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Identification of Skills Needed for the Hydrogen Economy

Research Report

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Abbreviations and Acronyms

ACRONYM/ABBREVIATION	TERM/DEFINITION
CAPEX	Capital expenditure
CESM	Classification of Education Subject Matter
CHIETA	Chemical Industry Sector Education and Training Authority
CHE	Council on Higher Education
CSIR	Council for Scientific and Industrial Research
CCUS	Carbon capture utilisation and storage
DHET	Department of Higher Education and Training
DSI	Department of Science and Innovation
DST	Department of Science and Technology
DTIC	Department of Trade, Industry and Competition
EESA	Employment Services of South Africa
EWSETA	Energy & Water Sector Education Training Authority
GENFETQSF	General and Further Education and Training Qualifications Sub-Framework
GETCA	General Education and Training Certificate for Adults
GHCS	Green Hydrogen Commercialisation Strategy
GHG	Greenhouse gas
Gt	Gigatonne
HEI	Higher education institution
HICC	Hydrogen Infrastructure Center of Competence
HySA	Hydrogen South Africa
HSRM	Hydrogen Society Roadmap
IEA	International Energy Agency
ICE	Internal combustion engine
IDC	Industrial Development Corporation of South Africa
IDEAS	Institute for the Development of Energy for African Sustainability
IRENA	International Renewable Energy Agency
ILO	International Labour Organization
JET IP	Just Energy Transition Investment Plan
LFS	Labour Force Survey
LGSETA	Local Government Sector Education and Training Authority
MerSETA	Manufacturing, Engineering and Related Services Sector Education and Training Authority
MQA	Mining Qualifications Authority

ACRONYM/ABBREVIATION	TERM/DEFINITION
Mt	Million tonne
NDC	Nationally determined contributions
NRF	National Research Foundation
NQF	National Qualifications Framework
NWU	North-West University
OECD	Organisation for Economic Co-operation and Development
OFO	Organising Framework for Occupations
OQSF	Occupational Qualifications Sub-Framework
PSET	Post-school education and training
PGM	Platinum group metal
QCTO	Quality Council for Trades & Occupations
SAIAMC	South African Institute for Advanced Materials Chemistry
SAPIA	South African Petroleum Industry Association
SU	Stellenbosch University
TUT	Tshwane University of Technology
TVET	Technical vocational education and training
UCT	University of Cape Town
UJ	University of Johannesburg
UNISA	University of South Africa
UWC	University of the Western Cape
VUT	Vaal University of Technology
WBL	Workplace-based learning
Wits	University of the Witwatersrand
W&R SETA	Wholesale and Retail Sector Education and Training Authority

Executive Summary

Globally, the hydrogen economy is growing rapidly. Green hydrogen is specifically crucial to developing a sustainable energy future by supporting the reduction of greenhouse gas emissions, as it can enable the decarbonisation of hard-to-abate sectors such as heavy-duty transport (trucks and shipping or bunkering fuel), cement, steel, mining, refineries, chemicals, agriculture, and plastics. South Africa has realised the potential of green hydrogen and is on a drive to determine how to use it to both aid its own path to net zero emissions and to capitalise on the opportunities created by the green hydrogen economy to alleviate the triple challenges of poverty, unemployment, and inequality. Furthermore, as global green hydrogen demand increases, South Africa seeks to use its abundant renewable energy resources to produce green hydrogen and its derivatives for international export.

The objective of the project is to determine the skills that will be required for the green hydrogen value chain in South Africa. The qualitative methodology adopted consists of synthesising secondary and primary data through a literature review and stakeholder consultations. The report qualitatively outlines the current skills demand–supply dynamics in the South African labour market with respect to the hydrogen economy. A detailed analysis of the skills required for the green hydrogen economy was undertaken. This is accompanied by an analysis of the capabilities that need to be developed or augmented in the qualifications offered at South African universities and at the technical vocational education and training (TVET) college ecosystem.

The project has identified 138 occupations required within the value chain, categorised as follows:

- Engineers (professionals according to the Organising Framework for Occupations (OFO))
- Technicians and tradespeople (technicians and associated professionals, skilled craftsmen, and related tradesmen according to the OFO)
- Specialists (professionals as per the OFO)
- Managerial occupations (managers as per the OFO)
- Elementary-level occupations

Out of the 138 occupations identified, 77 are not reflected in the OFO. Many of these occupations currently exist in our labour market, but the individuals in some of these occupations will require additional skills or new qualifications to align with the requirements of the green hydrogen economy. The various sector education and training authorities (SETAs), which primarily include the Chemical Industry Sector Education and Training Authority (CHIETA), the Manufacturing, Engineering and Related Services Sector Education and Training Authority (MerSETA), and the Energy & Water Sector Education Training Authority (EWSETA), support the Quality Council for Trades & Occupations (QCTO) to accredit skills development providers.

These providers, specifically, offer 27 occupational qualifications that can be augmented to incorporate green hydrogen capabilities into the curriculum for 25 of the 39 identified technicians and tradespersons in green hydrogen economy occupations. TVET colleges offer seven programmes as part of the National Certificate (Vocational) (NC(V)) qualification, and three engineering programmes as part of the National Accredited Technical Education Diploma (NATED) qualification. These 10 qualifications provide the necessary foundational knowledge and skills required to support the hydrogen economy in South Africa, with there being no need to introduce new programmes.

For institutions of higher learning, the research has identified that 74 degree and diploma programmes are required for the green hydrogen economy, 50 of which are already offered in South African institutions but would, along with the TVET college programmes, require a level of augmentation to include hydrogen capabilities in the curriculum. This means that 24 degree and diploma programmes needed for the hydrogen economy are not currently offered by the higher education institutions (HEIs) in South Africa.

In addition to reviewing HEI and TVET programmes, the project also highlights the need for capacitating teachers and lecturers so that they will be able to train South Africa's green hydrogen workforce for the many occupations identified in the project. The report discusses some interventions that could be used to 'train the trainers'. The project also includes an assessment of opportunities for workplace-based learning (WBL) available in South Africa and internationally for green hydrogen–related work. This assessment highlights that in contrast to developed countries such as Germany and due to the sector's nascency in South Africa, there are limited opportunities available for green hydrogen–specific WBL in the country.

