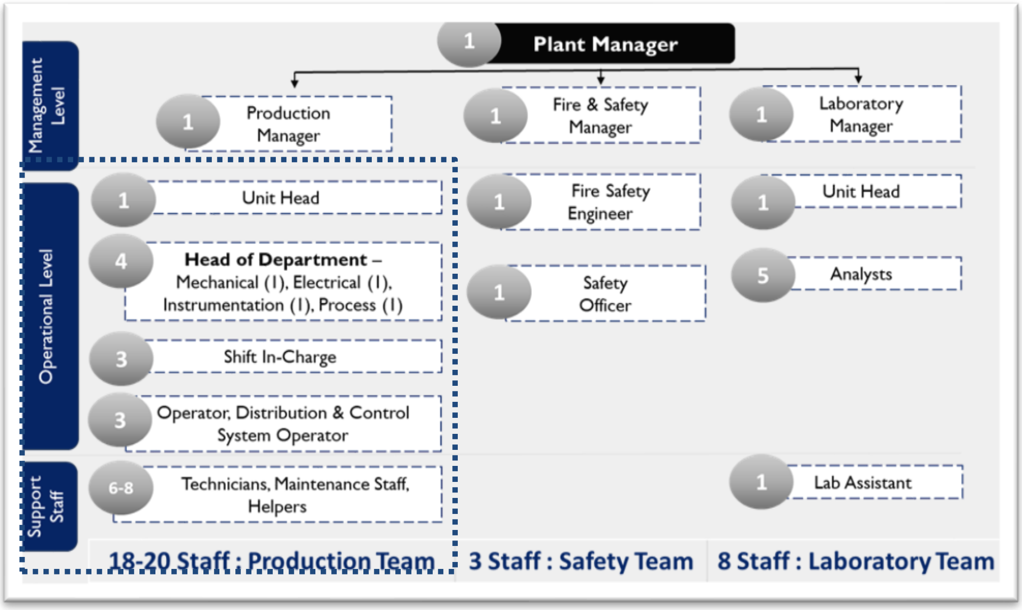


Figure 9.10 IFFCO Organogram – HGU unit

Source: ICF Analysis and Stakeholder Discussions

In future, with the introduction of green hydrogen production unit, following changes have been envisaged.

- The plant will require a separate green hydrogen generation unit.
- A Pressure Swing Adsorption (PSA) unit including a combination of gas operator and chemical engineer will be required. Members of this unit in-depth knowledge of the principles of adsorption, particularly the PSA process, familiarity with various gas separation technologies and the ability to troubleshoot and optimize these systems.
- Some of the existing support staff of technicians, maintenance and helpers can alter specific training, be moved to work exclusively in the green hydrogen production unit.

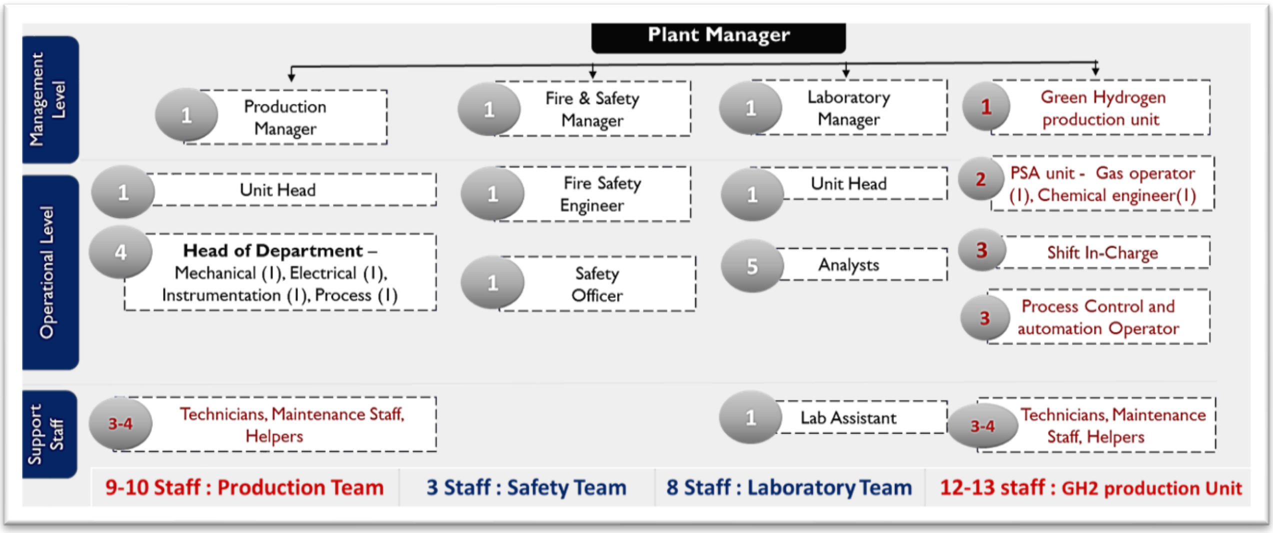


Figure 9.11 Fertilizer – expected organogram

Key Findings

Critical training area for future –

- Managing electrolyser operations
- Power management team for managing increase in RE power requirement & its variability.
- Process engineering team, since, using green H2 might necessitate process redesign for fertilizer plants (including additional PSA unit for N2 extraction & external CO2 requirement).

9.3.3 CHEMICALS

Currently in India, chloro-alkali plants, where hydrogen is a by-product, are the key producers of hydrogen for merchant sale. In many chlor-alkali plants, the hydrogen produced is either utilized in production of another chemical (hydrogen chloride etc.), or it is sold in the merchant market. Occasionally, the hydrogen is flared.

9.3.3.1 PROCESS

Caustic Soda Plant – Hydrogen is a by-product during the manufacturing of caustic soda through the electrolysis of brine (sodium chloride solution). The production process typically involves the following steps-

- **Brine Saturation:** The desired concentration of brine, a sodium chloride (NaCl) solution in water, is prepared.
- **Brine Purification**: Impurities including metals cations that might interfere with the electrolysis process are removed. The purification process enables efficient operation of the membrane cell.
- **Brine Settling, Filtering, Polishing:** Suspended particles and any remaining impurities are removed. Maintaining a clean brine solution is crucial for the successful operation of the electrolysis cell.
- **Secondary Brine Purification (Ion Exchange):** Ion exchange processes are used to further remove unwanted ions, ensuring high purity brine. The quality of the brine impacts the efficiency and longevity of the membrane cell.
- **Electrolysis:** In the electrolysis cell, an electric current is passed through the brine solution, generating H2 gas at the cathode and Cl2 gas at the anode. The chlorine is typically collected and used in various applications, while hydrogen is typically released or managed as a byproduct. When chlor-alkali (chlorine and caustic soda/ caustic potash) is made, hydrogen may be formed as a co-product. This is because water and salt (NaCl or KCl) are 'split', by electrolysis, into the base components Cl2, sodium/potassium (Na/K), hydroxide (OH-) and, potentially, hydrogen gas.

Change in Process with Green hydrogen.

The only change required for chlor-alkali plants for to shift to green hydrogen would be to replace its existing power source for electrolysers to a renewable energy source. Further, the chlor-alkali plant might have to incorporate process changes to manage renewable energy variability.

9.3.3.2 DRIVERS

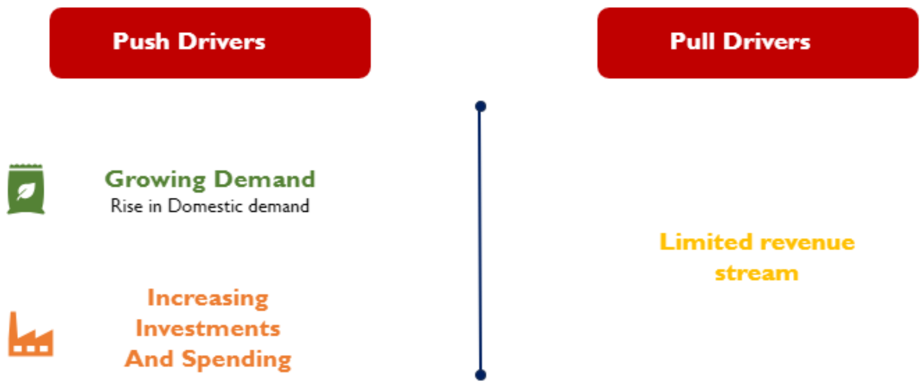


Figure 9.12 Drivers for Chemical Industry

Push Drivers for Chemical Industry

- **Growing Demand**: Increase in demand for caustic soda would increase production of hydrogen as a by-product in the industry. Further, an increase in demand of chemicals like methanol, hydrogen per oxide and hydrogen chloride would increase the demand of hydrogen in the chemicals sector.
- **Increasing Investments and Spending-** Availability of financing would encourage expansion of this sector.

Pull Drivers for Chemical Industry

- **Limited revenue stream** – By-product hydrogen has a limited revenue potential & is not the core business focus of the organization. Thus, the industry leaders are focused on expansion in other business areas and the growth in this sector remains organic.

Major Challenges –

- System integration – Managing variability of RE power.
- Availability of green hydrogen, its relatively high cost, and the logistics of its adoption. NFIL also stated that most of these challenges depend on the location of the plant as transportation to remote places can be problematic.

9.3.3.3 CHEMICALS - CASE STUDY - NAVIN FLUORINE INTERNATIONAL LTD (NFIL)

Navin Fluorine International Ltd (NFIL), an Indian manufacturer of fluorochemicals, is a key member of the Padmanabh Mafatlal Group. It was established in 1967 with major operating complexes in Surat, Dahej, and Dewas. They have integrated operations in the UK and India.

Organogram NFIL - Hydrogen handling staff only

It's a round the clock plant with a production capacity of 20,000 TPA. Like refineries and fertilizer industries, this unit also has shared resources and no specific job role for a hydrogen management unit. The current job roles highlighted by the respondents are -

- The production team comprised of engineers and operators who are general diploma holders.
- The quality control team of chemical experts and lab technicians.
- The Safety Department comprising of health and safety and chemical safety officers.
- The Logistics Team is comprising of contractual staff and administrative personnel.

The details of workforce of a chemical plant for handling hydrogen is as below:

Figure 9.13: Navin Fluorine International organogram – hydrogen handling staff only

Source: ICF Analysis and Stakeholder Discussions

With the introduction of green hydrogen, the following changes are expected in the organogram of the chemical industry.