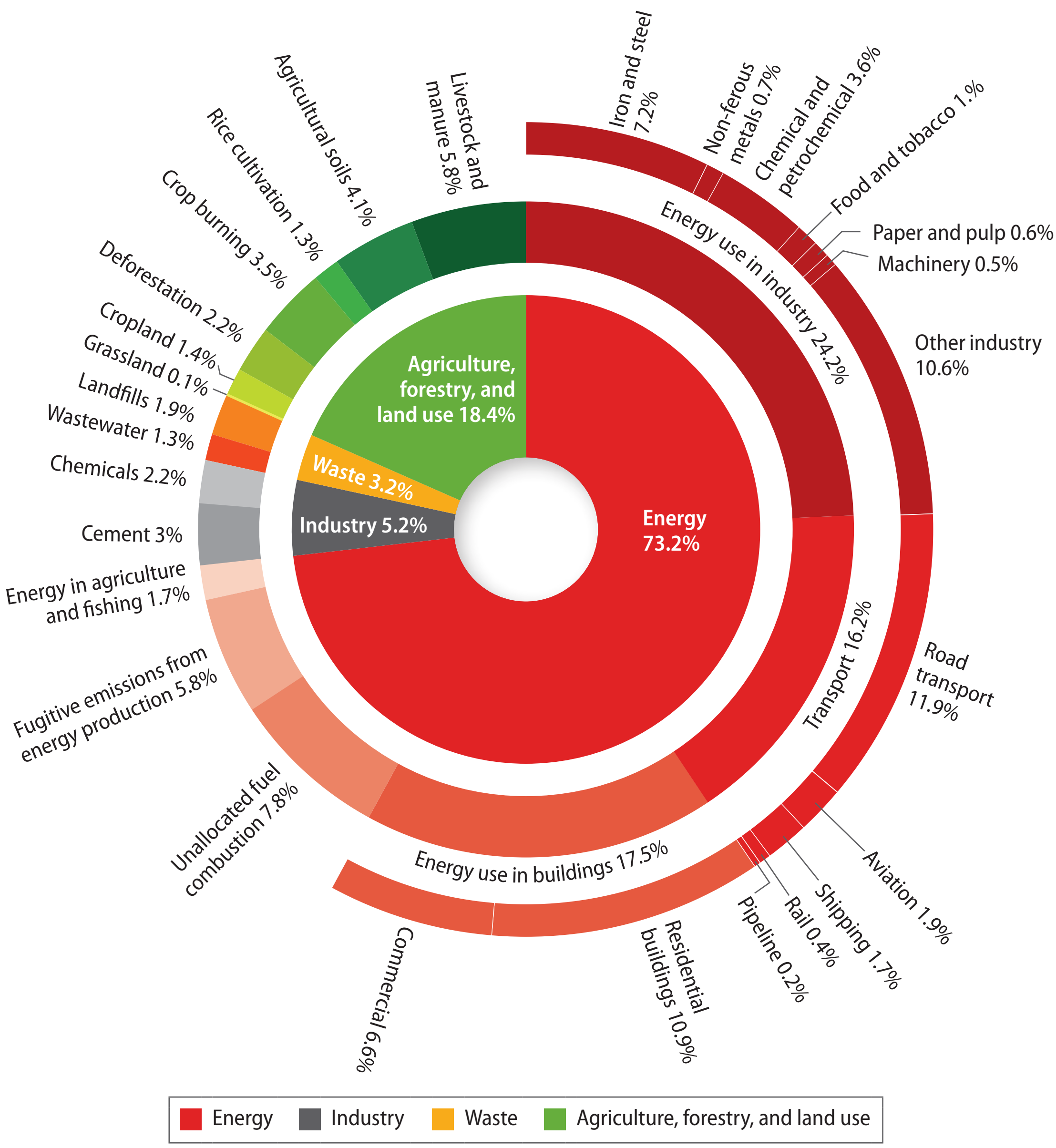
PART 1

Background

The Paris Agreement on climate change set a target to limit global warming by below 2 °C and to purse efforts to limit the temperature increase to 1.5 °C (United Nations, 2015).[1] As a result, there is increasing focus on the need to implement solutions that can decarbonise energy systems globally as the world grapples with the need for a sustainable energy future. It is against this backdrop that green hydrogen is emerging as a crucial energy source in the global energy transition landscape.

The broader energy sector contributes to approximately 73% of global greenhouse gas (GHG) emissions (see figure 1).

FIGURE 1: Global greenhouse gas emissions by sector in 2020



Source: Ritchie (2020)

1 The Paris Agreement is a legally binding international treaty on climate change that was adopted at the UN Climate Change Conference (COP21) by 196 parties in Paris, France on 12 December 2015. The agreement took effect on 4 November 2016.

For years, decarbonisation efforts have focused on electricity generation and passenger vehicles, which have easier-to-address emissions sources (Novak, 2021). The broader energy sector, however, includes what are termed the hard-to-abate sectors.[2] These sectors have less easy-to-address emission sources and include industries such as heavy-duty transport (trucks and shipping or bunkering fuel), cement, steel, mining, refineries, chemicals, agriculture, and plastics industries. Each hard-to-abate sector uses carbon as an integral part of their process, and together these sectors account for about 30% of global GHG emissions (Chammard, 2022).