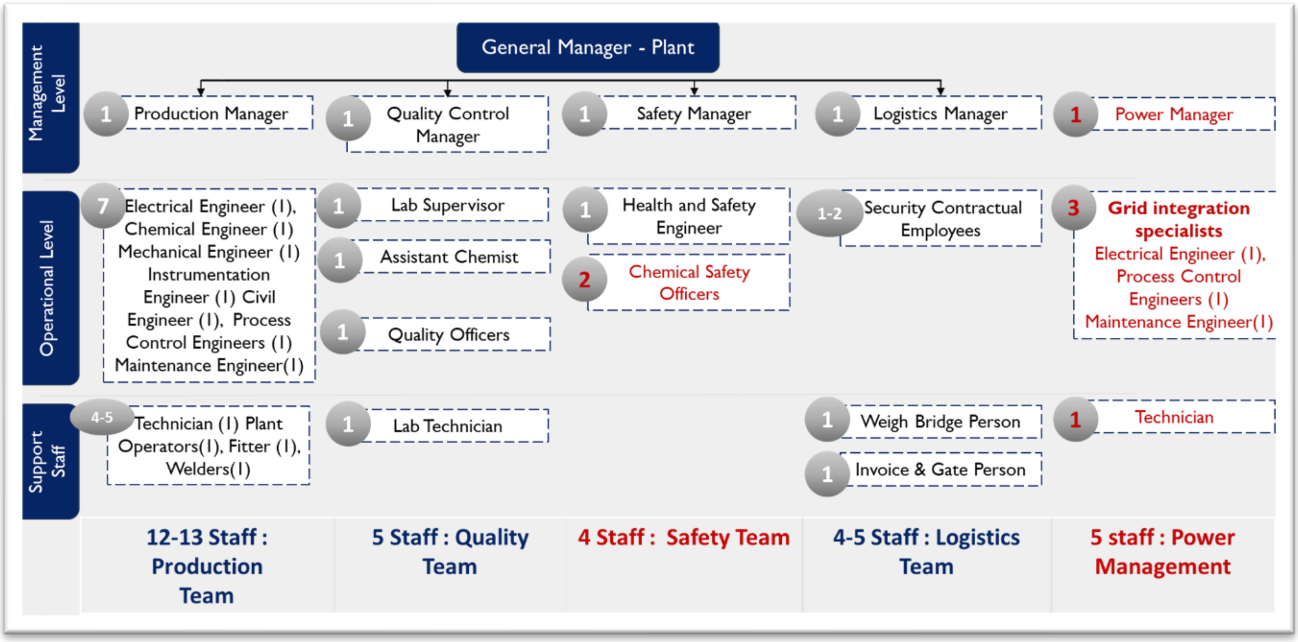


Figure 9.14 Chemical – expected organogram

The details of additional staff and skills required in the future are -

- A power management team for RE power sourcing & its integration. This team can be assembled by hiring dedicated staff or by upskilling technical staff in the existing production team.
- Grid integration specialists including electrical engineers, process control engineers, maintenance engineers and technicians with appropriate training.

Critical training area –

- Requirement of certifications/certified courses to ensure competence in managing operations involving hydrogen.
- Training for RE power integration (managing variability).

Additional safety training regarding the safety protocols, hazards, etc. specific to hydrogen usage.

9.3.4 IRON AND STEEL

India ranks second in the global steel producing leaderboard. It is also the second largest consumer of finished steel. In the fiscal year 2021-2022, the sector contributed about 2 percent of the nation's GDP and generated employment for about 2 million people.

Every ton of steel produced in 2018 emitted on average 1.85 tons of carbon dioxide, amounting to about 8 percent of global carbon dioxide emissions. In 2018, direct emissions solely from iron and steel production accounted for roughly 270 million tons of carbon dioxide equivalent (MTCO2e), contributing to nearly 9 percent of the country's total greenhouse gas emissions.

9.3.4.1 PROCESS

India's steel production relies mainly on the blast furnace-basic oxygen furnace (BF-BOF) process, which uses coke and fossil fuels to make pig iron and then crude steel. The direct reduction-electric arc furnace (DR-EAF), on the other hand, reduces ore to direct reduced iron (DRI) with natural gas, after which an electrically powered furnace melts the DRI to produce steel. However, a significant amount of carbon is still emitted. To make steel production carbon-neutral, fossil fuels can be replaced with clean hydrogen as the reductant, thereby reducing direct CO2 emissions.

DR-EAF Route-

In the iron and steel industry, the DR-EAF route is a specific steelmaking process that incorporates hydrogen in various ways to improve energy efficiency and reduce emissions. Here's how hydrogen is involved in the DR-EAF route:

1. **Direct Reduction (DR)**: The process starts with direct reduction, where iron ore is converted into DRI or sponge iron. Hydrogen gas is a common reducing agent used in this step. It reacts with iron ore to remove oxygen, leaving behind a highly pure iron. The use of hydrogen in direct reduction is considered a cleaner alternative to traditional methods that use carbon-based reducing agents.
2. **Electric Arc Furnace (EAF)**: The DRI produced in the direct reduction step is typically fed into an electric arc furnace, where it is melted and further refined into steel. While hydrogen is not directly involved in the EAF process itself, the use of DRI, which is a product of hydrogen-which can act as a reducing agent, improve temperature control, and reduce the overall carbon

footprint of the steelmaking process. based direct reduction, contributes to lower carbon emissions compared to traditional blast furnace routes.

3. **Hydrogen Injection**: Some steel plants are exploring the direct injection of hydrogen into the EAF to further reduce carbon emissions. This involves injecting hydrogen gas into the furnace,

4. **Hot Metal Desulfurization**: Hydrogen is sometimes used in the desulfurization of hot metal before it enters the EAF. Hydrogen reacts with sulfur to form hydrogen sulfide, which can be removed from the steel.

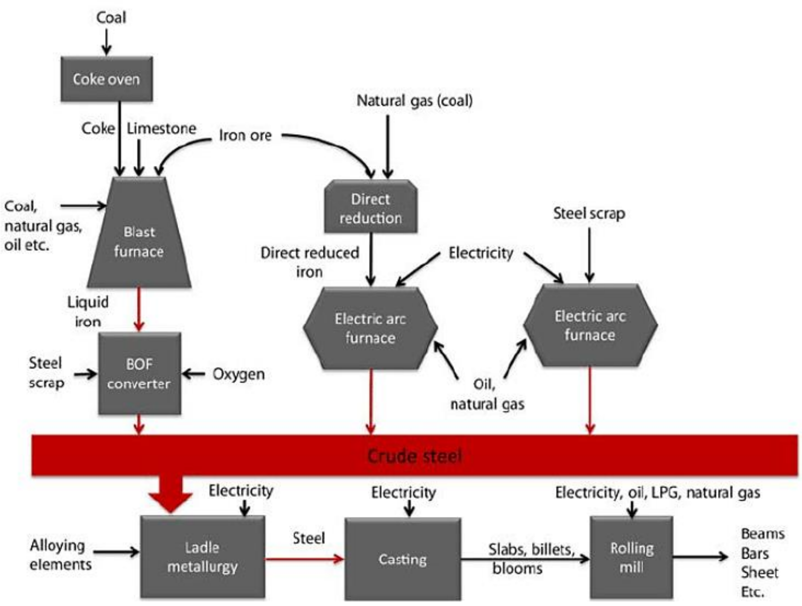


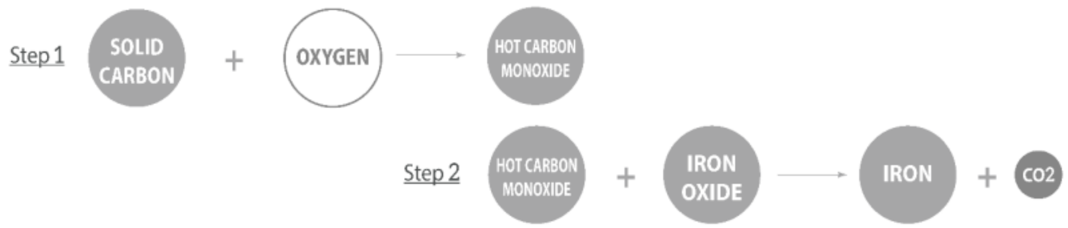
Figure 9.15 Production Technologies used in Iron and Steel Sector

Additionally, hydrogen can be used as a reducing agent and replace furnace oil, natural gas, and LPG as fuels in the sub-processes in the steel sector.

The global hydrogen demand for DRI in the steel industry is about 5 MT. In 2021, the post pandemic DRI production percentage rose by 12%. DRI production is highly concentrated in the Middle East, which accounts for 40% of the global production, while India, contributes to around 30% of the global production.

Change in Process with hydrogen.

In the direct reduction process, hydrogen serves as a reducing agent. Natural gas is currently used as a reductant in this DRI or EAF pathway by industries.



Inside the blast furnace, carbon particles initially react with a limited amount of oxygen to produce carbon-monoxide. This carbon monoxide gas will then chemically react with the iron oxide particles, producing iron and CO2. Decarbonization of the iron-making process therefore requires replacing carbon / carbon monoxide in this reaction with another gas that would lead to lower or zero carbon emissions, such as methane or hydrogen. Using methane (CH4), a chemical compound containing both carbon and hydrogen, would allow a reduction in CO2 emissions, partially replacing them with water vapor (H2O). Using hydrogen (H2) would completely decarbonize the process, since water vapor would be the only chemical by-product.[88]

Using hydrogen as a reducing agent in a steel plant is likely to require significant changes in the existing infrastructure. But using blended hydrogen with natural gas (less than 5% by volume) might not require significant changes. Replacing natural gas in Natural gas based DRI by hydrogen would require changes in the existing infrastructure (pipelines, furnace etc.) to ensure that hydrogen does not cause embrittlement of the material in infrastructure components, which may later result in hydrogen leakage. Further, changes in other operational components like burners would need to be made to ensure that the process is compatible with the changed operating conditions (pressure & flame temperature).

Further, to ensure continuous operation of the steel plant a hydrogen storage or battery storage facility may be required.

9.3.4.2 DRIVERS

The pushing and pulling drivers for the iron and steel industry are listed below -

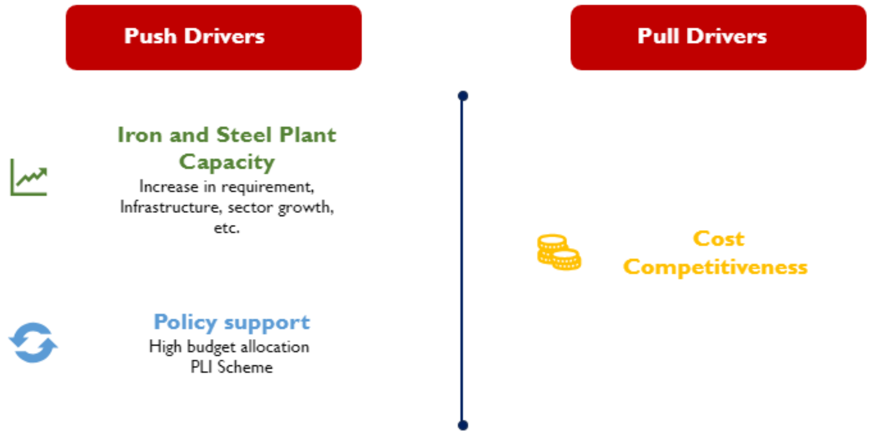


Figure 9.16 Drivers for Iron and Steel Industry

Push Drivers for Iron and Steel Industry

- **Iron and Steel Plant Capacity**: India's current steel policy seeks to increase per capita steel production from 60 kg in 2017 to 160 kg by FY 2030[89]. This, coupled with plans for infrastructure growth (infrastructure CAPEX expected to increase with CAGR of 11% between FY 2023 and FY

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[88] https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/641552/EPRS_BRI(2020)641552_EN.pdf
89 https://steel.gov.in/sites/default/files/policy1_0.pdf

2027.[90]) in the coming years, will lead to massive increases in iron and steel plant capacities to cater to the growing demand. Hydrogen can be utilized in these industries as fuel, or in DRI/EAF.

- **Policy Support**: Providing incentives for green hydrogen consumption and production could speed up the adoption of hydrogen related infrastructure and drive the green hydrogen demand in the sector.

Pull Drivers for Iron and Steel Industry

- **Cost Competitiveness -** Limited domestic market for the high-cost green steel (due to high cost of green hydrogen).

Major Challenges:

- Availability of uninterrupted, continuous power for a 24X7 operational plant.
- Due to high cost of green hydrogen required for production of green steel, the domestic market for the high-cost green steel is limited. Thus, currently, the only viable market for Indian green steel is in exports.

9.3.4.3 IRON AND STEEL - CASE STUDY – ESSAR STEEL

Essar Steel is a leading exporter of flat steel products to the US, Europe, Southeast Asia, and the Middle East. With fully integrated operations covering mining to retail, Essar Steel has a 10 MTPA production capacity. It owns the world's fourth largest single-location flat steel plant in Hazira, Gujarat.

Plans for Green Hydrogen and Scaling Up

- The Essar Group will invest $1.2 billion in India to develop a range of low-carbon energy transition projects over the next five years. "Essar Energy Transition (EET)" is a group of Essar companies investing in green hydrogen value chain internationally. EET will also invest in developing a cost-efficient global supply hub for low-carbon fuels in India, including green hydrogen and green ammonia. Ammonia will be shipped from India to the UK, Europe, and elsewhere to meet the expanding market demand for green hydrogen.
- Essar has plans to invest in production of blue hydrogen from natural gas with carbon capture, and green hydrogen from renewable sources, for sustainable hydrogen production.
- The company announced its investment of USD 8 billion in three mega projects, namely; a steel plant in Saudi Arabia, and iron pellet plants in Odisha and Minnesota, US.

Organogram for ESSAR Steel - Hydrogen handling staff only

ESSAR Steel India Limited, is a fully integrated steel mill in Hazira, of the Surat district in Gujarat, India, with a steel-making capacity of 10 MTPA. To ensure 24X7 monitoring and operation, the plant is run

90 https://dea.gov.in/sites/default/files/Monthly%20Economic%20Review%20July%202023_1.pdf

by various teams working in 3 different shifts. The details of the different organizational verticals are given below –

- Production team comprises of technical staff like engineers and operators.
- The quality team works with the production team.
- The Safety Department has emergency response teams and fire safety personnel.
- The Laboratory team designs and tests steel.

The workforce structure of an iron and steel plant is as follows:

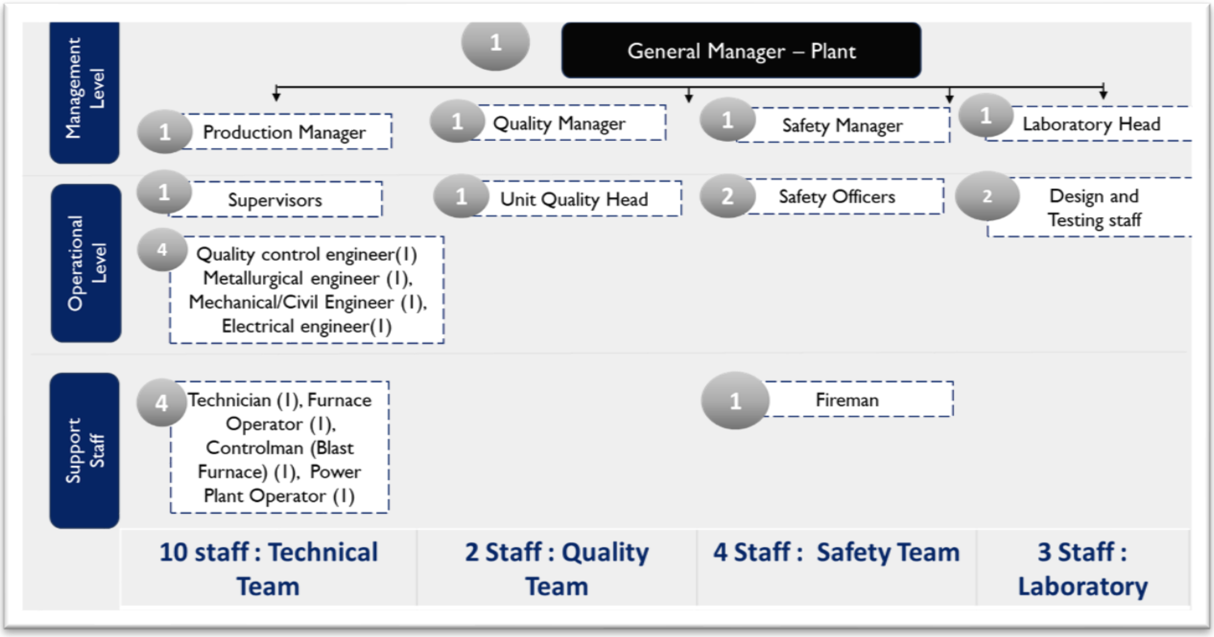

Figure 9.17: Essar Steel organogram

Source: ICF Analysis and Stakeholder Discussions

For the transformation of the iron and steel industry to green hydrogen, the following changes can be expected in the organogram.

With changes in the different departments in the iron and steel industry the number of staff would increase to around 23-24. Details are as below:

- A hydrogen storage facility, along with a team to manage it, shall be required.

- The production team will require engineers with specialized knowledge of electrolyser technology.

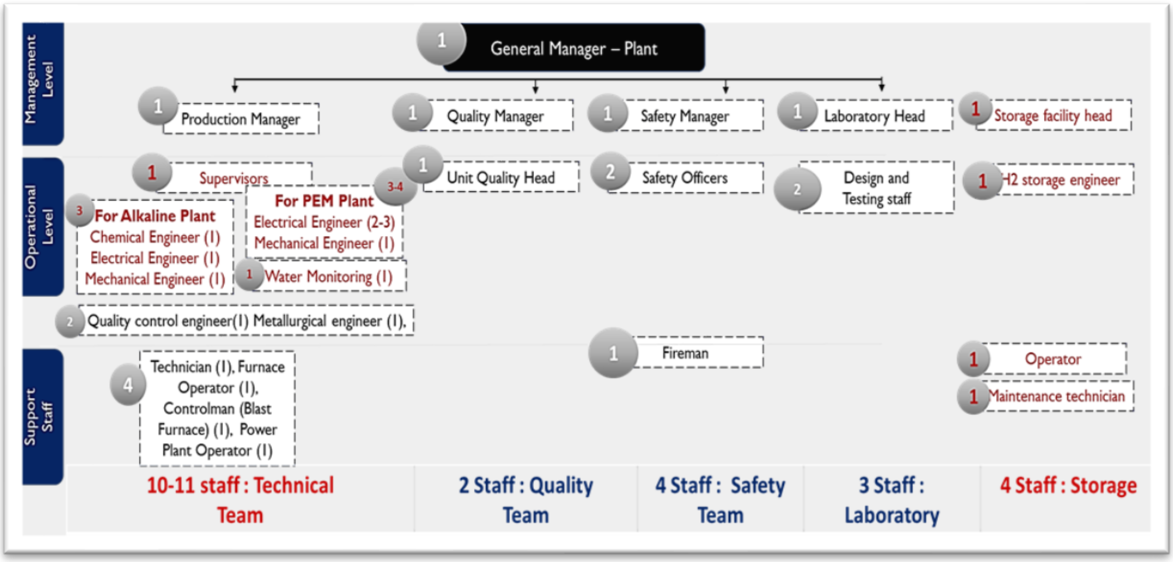

Figure 9.18 Iron and steel – Expected organogram

Critical training area –

- Safety protocols, hazards, etc., specific to using hydrogen.
- Managing storage facility - H2 storage may be required to manage variability of renewable energy.
- Certifications/certified courses for managing operations involving hydrogen.

9.3.5 SHIPPING

In India, there were approximately 2,000 passenger vessels and 1,600 cargo vessels in operation along inland waterways in 2019. The estimated emissions from the inland waterways transport (IWT) sector totaled around 277,000 tons of CO2 (tCO2). India also had a fleet of about 970 coastal shipping vessels in the same year, resulting in a consumption of approximately 1.6 million tons of fuel oil and emissions of 5.1 million tons of CO2 (MtCO2). [91]

On a global scale, efforts have been initiated to lower emissions in the shipping sector, notably with the International Maritime Organization (IMO) setting a challenging objective to decrease emissions by 50% by 2050 in comparison to 2008 levels. Towards this end, the shipping industry is actively investigating alternative fuels, which include ammonia, hydrogen, LNG, liquid biofuels, methanol, and electricity.

The shipping industry is transitioning to LNG as a cleaner and more environmentally sustainable fuel source. LNG offers a significant reduction in emissions compared to traditional marine fuels, making it a viable choice for meeting stricter environmental regulations. Indian ports are developing LNG

[91] https://www.ceew.in/sites/default/files/decarbonising-shipping-vessels-in-indian-waterways-with-clean-fuel.pdf

bunkering infrastructure to facilitate the adoption of LNG as a marine fuel, and several Indian shipping companies are investing in LNG-powered vessels. About 60% of the newly built ship orders are LNG fueled vessels (order of 952 ships in 2023).

In India, to meet the vision of achieving Zero Carbon Emission Goal, Ministry of Ports, Shipping & Waterways launched 'Harit Sagar' the Green Port Guidelines in May 2023.

9.3.5.1 PROCESS

Bunkering Process - To facilitate the use of green hydrogen in shipping, a dedicated bunkering infrastructure is required. This includes the development of hydrogen refueling stations and the establishment of bunkering facilities at ports. The efficient design and deployment of such infrastructure are crucial to ensure a reliable supply of green hydrogen to ships. At present **LNG bunkering processes** are operational. The bunkering process in ships is done in the following ways-

- Truck to Ship (TTS): Tank trucks are relatively inexpensive compared to other options and provide a flexible means of supplying small bunker volumes. Recommended for deliveries of a few cubic meters up to 200 cubic meters. The capacity of the most common tanker is around 48 cubic meters of deliverable LNG.
- ISO Containers: These are modular containers filled with LNG, mounted into a standardized frame, and loaded onto the vessel. The installation is a simple plug and play type concept, but cranes are required to lift and remove the containers.
- Ship to Ship (STS): Ship to ship transfers can be performed at the quay but are also possible at anchor or even at sea. The capacities of these vessels are in general between 1,000 and 10,000 cubic meters, but smaller vessels are possible. This is expected to be the major bunkering method for volumes more than 100 cubic meters.
- Terminal to Ship (TPS): This is a tailor-made solution for high loading rates and volumes, but it is only suitable for specialized solutions such as high frequency liner shipping services with short turnaround times at niche ports, and probably needs to be close to an LNG terminal.

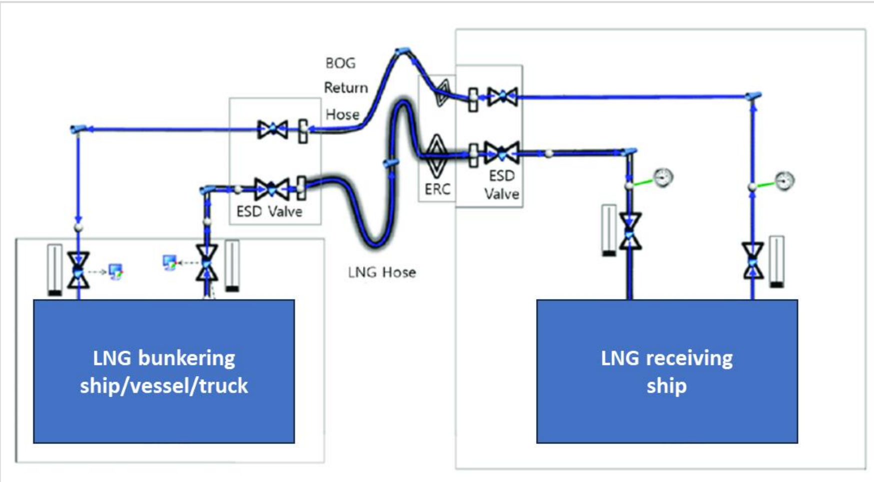

Figure 9.19 LNG Bunkering

Change in Process with Green hydrogen.