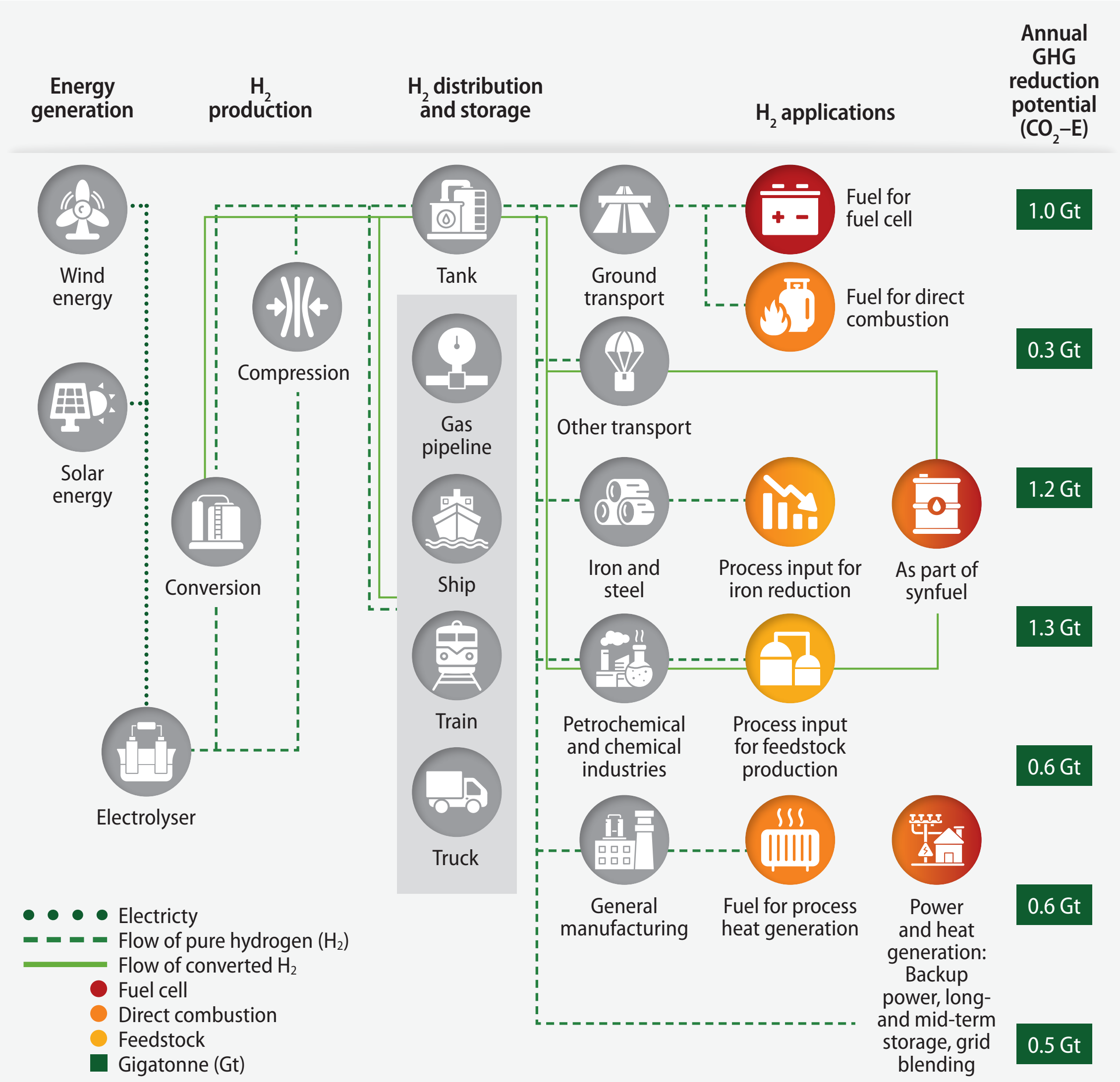
As the world moves towards a carbon-neutral economy, the demand for green hydrogen is therefore expected to grow significantly. South Africa is actively pursuing the development of the green hydrogen economy for local and export markets, and in February 2022, the Department of Science and Innovation (DSI) launched the Hydrogen Society Roadmap (HSRM). The South African government seeks to leverage the opportunities presented by green hydrogen through the HSRM. Opportunities for growth include the use of platinum group metals (PGMs) for reindustrialisation to manufacture components used in the green hydrogen value chains such as electrolysers and fuel cells, the production and export of green hydrogen and other derivatives, and low-carbon solutions for decarbonising hard-to-abate sectors in the country. Catalytic projects identified in the HSRM have the potential to create 20,000 and 30,000 jobs annually by 2030 and 2040, respectively. Furthermore, Industrial Development Corporation (IDC) and the Department of Trade, Industry and Competition (DTIC) developed a Green Hydrogen Commercialisation Strategy (GHCS), which was approved by Cabinet in October 2023. The GHCS envisions the creation of 650,000 jobs across the green hydrogen value chain by 2050 for both export and domestic use (DTIC, 2022)

Significant investment is being made into the development of green hydrogen in South Africa. The GHCS estimates that there is a need for R590 billion in equity and R1.36 trillion in debt funding for the hydrogen economy by 2050. 21.2% of the R1.48 trillion just energy transition budget has also been allocated for the development of green hydrogen, and 0.18% for skills development between 2023 and 2027, as stated in the South African Just Energy Transition Investment Plan (JET IP). The production and use of green hydrogen will require a skilled workforce with research in knowledge areas such as renewable energy, manufacturing, chemistry, logistics, engineering, and information technology.

The value chain of the green hydrogen economy (shown in figure 2) is embedded in various smaller value chains that include energy generation using renewables, green hydrogen production, hydrogen conversion to other derivatives, and value-added products such as ammonia or methanol, distribution, storage, and applications of green hydrogen including synthetic fuels, for energy generation and storage, transport, and in other industries. Each part of the value chain is made up of activities that require a variety of skills that South Africa needs to identify and develop to support the advancement of the hydrogen economy. However, it should be explicitly noted that the country already has some skills to support the development of the hydrogen economy. For example, South Africa has the capability to produce grey hydrogen in fuel production. Furthermore, skills that are unique to the country have been developed to produce synthetic fuels using Fischer-Tropsch technology with Sasol's operations. This is a step above other countries that will need to develop these processes and skills to produce the green fuels needed to decarbonise parts of the transport sector.

2 Hard-to-abate is a term often used in the context of climate change discussions. It refers to sources of pollution that are difficult to eliminate or reduce significantly using current technologies and practices.

FIGURE 2: The green hydrogen value chain and embedded value chains



Source: Ludwig et al. (2021)

Given the context provided above, this report seeks to identify the skills required for the development of the green hydrogen economy in South Africa by answering the following research questions:

1. What are the current and future demands for skills required for the hydrogen economy?
2. What is the available supply of skills for the development of the hydrogen economy?
3. What skills imbalances are envisaged for the development of the hydrogen economy (including occupational shortages and surpluses, skills gaps, and mismatches)? What are the reasons for these imbalances? How can they be addressed?
4. Are the qualifications, programmes, and curricula offered at South African HEIs and TVET colleges appropriate for the development of the hydrogen economy? If not, how can these be changed and/or improved upon?
5. Are there sufficient opportunities for workplace-based learning (WBL) for hydrogen economy–related skills in South Africa as well as internationally? If not, how can this problem be addressed?

In answering the research questions, this report serves as a critical tool that will ensure that South Africa can proactively develop the talent and expertise required for the establishment, growth, and long-term sustainability of the emerging green hydrogen economy.

PART 2

Methodology

The development of a skills needs assessment for a nascent industry such as green hydrogen is a strategic imperative. It enables proactive, targeted development of the skills required and expertise necessary to drive the industry's growth, innovation, and competitiveness—positively contributing to the growth of the South African economy.

Given the nascency of the industry in South Africa, the methodology used to compile the report included reviewing national and international literature to qualitatively identify occupations required in the value chain of green hydrogen production and the conversion to green ammonia and green methanol, including the mapping of OFO codes that correspond to those occupations where they exist. The analysis also included the following:

- The identification of hydrogen-specific capabilities that are required for the identified occupations.
- The identification of qualifications required for the hydrogen value chain and the unique hydrogen-related capabilities that are included in the curriculum. This serves two purposes: Firstly, it informs stakeholders of the augmentation required for qualifications currently being offered in South African institutions, and secondly, of the identification of new programmes or qualifications that may need to be introduced into the post-school education and training (PSET) system.
- An analysis on WBL opportunities that can be leveraged to support the development of the local hydrogen economy.

Stakeholder consultations were conducted with key organisations involved in the hydrogen economy and the PSET system. These consultations were a critical source of primary data, used to validate the accuracy, relevance, and completeness of the report in answering the research questions outlined in part 1.

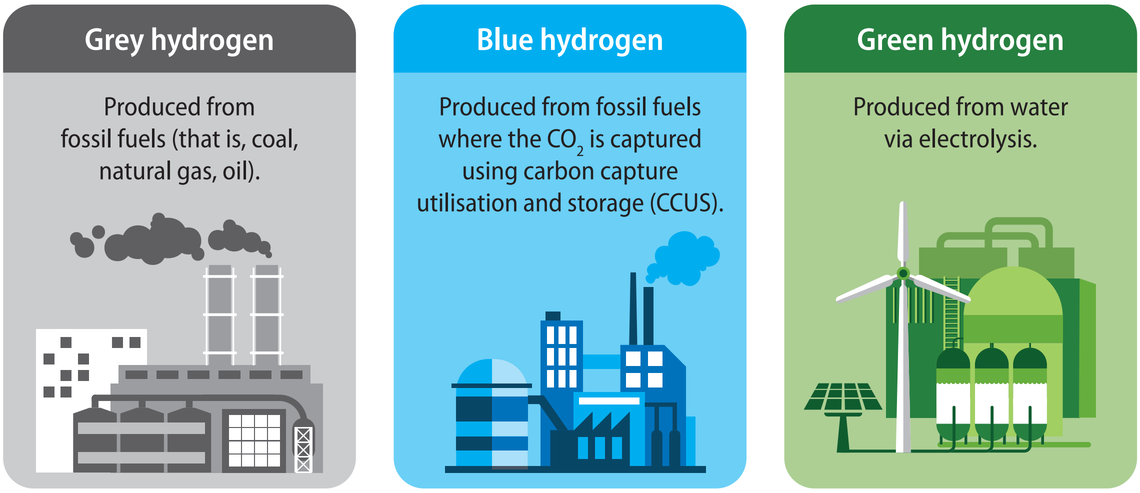
Note that the report does not cover skills required for indirect value chains that may be linked to the green hydrogen economy, such as manufacturing.

PART 3

The Global Hydrogen Landscape

Globally, hydrogen is currently predominantly produced from fossil fuels and is used in industrial processes including oil refining, steel production, methane production, and ammonia production. The emission intensity of these processes is significant, hence the need to transition to low-carbon sources. There are various colour classifications of hydrogen ranging from grey to green, with a description of the main types outlined in figure 3 below.

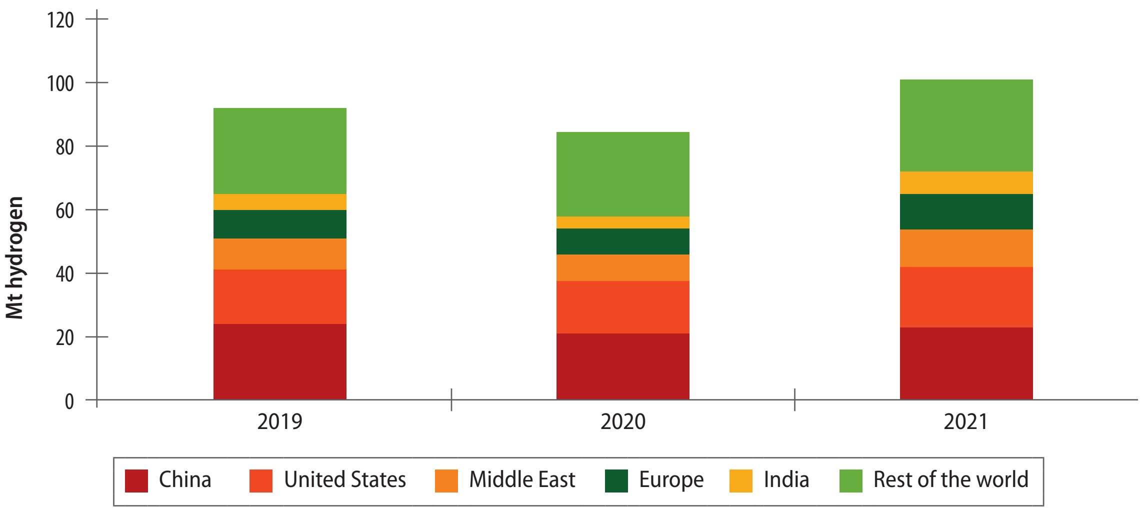
FIGURE 3: Description of grey, blue, and green hydrogen production



In 2021, global hydrogen demand increased to 94 million tonnes (Mt) of hydrogen from 91 Mt in 2019. Of the total hydrogen produced, 47% was from natural gas, 27% from coal, 22% from oil, and 4% from electrolysis (International Energy Agency (IEA), 2022). These figures imply that approximately 90% of the hydrogen produced came from fossil fuel (IEA, 2022). The highest demand came from petroleum refining (40 Mt) and industries (ammonia production ~34 Mt, methanol ~15 Mt, and steel industry ~5 Mt).

Furthermore, the largest hydrogen consumers were China (28 Mt), the United States (12 Mt), the Middle East (12 Mt), Europe (>8 Mt), and India (8 Mt) (see figure 4). China is the largest producer and consumer of grey hydrogen worldwide (Li et al., 2022). The country consumes approximately 33 Mt of hydrogen annually (Nakano, 2022). The hydrogen produced is used as feedstock in refineries or chemical facilities.