The production or final use may not be the bottleneck for the application of green hydrogen to ships. Hydrogen, even in liquid form, is less energy-dense than bunker fuel, this implies that hydrogen will take up more volume on cargo ships, which affects the efficiency and cost of a cargo. The process of bunkering in the shipping industry would require changes in the types of vessels, storage and other transportation infrastructure including pipelines, trucks etc. Liquid hydrogen is stored in special refrigeration tanks at -256 degree Celsius, which is likely to pose operational difficulties.

9.3.5.2 DRIVERS

The various pushing and pulling drivers for shipping industry are as below -

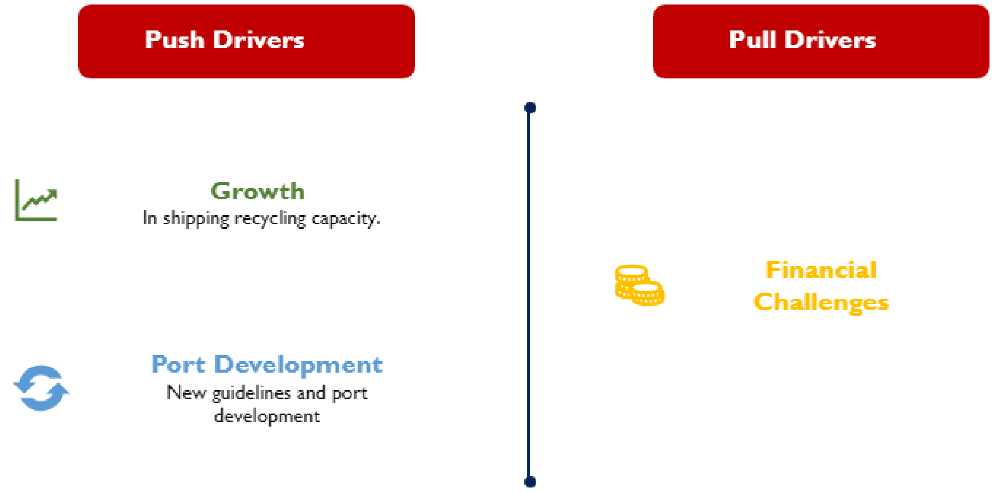

Figure 9.20 Drivers for Shipping Industry

Push Drivers for Shipping Industry

Growth in industry - The finance minister proposed to double the ship recycling capacity of ~4.5 million light displacement tons (LDT) by 2024. This is expected to generate an additional ~1.5 lakh employment opportunities in India. Also, ports sector in India is being driven by high growth in external trade.

Port Development - The key ports are expected to undertake multiple projects worth more than US$ 274.31 million (Rs. 2,000 crore) on a public-private partnership basis in FY22.

Transition to green fuels – Global focus on using green ammonia or green hydrogen as a fuel in the shipping sector to decarbonize the sector in the long-term will encourage adoption of green hydrogen infrastructure in this sector.

Pull Driver for Shipping Industry

Financial Challenges - Shipping companies in India do not have access to any lucrative government schemes that are available to other channels. The burden of taxes like Customs Duty on Bunkers, Landing Fees, Income Tax etc. with negligible exemptions, makes it difficult for shipping companies to thrive.

Major Challenges-

- There is a recent shift of shipping industry to LNG. About 60% of the newly built ship orders are LNG fuelled vessels (order of 952 ships in 2023). Making the shift to hydrogen would imply large capital cost. Thus, the transition is expected to be slow.
- Obtaining refrigeration tanks capable of carrying at -256 degrees Celsius will be challenging.

9.3.5.3 SHIPPING -CASE STUDY – MOL SYNERGY

MOL Synergy Group provides end-to-end maritime solutions with services to create optimal efficiency, productivity, and customer experience. It is a ship management company providing ship services for vessel management companies. MOL Synergy Group handles a wide variety of vessels, with over 640 vessels under technical management.

Organization Structure of MOL Synergy

- The deck and navigation vertical comprises of a captain, chief officer along with second and third officer.
- A couple of deck cadets at operational level are also required along with support staff.
- The workforce managing engine related processes mainly includes engineers and officers along with support staff.

The details of crew on mid-size ship are shown in the figure below –

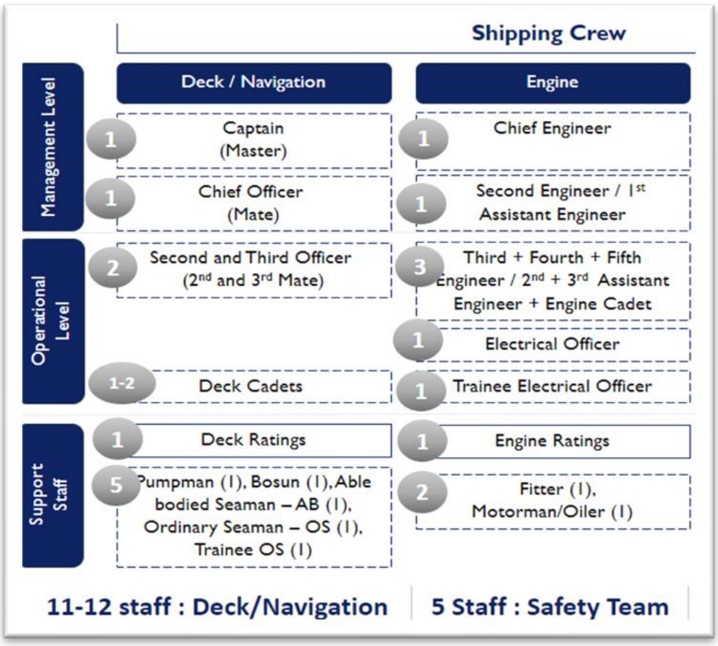

Figure 9.21 Shipping - organogram

Source: ICF Analysis and Stakeholder Discussions

Hydrogen in the shipping industry is currently in a developmental stage, mainly focused on advancements in port infrastructure. As ammonia or hydrogen-based ships transition into commercial use, there will be a growing demand for experts specializing in hydrogen storage, utilization, and safety within the shipping sector. But more case studies are needed to provide insights into the potential organizational changes that may occur upon the adoption of green hydrogen and ammonia technologies.

Key Findings

Requirement of Skilling:

Current job role -

- Engine Operators – Engineers in the crew are responsible for handling the major operations around fuel usage.
- Fuel Transport Personnel– Barge training and licensing is supervised by DG Shipping. Employees need to be adequately trained to transfer hydrogen and ammonia-based fuels.

Critical training area –

- Training would be required in the spheres of safety and emergency disaster management for hydrogen. All personnel would have to be trained in either basic or advanced firefighting and emergency response to conduct their respective operations.

9.3.6 CEMENT

India is the second largest producer of cement in the world, contributing to more than 8 percent.[92] in the global production capacity. Cement industry also ranks among the leading greenhouse gas producers, contributing to around 8 percent.[93] of total worldwide greenhouse gas emissions.

9.3.6.1 PROCESS

There are several ways in which hydrogen can be used in the cement industry to reduce emissions. These include:

Mixing of Raw Materials

- Raw materials used in cement production include calcium (from limestone), silicon, iron, and aluminum.
- There are two primary methods for mixing raw materials: the Dry Process a nd the Wet Process.
    - **Dry Process**: Raw materials are first crushed and ground separately. The finely ground materials are mixed, creating a dry raw mix, which is stored in silos.
    - **Wet Process**: Raw materials are crushed, ground into a powdered form, and stored in silos. Water-washed clay is mixed with powdered limestone, forming a paste.

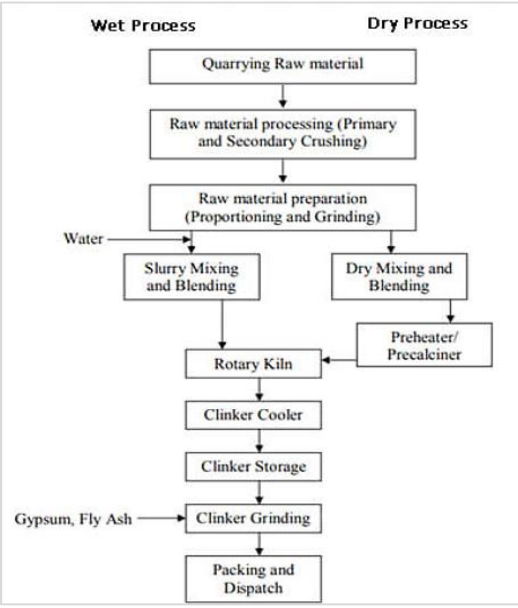

Figure 9.22 Primary Methods for Mixing Raw Materials

- Much of the carbon emissions are caused by clinkers, which are an important component in cement manufacturing. By employing hydrogen as a reducing agent in the raw mix, the quantity of

[92] https://www.ibef.org/industry/cement-presentation
[93] https://timesofindia.indiatimes.com/blogs/voices/reducing-carbon-footprint-the-journey-of-cement-industry-towards-sustainable-practices/

clinker required for cement manufacturing will be reduced. This alone can lead to a 50 percent decrease in carbon emissions.

Burning of Raw Materials (Clinker Formation)

- This process is carried out in a rotary kiln, which rotates at about 1-2 revolutions per minute.
- The raw mix, whether dry or a corrected slurry, is injected into the kiln from the upper end.
- Powdered coal, oil, or hot gases are used to heat up the kiln from the lower end, creating long hot flames. Hydrogen can replace traditional fossil fuels, as a clean-burning fuel source for the kiln's high-temperature requirements. Hydrogen combustion generates only water vapor as a byproduct, reducing carbon emissions.
- In the clinkering zone, at temperatures between 1500-1700 degrees Celsius, lime and clay react to form calcium aluminates and calcium silicates. Hydrogen's high flame temperature and heat transfer efficiency are advantageous for maintaining the required high temperatures.
- These calcium compounds fuse together to form small, hard stones known as clinkers.

Grinding of Clinkers

- The cooled clinkers are received from the cooling pans and sent into mills. The clinkers are finely ground into a powder in a ball mill or tube mill. The final product obtained is cement, which does not settle quickly when in contact with water.

Change in Process with Green hydrogen.

In the cement industry, hydrogen can serve as a clean and high-temperature fuel source for the chemical process of converting limestone into clinker. To use hydrogen significant changes will be required in the combustion infrastructure. The equipment will require adjustments to utilize hydrogen fuel, which burns at a higher temperature and has different combustion characteristics compared to conventional fossil fuels.

Implementation of on-site hydrogen storage systems to ensure a continuous and reliable supply of hydrogen will also be required. This may involve compressed or liquid hydrogen storage, depending on the specific requirements.

9.3.6.2 DRIVERS

The pushing and pulling drivers for cement industry are listed below -

Push Drivers for Cement Industry

Robust Demand -

- As per ICRA, in FY22, the cement production in India is expected to increase by ~12% year-on-year, driven by rural housing demand and government's strong focus on infrastructure development.
- As per Crisil Ratings, the Indian cement industry is likely to add ~80 million tons (MT) capacity by FY24, the highest in the last 10 years, driven by increasing spending on housing and infrastructure activities.

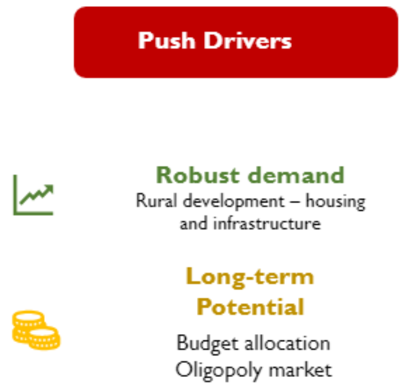

Figure 9.23 Pushing Drivers for Cement Industry

Long term Potential for manufacturers -

- With high allocation under the Union Budget 2023-24 for infrastructure, affordable housing schemes and road projects to fuel the economy, the domestic cement industry is poised for a volume surge.
- Oligopoly market is where large players have partial pricing control, and therefore, low threat from substitutes or competition.

Major Challenges:

- Cement industry is a labor-intensive industry, that extensively uses coal. Since transition to hydrogen will require significant infrastructure upgradation & capital cost, the transition will be gradual.

9.3.6.3 CEMENT - CASE STUDY - ULTRA TECH CEMENT

Ultra Tech Cement Limited, is the largest manufacturer of grey cement, white cement, and ready-mix concrete in India. It has set a 100 per cent renewable electricity target for its global operations by 2050. The company has already scaled up its contracted renewable energy capacity by 2.5 times in the past two years.

Organization Structure of Ultra Tech Cement

UltraTech Cement Ltd. has a total installed capacity of 67.7 MTPA of grey cement. To meet the various needs of clients, they supply different sizes of cement plants, ranging from 50 - 500 TPD. The capacity of plant captured in detail is **2-3 MTPA**. The plant is run by different teams working in 3 shifts as the plant needs to be monitored and operated 24x7.

- The production team comprises of mechanical and chemical engineers and operators who are general diploma holders.
- The Material and Quality team comprising of quality control engineers, material engineers, and technicians works with the production team.
- Additionally, the Logistics and Maintenance Department comprises of a logistic officer, a maintenance in charge and several foremen.
- The Installation/Erection Team comprises of project and planning engineers and support staff.

The details of each department are hereby shared -

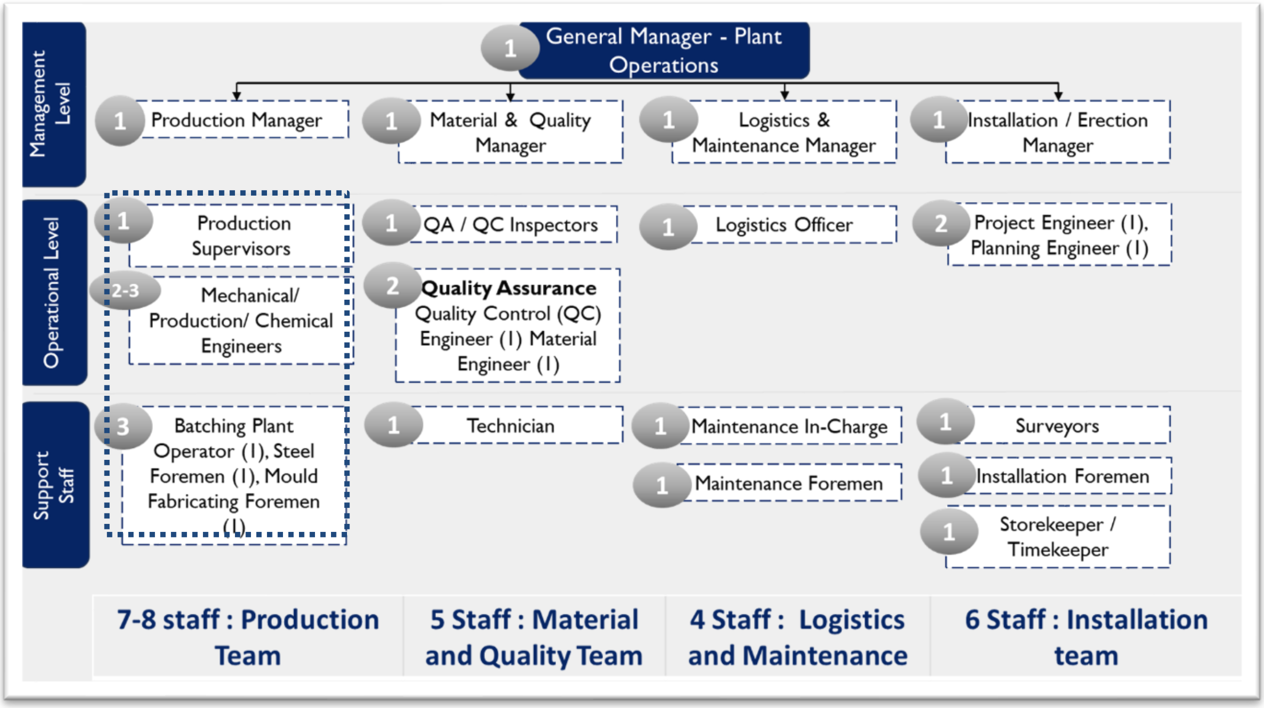

Figure 9.24 Ultra tech cement - organogram

Source: ICF Analysis and Stakeholder Discussions

Currently, the cement industry in India, has made no major advancement towards adopting green hydrogen or its derivatives. Therefore, there aren't enough case studies to provide insights into the potential organizational changes that may occur upon the adoption of green hydrogen and ammonia technologies by the cement industry.

Plans for Green Hydrogen and Scaling Up

Ultra Tech Cement has taken several steps to establish a significant presence in India's emerging Green Hydrogen sector.

- UltraTech Cement Ltd.'s board has approved an investment of ₹12,886 crore to add 22.6 MTPA capacity to its total production, with a mix of brownfield and greenfield expansion.
- Ultratech aims to expand its annual production capacity to 200 million tons, making it one of the largest producers of cement.
- UltraTech Cement aims to achieve 100% electricity reliance on renewable sources by 2050, reaffirming its commitment to sustainable energy practices.
- In their ESG report, UltraTech Cement has articulated a medium to long-term objective: to augment the utilization of hydrogen as an integral component of their decarbonization strategy.

Requirement of Skilling:

Current job role -

- Current direct job roles which may be impacted are fuel and raw material technical managers, senior environment and compliance officers, lab analysts, pre-treatment and CDM monitoring officers.

Critical training area –

- New skills and knowledge will be required to build alternative fuel and raw material units.

9.4 ESTIMATION OF JOBS BY 2030 (ASSUMPTIONS AND OTHER CASES)

9.4.1 GENERAL ASSUMPTIONS

For the estimation of job roles across the 2 verticals discussed, certain general and vertical specific assumptions are considered. General assumptions are discussed below -

1. Green Hydrogen Capacity

Based on the expected green hydrogen capacity from National Green Hydrogen Mission, the incremental green hydrogen capacity in for year is determined to reach 10 MTPA (including additional 5 MTPA for green hydrogen export) by 2030 as below.[94]

A similar scenario can be built for green hydrogen capacity as per the NITI Aayog's target of 5 MTPA by 2030. The outcome would be 50% of the projections from National green hydrogen mission.

Table 9.5 Green Hydrogen Capacity Assumption

Year	2025	2026	2027	2028	2029	2030
Cumulative green H2 Capacity (MTPA)	0.20	0.50	2.00	4.00	7.00	10.00

2. Capacity of Plant

For calculation purposes, the market is divided into 3 average capacities of hydrogen production plants.[95]

- **10 MW**
- **100 MW**
- **1000 MW**

Estimation of jobs

This section focuses on estimating the number of jobs in the verticals-

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[94] As per inputs from discussions, 6 lakh jobs estimated by MNRE are based on 10 MTPA green hydrogen production.

[95] This is based on market analysis as well as stakeholder consultations with ACME, GAIL & other key market players, since a typical commercial electrolyser module has a size of ~2.5 MW, a typical small commercial plant would have size ~10 MW, while medium & large plants have been considered at 10X the previous size for modelling the market capacities. Large green hydrogen plant announcements of 1 GW have already been made by private sector in India (Reliance) and others are expected to be there in future.

1) Hydrogen Production

For hydrogen production, three cases have been developed based on the expected average size of plants (10 MW, 100 MW, 1000 MW) which are expected to come up from 2025 to 2030. Case 1 assumes that the proportion of plants with average size of ~1000 MW would be relatively higher, while Case 3 assumes that the proportion of plants with average size of ~10 MW is higher. Case 2 represents a scenario represents a middle-ground between Case 1 & Case 3.

The relative proportions are assumed based on stakeholder consultations and analysis of possible market configurations based on recent announcements and estimated plant developments per year to reach the 10 MTPA green hydrogen goal as envisaged in the NGHM.

Assumption - The cases have been developed based on the expected average size of plants (10 MW, 100 MW, 1000 MW) which are expected to come up from 2025 to 2030, which are outlined for Case 1, 2 & 3 as:

In case 1, a greater portion of the total installed capacity up to 2030 will come from larger power plants with a capacity of 1000 MW, ranging from 75% to 80%. The number of smaller plants will still increase at the same rate, but the larger plants will make up a higher proportion over time.

Table 9.6 Assumption on Green Hydrogen Capacity by Plant Size Share – Case 1

Average Plant Size	2025	2026	2027	2028	2029	2030
10 MW	30%	20%	4%	2%	2%	2%
100 MW	70%	80%	20%	20%	20%	20%
1000 MW	-	-	76%	78%	78%	78%

Case 2 is the average of case 1 and case 3, with around 40% - 45% of larger plants in the total installed capacity by 2030.

Table 9.7 Assumption on Green Hydrogen Capacity by Plant Size Share – Case 2

Average Plant Size	2025	2026	2027	2028	2029	2030
10 MW	30%	30%	22%	21%	21%	21%
100 MW	70%	65%	35%	35%	35%	35%
1000 MW		5%	43%	44%	44%	44%

In case 3, a low share of larger plants is taken. From 2026, a constant share across the capacities is considered.

Table 9.8 Assumption on Green Hydrogen Capacity by Plant Size Share – Case 3

Average Plant Size	2025	2026	2027	2028	2029	2030
10 MW	30%	40%	40%	40%	40%	40%
100 MW	70%	50%	50%	50%	50%	50%
1000 MW		10%	10%	10%	10%	10%

Analysis of number of plants

The number of plants is estimated on the bases of the yearly incremental contribution and percentage share of each average capacity plant. The estimates for the scenarios discussed are as below:

Case 1

Table 9.9 Assumption on Number of Plants by Plant Size Case 1

Average Plant Size	2025	2026	2027	2028	2029	2030	Total

10 MW	39	39	39	26	39	39	**221**
100 MW	9	16	20	26	39	39	**149**
1000 MW	-	-	8	10	15	15	**48**

From the analysis conducted in case 1, it is estimated that a collective green hydrogen capacity of 10 MTPA would necessitate the establishment of 418 plants of varying capacities.