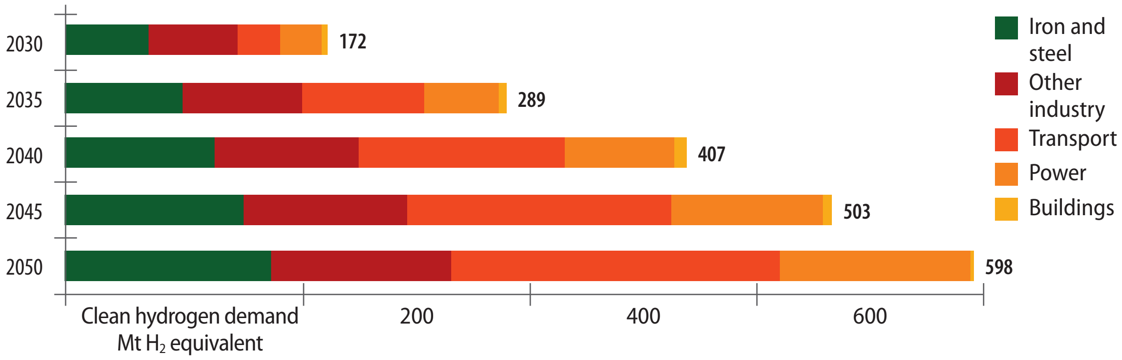
FIGURE 4: Global demand for hydrogen by regions in 2019–2021



Source: IEA

According to Deloitte's analysis, approximately 170 and 600 Mt of low-carbon hydrogen will be required by 2030 and 2050, respectively, for decarbonisation (see figure 5). The increase in demand will be driven by the need to decarbonise hard-to-abate sectors such as transport and industry (that is, the iron, chemicals, cement, and steel industries) to reach net zero by 2050 (Deloitte, 2023b). It is expected that the rise in demand will be enabled by policies and measures that are being implemented by various governments around the world.

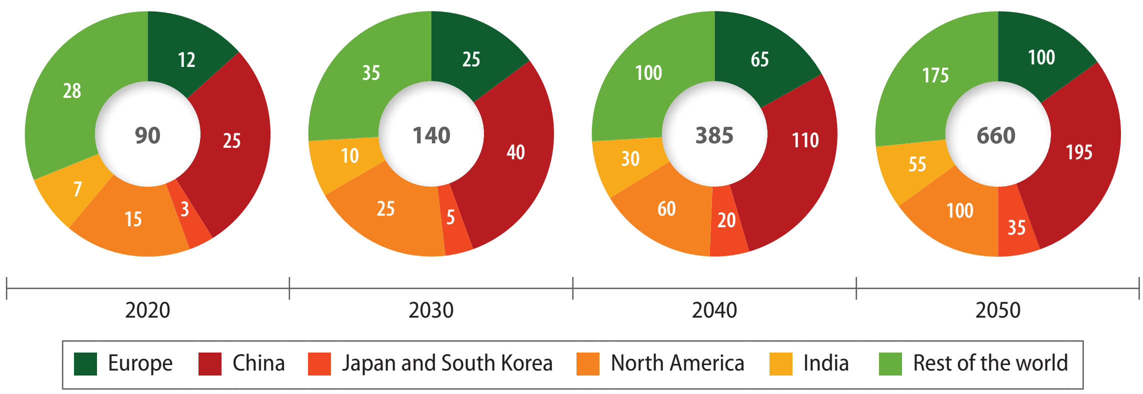
FIGURE 5: Global demand for hydrogen by sectors



Source: Deloitte (2023b)

By 2050, the demand for green hydrogen will be driven by regions such as China (~200 Mt), Europe (100 Mt), North America (100 Mt), India (55 Mt), Japan and South Korea (35 Mt), and the rest of the world (175 Mt) (see figure 6) (Hydrogen Council and McKinsey & Company, 2022).

FIGURE 6: Global hydrogen demand by region



Source: Hydrogen Council and McKinsey & Company (2022)

The top hydrogen market players

Linde (UK-based), Air Liquide (French-based), Air Products and Chemicals (US-based), and Shell (UK-based) are among the top hydrogen producers globally. In South Africa, Sasol is the largest producer of grey hydrogen, producing approximately 2.4 Mt annually (Hydrogen Council, 2023).

PART 4

The Future of South Africa's Hydrogen Economy

South Africa is actively exploring the potential for green hydrogen as an energy source that can be used to facilitate the achievement of the country's net zero ambitions and to stimulate economic growth. In 2022, the HSRM was launched, followed by Cabinet's approval of the GHCS in 2023. According to the HSRM, South Africa will deploy at least 15 gigawatts of electrolysis to produce 500 kilotonnes of green hydrogen annually for use in the transport, built environment, industrial, and power sectors, creating approximately 30,000 jobs annually by 2040.

Currently, through Sasol, South Africa produces 2% of global grey hydrogen demand and has ambitions of capturing 4% of the global green hydrogen market share by 2050 (Salma and Tsafos, 2021). To achieve this goal, the country intends to leverage its existing competitive advantages, which include:

- Renewable energy resources and land availability
- Sasol's Fischer-Tropsch skills and capabilities
- Availability of PGMs
- Existing port and gas infrastructure

These resources will be leveraged to develop the local green hydrogen economy and allow the country to position itself as one of the largest producers and exporters of green hydrogen and hydrogen products.

PART 5

The Green Hydrogen Value Chain

The green hydrogen value chain involves the production, transportation, and use of green hydrogen, which is produced through a clean and sustainable method, typically through electrolysis powered by renewable energy sources. This section of the report briefly describes the activities involved in the hydrogen value chain, beginning with electricity generation. The occupations related to the different segments of the value chain are detailed in part 6.4.4.

5.1 Renewable energy generation and storage

Renewable energy plays a fundamental role in the green hydrogen production process. Green hydrogen, unlike grey hydrogen, which comes from fossil fuels, is produced by electrolysing water using renewable electricity.

The dominant renewable energy sources in South Africa include solar photovoltaics (PVs) and onshore wind. The country is expected to implement additional renewable energy projects as part of the just energy transition. These projects, however, need to be coupled with technologies such as battery storage systems to ensure grid stability (Pandarum et al., 2023). Therefore, the skills required for solar PVs, onshore wind, and lithium-ion battery storage are only outlined at a high level in this section of the report, given that the focus of the report is on the remaining segments of the green hydrogen value chain. The skills required are divided into three levels, high (H), medium (M), and low (L) (see figures 7 to 9).