Case 2

Table 9.10 Assumption on Number of Plants by Plant Size Case 2

Average Plant Size	2025	2026	2027	2028	2029	2030	Total
10 MW	39	58	211	268	402	402	**1,380**
100 MW	9	13	34	45	67	67	**235**
1000 MW	-	1	5	6	9	9	**30**

From the analysis conducted in case 2, it is estimated that a collective green hydrogen capacity of 10 MTPA would necessitate the establishment of 1,645 plants of varying capacities.

Case 3

Table 9.11 Assumption on Number of Plants by Plant Size Case 3

Average Plant Size	2025	2026	2027	2028	2029	2030	Total
10 MW	39	77	383	510	765	765	**2,539**
100 MW	9	10	48	64	96	96	**323**
1000 MW	-	1	1	2	2	2	**8**

From the analysis conducted in case 3, it is estimated that a collective green hydrogen capacity of 10 MTPA would necessitate the establishment of 2,870 plants, varying in capacity sizes.

9.4.2 ESTIMATED JOB ROLE-WISE WORKFORCE REQUIREMENT BY 2030 (OTHER CASES)

Hydrogen production

Details of the estimated overall workforce in hydrogen production categorized by skill groups is discussed below:

Case 1

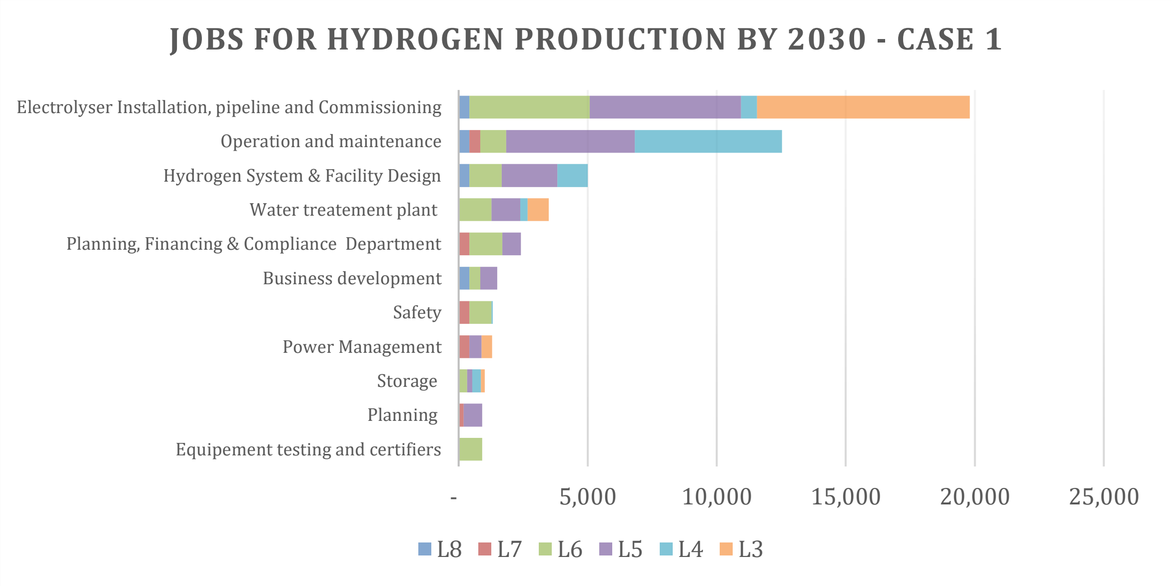

Figure 9.25 Jobs for Hydrogen Production by 2030 - Case 1

A total of **61,527 jobs** are estimated in case 1 across all skill groups. The major contributor is the electrolyser installation and commissioning and pipeline commissioning (19,803 jobs) followed by operations and maintenance (12,534 jobs).

Case 2

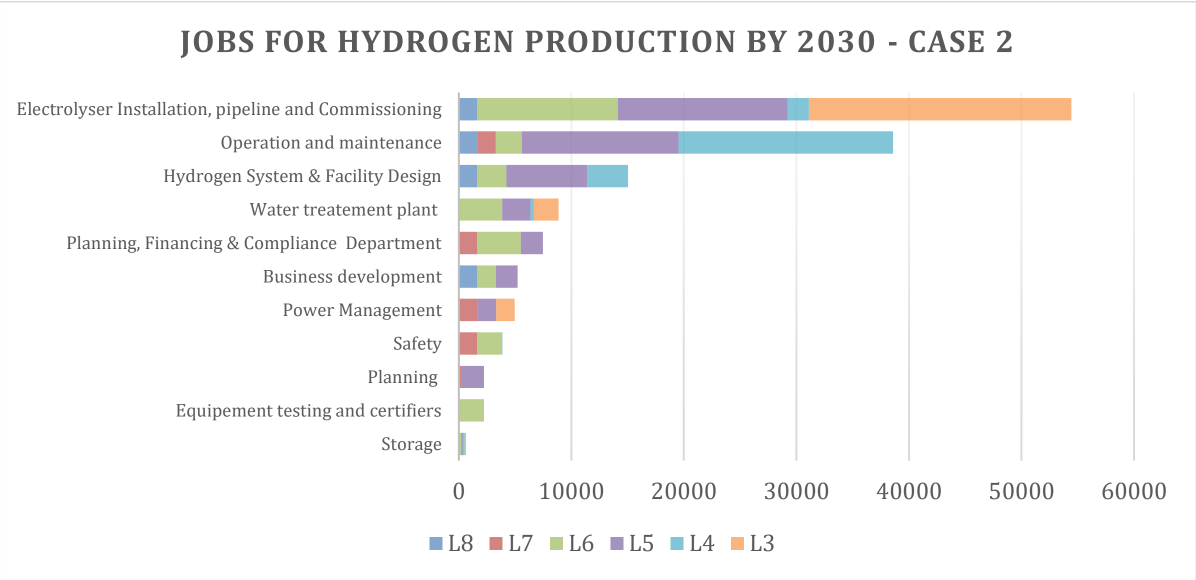

Figure 9.26 Jobs for Hydrogen Production by 2030 - Case 2

A total of **1,73,135 jobs** are estimated in case 2 across all skill groups. The major contributor is the electrolyser installation and commissioning, pipeline commissioning and operations and maintenance (93,015 jobs), contributing to about 54% of the total estimated jobs by 2030.

9.4.3 ESTIMATED DEMAND FOR RESKILLING / UPSKILLING TILL 2030

The three cases built for year-wise upskilling / reskilling requirement are –

Case 1

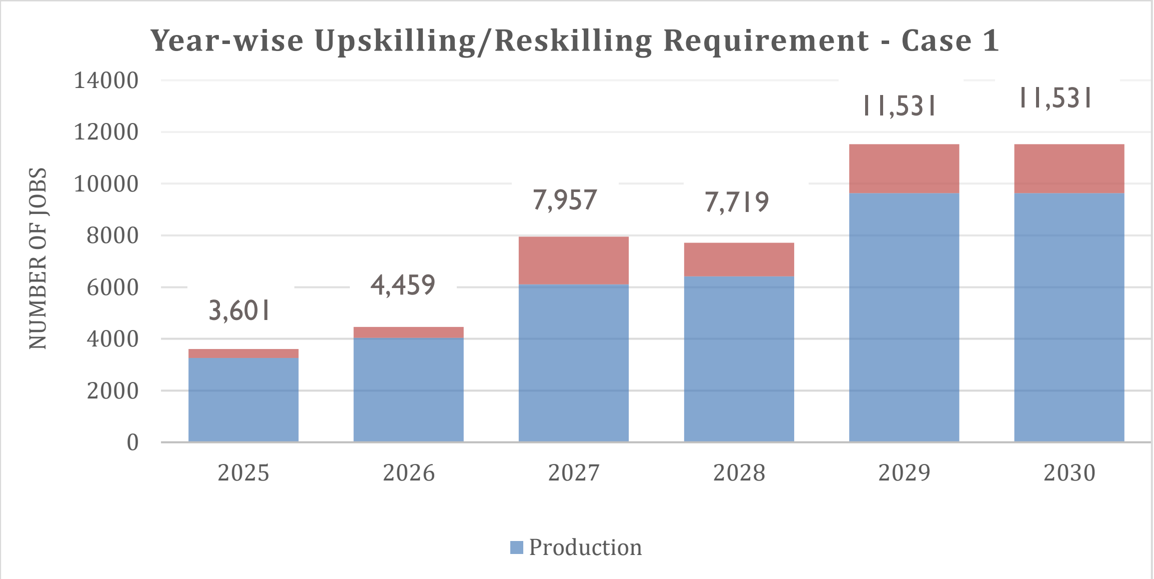

Figure 9.27 Year-wise Upskilling/Reskilling Requirement - Case 1

Case 2

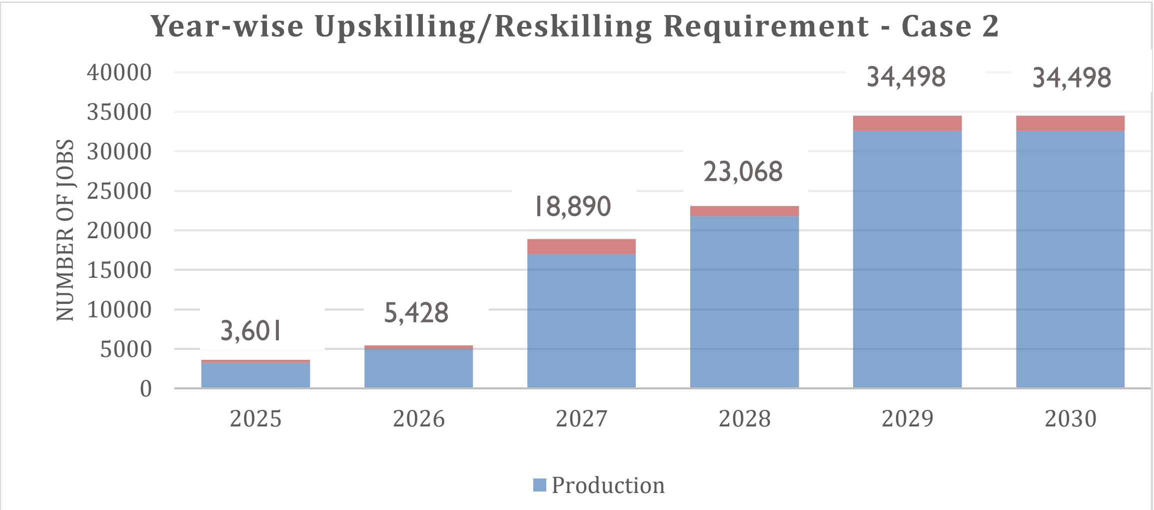

Figure 9.28 Year-wise Upskilling/Reskilling Requirement - Case 2

9.5 GLOBAL INSIGHTS ON SKILLING AND JOBS IN GREEN HYDROGEN SECTOR

9.5.1 AUSTRALIA

Table 9.12: Detailed Hydrogen Job Roles

Value chain	Job Roles
Planning and Design	Hydrogen/fuel cell R&D director, Director of hydrogen energy development, Hydrogen fuels policy analyst, Emissions accounting & reporting consultant, Emissions reduction credit portfolio manager, Emissions reduction project developer specialist, Emissions reduction