FIGURE 7: The skills required for the solar PV value chain

PROJECT DEVELOPMENT

- Project designers (engineers) (H)
- Architects (small projects) (H)
- Atmospheric scientists and meteorologists (H)
- Resource assessment specialists and site evaluators (H)
- Environmental consultants (H)
- Lawyers, government program debt financier representatives (H)
- Developers and facilitators (H, M)
- Land development advisors (H)
- Land use negotiators (H)
- Lobbyists (H)
- Mediators (H)
- Environmental and social NGO representatives (H)
- Public relations officers (H)
- Procurement professionals (H)

EQUIPMENT MANUFACTURE AND DISTRIBUTION

- Researchers (chemists, physicists, engineers specialising in electrical, mechanical, chemical, materials, system design, and process engineering) (H)
- Chemical laboratory technicians and assistants (M)
- Software engineers (H, M)
- Modellers (H)
- Manufacturing (engineers (H), technicians (M), operators (M, L), quality assurance experts (H, M))
- Building systems specialists (H)
- Logistics (professionals (H, M) and operators (L))
- Equipment transporters (L)
- Procurement professionals (H, M)
- Marketing specialists (H, M)
- Sales personnel (H, M)

CONSTRUCTION AND INSTALLATION

- System designers (electrical engineers or technologists) (H, M)
- Roofers specialising in solar (M)
- System designers (electrical, mechanical, structural engineers) (H)
- Installers (M)
- Electricians specialising in solar (M)
- Project designers and managers (H)
- Project and installation evaluators (H, M)
- Construction professionals (H)
- Software engineers (H, M)
- Quality assurance specialists (H, M)
- Business developers (H)
- Commissioning electrical engineers (H)
- Transportation workers (L)

OPERATIONS AND MAINTENANCE

- Photovoltaic maintenance specialists (electricians specialising in solar) (M)
- Inspectors (M, L)
- Recycling specialists (H)

CROSS-CUTTING ACTIVITIES

- Policymakers and government office workers (H, M)
- Trade association and professional society staff (H, M, L)
- Educators and trainers (H)
- Managers (H, M)
- Administrators (H, M, L)
- Publishers and science writers (H, M)
- Insurer representatives (H, M)
- IT professionals (H, M)
- Human resources professionals (H)
- Financial professionals (accountants, auditors, and financers) (H)
- Health and safety consultants (H, M)
- Clients (H, M, L)

Source: International Labour Organization (ILO) (2011)

PART 5

FIGURE 8: The skills required for the onshore wind value chain

PROJECT DEVELOPMENT

- Project designers (H)
- Specialists (environmental impact assessment, social impact assessment, economics, financial and risk) (H)
- Legal professionals
- Atmospheric scientists (H)
- Public relations officers (H)
- Land use negotiators and land development advisors (H)
- Procurement professionals (H, M)
- Wind resource assessment specialists (H)
- Geographers (H)
- Oceanographers (H)
- Marine biologists (H)

MANUFACTURING

- Manufacters (engineers (H), technicians (M), operators (L), and quality assurance experts (H, M))
- Research and development engineers (electrical, mechanical, wind power design, computer, and environmental) (H)
- Software engineers (H, M)
- Modellers (prototype testing) (H, M)
- Industrial mechanics (M)
- Certifiers (H)
- Professionals (logistics, procurement) (H, M)

TRANSPORT

- Equipment transporters (L)
- Logistics professionals (H, M)
- Logistics operators (L)
- Administrators (M, L)
- Regulatory experts (M, H)

CONSTRUCTION AND INSTALLATION

- Electrical, civil, and marine engineers (H)
- Small turbine installers (M)
- Construction electricians (M)
- Power line technicians (M)
- Construction workers (M, L)
- Quality control inspectors (M)
- Instrumentation and control technicians (M)
- Commissioning electrical engineers (H)
- Crane operators (M)

OPERATIONS AND MAINTENANCE

- Wind smiths, millwrights, and wind service, mechanical, and mechatronics technicians (H, M)
- Operations and maintenance specialists (M)
- Power line technicians (M)
- Wind service mechatronics (M)
- Field electricians (M)

DECOMMISSIONING

- Construction workers and technical personnel (M, L)
- Truck drivers and crane operators (M, L)
- Industrial, mechanical, and electrical engineers (H)
- Environmental experts (H)
- Health and safety experts (H)
- Logistics experts (H, M, L)

Sources: ILO (2011); International Renewable Energy Agency (2017)

FIGURE 9: The skills required for the lithium-ion battery value chain

RAW MATERIALS AND PROCESSING
- Battery materials scientists and engineers (H, M)
- Chemical laboratory technicians and assistants (M)
- Process engineers (H, M)
- Chemists (H, M)
- Metrologists (H, M)
- Automation or process operators (H, M)

CELLS AND COMPONENTS MANUFACTURING
- Battery materials scientists (H, M)
- Manufacturing engineers (H)
- Technicians (H, M) and operators (M, L)
- Quality assurers (H, M)
- Component (electrode, electrolyte, separator) design engineers (H, M)
- Mechanical and electrical engineers (H, M)
- Calibration technicians (M)
- Machine operators (M, L)

BALANCE OF SYSTEM DEVELOPMENT
- Battery management system developers (H, M)
- Controls engineers (H, M)
- Embedded software engineers and developers (H, M)

BATTERY MODULE AND PACK ASSEMBLY
- Automation engineers (H, M)
- Battery assemblers (M, L)
- Quality assurance technicians (H, M, L)

INSTALLATION, OPERATIONS, AND MAINTENANCE
- System designers (H, M)
- Electricians specialising in battery energy storage systems (M)
- Installers (M)
- Maintenance specialists (M)
- Inspectors (M, L)

END OF LIFE
- Waste collectors (L)
- Recyclers (L)
- Battery materials scientists or engineers (H, M)
- Chemical laboratory technicians and assistants (M)
- Automation or process operators (H, M)
- Process engineers (H)

Source: Adapted from ALBATTS (2023)

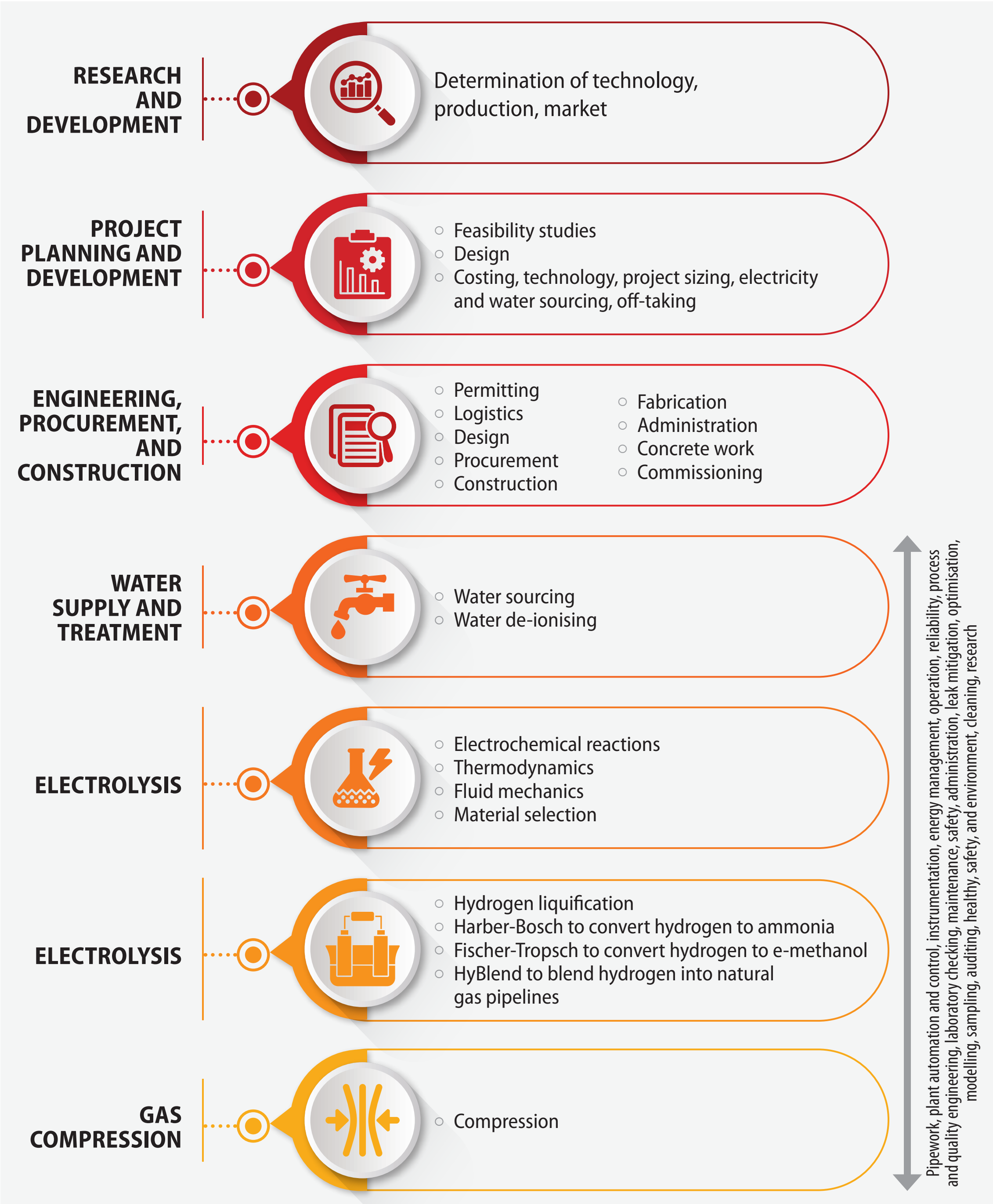
5.2 Hydrogen production

Activities in green hydrogen production as outlined by Aziz et al. (2020) and Guo et al. (2019) include:

- Electrolysis, through which electricity is used to split water molecules into oxygen and hydrogen
- Conversion of hydrogen gas to liquid hydrogen, green ammonia, or e-methanol
- Compression to increase the pressure for transportation

These activities can be broken down as shown in figure 10.

FIGURE 10: Activities in the production of green hydrogen



Sources: Arup (2022); Aziz et al. (2020); Swinburne (2022)

5.3 Hydrogen storage and transportation

Activities in the storage and transportation of green hydrogen, ammonia, and e-methanol are shown in figures 11 and 12.

FIGURE 11: Activities in the storage of green hydrogen, ammonia, and e-methanol

Tanks

- Engineering (structural, electrical, automation, instrumentation, thermal)
- Control, operations, and maintenance
- Welding and fitting
- Quality management
- Measurements
- Refrigeration, air-conditioning
- Reservoir monitoring
- Modelling and simulation
- Leak detection
- Planning and scheduling
- Insulation
- Environmental, health, and safety

Chemical storage

- Engineering (chemical, structural, electrical, automation, control, research, process, instrumentation)
- Environmental, health, and safety
- Modelling and simulation
- Leak detection

Natural gas pipelines

- Engineering (structural, electrical, automation, control, pipeline, process, instrumentation, process)
- Pipework
- Welding and fitting
- Quality and integrity assessment
- Measurements
- Modelling and simulation
- Planning and scheduling
- Environmental, health, and safety
- Control, operations, and maintenance
- Corrosion assessment
- Compression
- Leak detection

Underground storage

- Geoscience
- Pipework
- Drilling and rigging
- Equipment operation
- Engineering (structural, electrical, cavern, instrumentation)
- Underground well control, operations, and maintenance
- Leak detection
- Quality assessment
- Measurements
- Modelling and simulation
- Data analysis or modelling
- Equipment servicing
- Environmental, health, and safety

Sources: Swinburne (2022); Weichenhain (2021)

FIGURE 12: Activities in the transportation of green hydrogen, ammonia, and e-methanol

Pipes

- Engineering (structural, electrical, automation, control, pipeline, instrumentation, process)
- Hydraulics
- Control, operations, and maintenance
- Leak detection
- Environmental, health, and safety

Ships

- Navigation
- Engineering (marine, structural, electrical, automation, control, instrumentation)
- Planning and scheduling
- Information systems
- Leak detection
- Weather or geography analysis
- Maritime law
- Maritime survey
- Design and fabrication
- Ship management
- Port management
- Environmental, health and safety

Trucks

- Driving
- Tank operation and maintenance
- Welding and fitting
- Truck maintenance
- Truck inspection
- Truck safety
- Refrigeration, air-conditioning
- Road safety
- Logistics coordination
- Fleet management
- Environmental, health, and safety

Railway

- Engineering (structural, electrical, automation, control, instrumentation)
- Welding and fitting
- Train driving
- Train operation
- Railway operation and maintenance
- Logistics
- Energy management
- Planning and scheduling
- Environmental, health, and safety

Sources: Swinburne (2022); Weichenhain (2021)

5.4 Hydrogen end-use applications

The 'hydrogen economy' refers to the application of hydrogen in a variety of areas across the economy both as a feedstock and an energy source. These application areas include the industrial, transportation, power, and built environment sectors. Activities in these sectors include hard-to-abate activities—those heavily reliant on fossil fuels and would be difficult to decarbonise, such as steelmaking. Green hydrogen holds great potential for the decarbonisation of these activities. Tables 1–3 highlight hydrogen applications in the above-mentioned sectors.