Value chain	Job Roles
	project manager, Regulative experts, Hydrogen systems & retrofit designer, Fuel cell designer, Hydrogen systems sales consultant
Manufacturing	Hydrogen fueling station designer & project engineer, Fuel cell plant manager, Hydrogen energy engineer, Fuel cell vehicle development engineer, Fuel cell retrofit manufacturer plant laborer, Fuel cell engineering intern, Hydrogen energy systems designer, Fuel cell retrofit installer, Hydrogen lab technician, Fuel cell and electrolysers manufacturing workers, High voltage electrician, Construction workers, Architects, Builders, Building inspectors, Safety inspectors, Quality auditors
Operations and Maintenance	Electrical management, Hydrogen systems program manager, Fuel cell quality control manager, Hydrogen plant operations manager, Engineers, Hydrogen energy system operations engineer, Automotive fuel cell power electronics engineer, Computer/ software engineers, Control engineers, Electrical engineers, Mechanical (HVDC) engineers, Fuel cell power systems operator and instructor, Fuel cell backup power system technician, Fuel cell power systems engineer, Systems engineers, Power electronics engineer, Fuel cell power systems operator and instructor
Transport & Distribution	Hydrogen fueling station manager, Drivers, Heavy vehicle driver, Hydrogen fuel transport driver, Fueling station operator, Telematics system operator, Logistics manager, Marine workers, Aviation workers, Train drivers, Service, and repair
Energy	Gas pipeline worker, Gas service technician, Mechanical fitters, Gas pipeline supervisor, Gas industry operations supervisor, Gas meter reader, Energy generation plant operators, Energy generation plant technician/ operator, Hydrogen plant operator, Control center operator, Hydrogen energy technician, Hydrogen energy system installer, Pressure pipe welders and fabricators, Transmission controller, Pressure controller, Mechanical electrical instrumentation technician, Plumber gas fitters, Meter readers, Safety inspectors, Hydrogen fuel cell system technician, Fuel cell fabrication technician Fuel cell manufacturing technician, Fuel cell fabrication and testing technician, Assemblers
Miscellaneous	Production line workers, Fabricators, Hazardous materials management specialist, Retail workers (BBQ gas bottle exchange), Purified water producers, Environmental, social, and corporate governance (ESG) workers (for transition from fossil to green hydrogen)

Value chain	Job Roles
Emergency Services	Fire fighters, Rural fire services, Police, Ambulance, State emergency workers, Tow truck/vehicle recovery operators, Protective service officers, Hydrogen systems safety investigator

9.5.2 QUEENSLAND: A CASE STUDY

In Australia, skilling requirement is not only being addressed at national level, but it has also been taken up at the State level. In Queensland, more than $50 million[96] is being invested in training facilities that will equip workers with skills to enter the growing renewable energy and hydrogen industry. A broad range of job roles created and evaluated in collaboration with industry stakeholders across Queensland for hydrogen are listed in Table 9.13.

Table 9.13 Hydrogen Value Chain Job Roles and Skilling Pathways

Hydrogen Value Chain		Job Roles	Skilling Pathways
Planning and Design	Hydrogen System & Facility Design	Engineers – Systems/Integration, Robotics, Automation Industrial designers	Higher Education
		Drafts People	Vocational Education and Training
	Design of Integrated Systems & Facilities	Engineers – Systems/Integration, Robotics, Automation Industrial designers	Higher Education
		Drafts People	Vocational Education and Training
	Hydrogen Pipeline, Storage & Transport Facility Design	Engineers – Mechanical, Electrical, Chemical, Automation Industrial Designers	Higher Education
		Drafts People	Vocational Education and Training
	Planning, Approvals & Compliance processes	Planners, Regulatory Officers, Project Managers and Consultants	Paraprof.* / Higher Education
Construction & Installation	Electrolyser Installation & Commissioning	Project Managers	Paraprof.*
		Electrolyser Technicians, Instrumentation & Electrical Technicians	Vocational Education and Training / Paraprof.*
		Engineering Trade, Mechanical Fitters	Vocational Education and Training

[96] https://www.publications.qld.gov.au/ckan-publications-attachments-prod/resources/11162290-c0d7-4cc2-91fb-02b33d90a362/hydrogen-industry-workforce-development-roadmap-reduced-size.pdf?ETag=2a6bc02ee53980d22015925e61f7449b

Hydrogen Value Chain		Job Roles	Skilling Pathways
	Pipeline Construction, Commissioning & Testing	Pipeline Technicians	Vocational Education and Training / Paraprof.*
		Project Managers	Paraprof.*
		Engineering Trades	Vocational Education and Training
		Surveyors	Higher Education
	Installation of Stationary Fuel Cells – Industrial/Commercial Scale	Project Managers	Paraprof.*
		Fuel Cell Technicians	Vocational Education and Training / Paraprof.*
		Engineering Trades	Vocational Education and Training
	Installation of Stationary Fuel Cells – Industrial/Commercial Scale	Project Managers	Paraprof.*
		Instrumentation & Electrical Technicians, Engineering Trades, including for pressure vessels, etc.	Vocational Education and Training
	All above	Equipment Certifiers	Vocational Education and Training
Operations & Maintenance	Hydrogen Production Process Operation	Specialist Hydrogen Process Operators	Vocational Education and Training / Paraprof.* / Higher Education
		Engineers – Electrical, Gas, Chemical, Quality and Safety Managers	Higher Education
		Mechanical fitters	Vocational Education and Training
	Electrolyser Maintenance	Electrolyser Technicians, Instrumentation & Electrical Technicians, including SCADA	Vocational Education and Training / Paraprof.*
	Pipeline & Hydrogen Storage Facilities Operations & Maintenance	Pipeline Technicians	Vocational Education and Training / Paraprof.*
		Specialist Hydrogen Process Operators, including SCADA	Vocational Education and Training
		Safety Managers	Vocational Education and Training / Higher Education
		Engineering Support	Paraprof.* / Higher Education
	Hydrogen Compression, Liquefaction and Conversion using multiple carriers – for domestic use	Specialist Hydrogen Process Operators	Vocational Education and Training / Paraprof.* / Higher Education
		Mechanical Fitters	Vocational Education and Training

Hydrogen Value Chain		Job Roles	Skilling Pathways
	Stationary Fuel Cell Maintenance	Fuel Cell Technicians	Vocational Education and Training / Paraprof.*
	Dangerous Goods Transport	Drivers, Vehicle Inspectors	On the job training
	Hazardous Areas	Electricians	Vocational Education and Training
		Inspectors	Paraprof.*
		Safety Managers	Vocational Education and Training / Paraprof.*
Transport	Hydrogen Refueling/Dispensing – Fleet & Retail	Service Station Workers	On the job training
	Installation of Refuellers	Hydrogen Dispenser Technicians	Vocational Education and Training / Paraprof.*
		Gas Fitters	Vocational Education and Training
	Fuel Cell Electric Vehicle (FCEV) Maintenance	Automotive Trades & Technicians	Vocational Education and Training
Export	Compression, Liquefaction & Conversion using multiple carriers – for export	Specialist Hydrogen Process Operators	Vocational Education and Training / Paraprof.* / Higher Education
	Ship Loading for Hydrogen Export	Specialist Hydrogen Process Operators	Vocational Education and Training / Paraprof.* / Higher Education
Manufacturing	Production & Assembly of electrolysers, fuel cells and components	Engineers – Manufacturing, Robotics, Automation	Higher Education
		Manufacturing Workers	Vocational Education and Training / On the job training
		Engineering Trades, Composites Technicians	Vocational Education and Training
Water Treatment	Establishing and Operating Facilities to Purify Water for Hydrogen Production	Plumbers and engineering trades, including for pumps	Vocational Education and Training
		Instrumentation & Electrical Technicians, Process Operators, Specialists in treatment, testing, and compliance of water quality	Vocational Education and Training / Paraprof.*
		Engineers – Process, Chemical, Civil, Mechanical	Higher Education
Energy	Injecting Hydrogen into Gas Networks	Pipeline Technicians	Paraprof.*
		Engineers – Mechanical, Electrical	Higher Education

Hydrogen Value Chain		Job Roles	Skilling Pathways
	Hydrogen Combustion Turbine Design & Operation	Power Plant Operator	Vocational Education and Training
	Residential Hydrogen System Design	Plumbers, Electricians	Vocational Education and Training
	Residential Stationary Fuel Cell Installation & Maintenance	Plumbers, Electricians	Vocational Education and Training
	Hydrogen Combustion Appliance Installation & Maintenance	Plumbers, Electricians, Gas Fitters	Vocational Education and Training

** Paraprof.: 'Paraprofessional – Advanced diploma or Associate degree'.*

The skilling requirements have been identified across 8 different value chains viz planning & design, construction & installation, operation & maintenance, transport, export, manufacturing, water treatment and energy. Across the value chain, skilling is to be implemented mainly through vocational education and training. For instance, across planning & design skilling is to be implemented through higher education and vocational education and training, in construction & installation through vocational education and training/Paraprof., in operation & maintenance through vocational education and training/Paraprof./higher education, in transport through vocational education and training, in export through vocational education and training/paraprof./higher education, in manufacturing through higher education as well as vocational education and training/on the job training, in water treatment & energy mainly through vocational education and training.

The roadmap highlights that core skills will consistently be in demand across various stages and types of hydrogen projects. These skills encompass areas such as plumbing, electrical work, process operations, and engineering. Engineers, technicians, and specialists who have played pivotal roles in the growth of Queensland's LNG industry possess valuable expertise transferable to numerous facets of hydrogen production and transportation facilities, including proficiency in instrumentation and pipeline construction.

Moreover, essential skills for the hydrogen industry encompass project management, design, and workplace safety. A variety of job of roles are expected to open up in corporate, operational functions, financial analysis, human resources, and ESG management and compliance. A solid foundational understanding of safety requirements will be essential.

Existing workers will need to undergo upskilling to acquaint themselves with the unique properties of hydrogen, the intricacies of handling it, and the specific storage pressures involved. In addition, trainers, assessors, teachers, and academic staff should keep up with industry developments as the hydrogen sector continues to evolve. In recent times, Queensland has taken plenty of measures to meet the upcoming skill demand as detailed below:

- $10.6 million was committed towards the Hydrogen and Renewable Energy Training Facility.[97]
- A Partnership was forged with Fortescue Future Industries (FFI) to establish a Vocational Training and Employment Centre program at the Gladstone facility. Production is to commence in 2023 and is estimated to create more than 300 local jobs over the life of the project.
- Construction Skills Queensland (CSQ) is partnering with CSIRO for local workforce development solutions to support the emergence of the hydrogen industry.
- The Cape York Institute and HDF Energy Australia plans to offer traineeships, so locals can gain the skills and experience necessary to launch a career in the renewable energy and hydrogen industries.
- The Women in Renewables Initiative by the Clean Energy Council empowers, and champions women involved in the renewable energy sector, which includes green hydrogen.
- In 2022, Government-Owned-Corporation CS Energy and the Toowoomba and Surat Basin Enterprise (TSBE) partnered to deliver an online portal to sign up for opportunities in the emerging hydrogen industry. Through the portal, TSBE maintains a directory showcasing the regional supply chain and available local skills.

9.5.3 EUROPEAN UNION

The EU strategy (European Green Deal) launched in December 2019[98] aims to set the EU on the path to a green transition, with the primary objective of leading the region through a sustainable transition, ultimately culminating in achieving climate neutrality by 2050. This comprehensive plan unfolds in several phases, as outlined in Figure 9.29. It aims to establish a minimum of 6 GW of electrolyser capacity by 2024, enabling an annual production of up to 1 million tons per year (Mt/yr) of green hydrogen. This capacity is anticipated to grow to 40 GW within the EU member states by 2030, along with an additional 40 GW of electrolyser capacity in countries situated in southern and eastern regions, such as Ukraine or Morocco. The EU envisions importing green hydrogen from these nations. The strategy encompasses a range of measures, including regulatory adjustments supported by impact assessments and investment support designed to kick-start deployment.

The European Green Deal comprises a set of policy initiatives, including the “Fit for 55” program, “REPowerEU”, and the “Green Deal Industrial Plan”. The "Fit for 55" initiative seeks to attain climate neutrality by 2050 and reduce net greenhouse gas (GHG) emissions by 55%[99] by 2030, in comparison to the levels recorded in 1990. The “REPowerEU” strategy sets its sights on producing 10 million tonnes of domestic green hydrogen and importing an additional 10 million tons of green hydrogen by 2030[100].

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[97] https://statements.qld.gov.au/statements/96259
[98] https://www.consilium.europa.eu/en/policies/green-deal/#what
[99] https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/733513/EPRS_BRI(2022)733513_EN.pdf
[100] https://www.reuters.com/business/energy/european-hydrogen-bank-strategy-be-tested-autumn-auction-2023-04-27/

2020-2024	2025-2030	2030-2050
1. Installation of at least 6GW of renewable hydrogen electrolysers. 2. Up to 1 million tonnes of renewable hydrogen production	1. Installation of at least 40GW of renewable hydrogen electrolysers 2. Up to 10 million tons of renewable hydrogen production	• Implementation of renewable hydrogen at a large scale across all hard-to-decarbonize sectors.

Figure 9.29: Stage-wise strategy plan

The goal of the "Green Deal Industrial Plan"[101] is to foster the expansion of the EU's manufacturing capacity in the field of net-zero technologies and products, essential for meeting Europe's ambitious climate objectives. One of the key areas of focus within the Green Deal Industrial Plan is skill enhancement. The plan anticipates that approximately 35% to 40% of all jobs may be influenced by the transition to a green economy, necessitating the development of relevant skills. To address this need for skills for a people-centered green transition, the commission will propose the establishment of net-zero industry academies to implement upskilling and reskilling programs in strategic industries. Additionally, the commission will explore ways to promote a 'Skills-first' approach, which recognizes actual skills, alongside traditional qualifications.

The most recent amendment to the EU Emissions Trading System (ETS) Directive, approved in 2018, establishes the overall quantity of emission allowances for phase 4, which covers the period from 2021 to 2030. This allocation aligns with the earlier EU emissions reduction objective of achieving a 40% reduction below 1990 levels by 2030.[102] CBAM, the Carbon Border Adjustment Mechanism, aims to align carbon emissions costs for EU products under the ETS and imports. Beginning October 1, 2023[103], it applies to EU imports like iron, steel, aluminum, electricity, fertilizers, cement, hydrogen, and some precursor materials. In the transitional phase from October 1, 2023, to December 31, 2025, only quarterly reporting of emissions is required. From 2026, CBAM certificates will be needed to offset emissions, priced according to EU ETS carbon prices. This imposes an additional cost on exporting to the EU, potentially affecting exporters' strategies.

Skill mapping for hydrogen

The EU aims to generate one million jobs within the hydrogen value chain by 2030[104]. As an initial move toward this goal, the government introduced the "European Hydrogen Skills Strategy"[105] in October 2023. This strategy outlines the current and future demand for occupational profiles related to hydrogen. The Table 9.14 gives details of the occupational profiles that are expected to be in demand in the future.

[101] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_510
[102] https://www.europarl.europa.eu/legislative-train/package-fit-for-55/file-revision-of-the-eu-emission-trading-system-(ets)
[103] https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en
[104] https://www.cleanenergywire.org/news/eu-wants-become-market-leader-hydrogen-technologies-create-1-million-jobs
[105] https://greenskillsforhydrogen.eu/wp-content/uploads/2023/10/Green-Skills-for-Hydrogen-European-Hydrogen-Skills-Strategy-last-update-24102023.pdf

Table 9.14: Details of the occupational profiles

Job Function	Details
Managers	H2 business development manager, Industrial process project manager, Chemical project manager, Green fuel project manager, Gas facilities construction manager, H2 production project manager, Business development manager
Policy and Legal strategy specialist	International project developer, Legal and regulations specialist, Public relations specialist, public strategy specialist
Environmental, HSE, Engineers, Technicians	• Environmental engineer, Health, safety and risk engineer, Safety and hazards specialist, Engineers (fuel cell, electrical, electromechanical H2 production, chemical process, mechanical, system integration, process, materials, design, simulation, infrastructure repurposing) • Technicians
Experts & Specialists, Environmental, HSE, Engineers, Technicians	• H2 Project manager, Business development manager, Technology development manager • Experts in fuel conversion, H2 global market & trading, Energy storage, etc. • Specialists including economy & finances, Renewable generation, Interconnections, Grid operation, etc. • Hazardous materials engineer, Health, and safety design engineer, Technology • Engineers including power electronics, electrolysers, fuel cells design robotics &production, chemical process, mechanical engineer, H2 production, materials, etc. • Technicians, System operator, Refueling stations operator

The strategy outlined presents a comprehensive approach to address the surging demand for skilled professionals in the hydrogen sector. To ensure a robust and capable workforce, it focuses on several key actions, each of which plays a critical role in building a sustainable and knowledgeable hydrogen workforce as detailed below.

1. Develop modular training programs
   - Build a modular training corpus
   - Adapt existing training programs
   - Develop new specialized training programs

2. Define training standards for hydrogen.
   - Establish training standards for safe hydrogen handling
   - Establish a governing body responsible to enforce and regularly update the training standards related to hydrogen

3. Improve access to continuing professional development
   - Prepare skilling plans in anticipation of hydrogen development
   - Support continuing professional development with policies and funding
   - Open initial education modules to workers for continuous education

4. Establish an online hydrogen community
    - Deliver online training content building on existing e-infrastructures
    - Map out physical labs and infrastructures

5. Encourage the uptake of mobility for education to hydrogen
    - Enable learners' mobility
    - Enable trainers' mobility
    - Secure funding for mobility

6. Raise awareness about the hydrogen sector focusing on the advantages
    - Share information on hydrogen related careers in secondary schools
    - Provide targeted information on transition paths to workers from declining sectors
    - Organize discovery activities in lower levels of education
    - Disseminate best practices on hydrogen training

9.6 KEY ACTIONS REQUIRED FOR DELIVERING TRAINING

Training pathways	Current initiatives	Actions required
Accredited training	○ NISE initiated a one-day training session on hydrogen energy, focusing on production, storage, and utilization for a group of 50 participants since 2022. ○ SCGJ is conducting a two-day hands-on training program called Green Hydrogen Entrepreneurship, designed to equip participants with the essential knowledge, skills, and competencies needed to excel as entrepreneurs in the green hydrogen sector in India. ○ The Gujarat Energy Research and Management Institute (GERMI) hosted a one-day webinar titled "Introduction to Green Hydrogen." ○ The National Programme on Technology Enhanced Learning (NPTEL) has introduced a 12-week course covering Production, Storage, Transportation, and Safety, as	**Trainees:** ○ Implement skill development programs like Suryamitra for solar and Vayumitra for wind and assign institutes to facilitate the training. ○ Select training institutes based on infrastructure, faculty strength, and past experience in renewable energy technologies. ○ Develop standardized curricula. ○ Access to infrastructure and necessary equipment for practical, hands-on education. ○ Issue of appropriate certifications to students/participants. ○ Monitor the placement of trainees, both as apprentices and employees.

Training pathways	Current initiatives	Actions required
	well as an 8-week course specifically focusing on Cryogenic Hydrogen Technology.	○ Introduce of incentives, including mechanisms to support trainees from lower income groups. ○ Assessments / test the capabilities of trainees. **Trainers:** ○ Establish training-of-trainer programs by industry experts and international specialists for faculties of training institutes. ○ Implement post-training assessment and subsequent yearly assessments to align the skill set of trainers with market demand. ○ Entice trainers by offering a permanent position after two years, or by subsidizing for those in remote locations. ○ Give incentives to existing instructors who apply for occupational skills upgrading training.
Non-accredited training	○ TUV has launched a Hydrogen Safety Training Program, featuring a free four-day e-learning module (four hours per day) and a 120-minute course focusing on the safety protocols and the hazards of handling hydrogen. ○ Udemy offers various courses on green hydrogen, including a Mastership Diploma in Hydrogen Technology (1 hour and 32 minutes), Beginner's Guide to Green Hydrogen Energy Technology (4 hours), Electrolysis - The Path to Green Hydrogen (4.5 hours),	○ Establish standardized training protocols. ○ Offer training programs for varying durations, ranging from a few hours to several months, with corresponding certification upon completion. ○ Accept certification from these training programs across different industries. ○ Facilitate diverse delivery options, including traditional classroom sessions led by an instructor (either in-person or online) and, e-learning utilizing

Training pathways	Current initiatives	Actions required
	Introduction to Hydrogen Storage, Compression & Transport (2 hours), and Green Hydrogen Fundamentals: A Renewable Energy Course (2 hours). ○ Indian Energy Skill Development Pvt. Ltd. has introduced several programs, such as a Certification program providing advanced knowledge of hydrogen as a future fuel (101 days), the Mastering Blue Hydrogen (CCUS Technology) program (51 days), Certification Program on Hydrogen Storage, Transportation, and Distribution (60 days), and an Elementary Program introducing hydrogen as a future fuel (15 days). ○ The Advance Electrical Design and Engineering Institute has initiated a training program on Green Hydrogen plant Design. ○ The India Energy Storage Alliance has launched a two-day Masterclass on Green Hydrogen, designed to elucidate the policy framework, government-laid targets, drivers for Hydrogen, current and future market trends, production technologies, storage and transportation solutions, safety and risk factors, various applications, and the roadmap for 2030.	pre-recorded materials, and online tools. ○ Encourage local partnerships between training providers and industries to ensure the continued relevancy of the training content.
Training through universities/colleges	○ IIT Madras is conducting a four-day certification course in multiple batches. The	○ Incorporate hydrogen modules into established courses and curricula. This might involve

Training pathways	Current initiatives	Actions required
	course covers essential principles, production methodologies, safety protocols, practical applications of hydrogen, including cost considerations, and offers insights into policy perspectives regarding hydrogen adoption. ○ Additionally, IIT Madras has introduced the 'Applied Petroleum Engineering and Hydrogen Energy' course in partnership with Zemblance Hydrocarbons. This collaborative initiative aims to address the disparity between industry requirements and the current curricula, thus enhancing skills and employability for participants with an engineering background.	integrating hydrogen modules into training programs focused on gas process engineering. ○ Establish multiple research labs or centres of excellence within institutes and foster collaboration with industries for joint research efforts. ○ Formulate research programs specifically dedicated to green hydrogen to advance knowledge and innovation. ○ Implement demonstration projects within the institute to create opportunities for practical exposure. ○ Engage in partnerships with industries to conduct capacity-building training, encompassing current market trends across technologies, policies, and guidelines, to enhance employability. ○ Facilitate internships for undergraduate students through formal agreements to strengthen industry-academic collaboration and provides students with valuable real-world experience. ○ Support training initiatives by offering trainees access to laboratory facilities for practical education.