TABLE 1: Hydrogen application areas in the industrial sector and the associated end-uses

INDUSTRY	HYDROGEN APPLICATION AREA	END-USE AND RELATED ACTIVITIES
OIL REFINING	Hydrotreatment	Removal of pollutants such as sulphur, nitrogen, olefins, and metals
	Hydrocracking	Breaking long hydrocarbon chains of heavy oils into short chains with low viscosity and molecular weight
CHEMICALS	Ammonia production	Haber-Bosch process Ammonia end-uses: ○ Fertilisers ○ Explosives ○ Hydrogen carriers
	Methanol production	Catalytic reduction of CO and hydrogenation of CO_2 Methanol end-uses: ○ Formaldehyde ○ Production of olefins used to produce plastics ○ Transport fuels through blending or direct use
	Other chemicals	Synthetic transport fuels through processes such as Fischer-Tropsch synthesis
STEELMAKING	Direct reduction of iron (DRI)	Iron ore reducing agent in the DRI electric arc furnace process to produce green steel
HIGH-TEMPERATURE HEAT	Industrial heat	Heat generation for high-temperature heat applications (>400 °C) such as steelmaking and cement or concrete production

Sources: Abdin et al. (2020); Bozzano and Manenti (2016); Deloitte (2023a); Dieterich et al. (2020); Energy Transitions Commission (2020); IEA (2019); International Renewable Energy Agency (IRENA) (2021b); Kearney Energy Transition Institute (2020); Liu et al. (2010); World Steel Association (2023)

TABLE 2: Hydrogen application areas in the transport sector and the associated end-uses

TRANSPORT	HYDROGEN APPLICATION AREA	END-USE AND RELATED ACTIVITIES
ROAD	Fuel cell electric vehicle	○ Fuel cells ○ Hydrogen storage tanks ○ Auxiliary components
	Hydrogen internal combustion engine vehicle	○ Conversion of conventional internal combustion engines (ICEs) to hydrogen ICEs ○ Hydrogen-based fuels and hydrogen blends
MARITIME	Domestic shipping	○ Fuel cells ○ Hydrogen storage tanks ○ Hydrogen blends for ICEs
	International shipping	○ Bunkering or storage facilities at ports ○ Hydrogen conversion to ammonia and reconversion ○ Distribution systems ○ Retrofitting vessels for fuel switch to ammonia ○ Hydrogen storage tanks
AVIATION	Aircraft	○ Sustainable aviation fuel using the Fischer-Tropsch process ○ Fuel cells (for FuelCell Energy (FCE) powered aircraft) ○ Hydrogen storage tanks (for FCE-powered aircraft)
RAIL	Fuel cell electric trains	○ Fuel cells ○ Hydrogen storage tanks ○ Auxiliary components
	Refuelling stations	○ Hydrogen storage ○ Distribution or piping system ○ Operations (for example, refuelling)

Sources: IEA (2019, 2022); IRENA (2021a), International Transport Forum and OECD (2018); Lu (2022); Pape (2020); World Bank (2021)

Note: Refuelling stations are cross-cutting for most applications where fuel cells would be used.

TABLE 3: Hydrogen application areas in the power and buildings sectors and associated end-uses

SECTOR	HYDROGEN APPLICATION AREA	END-USE AND RELATED ACTIVITIES
POWER	Baseload power generation	○ Co-firing ammonia in coal plants to reduce coal usage and overall emissions
	Flexible power generation	○ Internal combustion engine ○ Hydrogen-fired simple natural gas turbines ○ Combined cycle gas turbines ○ Fuel cells
	Back-up and off-grid power supply	○ Fuel cells
	Large-scale and long-term energy storage	○ Storage of pure hydrogen in salt caverns for seasonal energy storage
BUILDINGS	Space heating	○ Blending hydrogen into natural gas grids ○ Retrofitting and upgrading natural gas grid infrastructure for hydrogen distribution

Sources: DNV (2019); IEA (2019); Kearney Energy Transition Institute (2020)

PART 6

Skills Supply, Demand, and Imbalances in the Hydrogen Economy

As the green hydrogen economy develops in the country, the need for a skilled workforce to service the sector and sustainable economic growth emerges. As outlined in part 1 of this report, catalytic projects identified in the HSRM have the potential to create 20,000 jobs annually by 2030 and 30,000 jobs annually by 2040. Furthermore, the GHCS envisions the creation of 650,000 jobs across the green hydrogen value chain by 2050 for both export and domestic use. To realise these job opportunities, the current workforce will require reskilling and/or upskilling to be able to participate in the green hydrogen economy. New curricula will need to be developed and/or the modification of current curricula will be required in institutions of higher learning and in the TVET college ecosystem to ensure that the future workforce is adequately prepared to participate in the hydrogen economy.

This section of the report outlines the skills required (skills demand) for the hydrogen economy, reviews the existing skills (skills supply), and assesses the skills imbalances envisaged for the development of the hydrogen economy. This analysis is undertaken using a qualitative approach.

6.1 Definitions of skills demand, supply, and related terms

This report defines capabilities, skills supply, skills demand, and skills imbalances as follows:

TERM	DEFINITION
CAPABILITIES	Refers to the "Skills and knowledge that will be required to undertake hydrogen-related activities safely and effectively".
SKILLS SUPPLY	Refers to the "Skills possessed by individuals who are either employed or willing, able and available to work".
SKILLS DEMAND	Refers to the "Skills required by employers at prevailing wages rates to meet their operational needs at a given point in time. In this sense, the demand for skills derives from demand for goods and services produced by employers".
SKILLS IMBALANCES	"Skills imbalances arise when skills demanded by employers and the skills supplied by individuals in the labour market are not aligned. Types of imbalances include skills shortages, skills surpluses, and skills mismatches". ○ Skills shortages: When the skills demanded exceed supply. ○ Skills surpluses: When the skills supplied exceed demand. ○ Skills mismatches: Results from individuals being employed in roles that do not match their skills profile.
RESKILLING	Refers to a new set of skills acquired to perform a new role.
UPSKILLING	Refers to the enhancement of existing skills through additional education and training.

Sources: Rasool (2021); Mercer and Mettle (2021); Khuluvhe et al. (2022); PwC (2022); Vandeweyer and Verhagen (2022)

6.2 Skills demand for hydrogen

6.2.1 The skills required for the green hydrogen economy

To understand the future demand for hydrogen skills in South Africa, a literature review was conducted, including reports on the skills needs for the green hydrogen economies of regions such as Australia, Canada, France, and the European Union. This review enabled the identification of both occupations and associated capabilities that will be required to carry out hydrogen-related activities safely and effectively across the hydrogen value chain segments (that is, production, storage, distribution, and end-use applications). These are outlined in tables 4 and 5 (occupations) and table 6 to 10 (capabilities) and include the identification of the following:

- The core skills (including capabilities) required and their applicability across the value chain are denoted by 'x' in tables 4 to 10. In total, 138 occupations are identified, and these are categorised as follows:
  - 35 engineers (professionals according to the OFO)
  - 39 technicians and tradespeople (technicians and associated professionals, skilled craftsmen and related trades workers according to the OFO)
  - 38 specialists (professionals according to the OFO)
  - 15 managerial occupations (managers according to the OFO)
  - 11 elementary-level occupations

- The skills required are divided into three levels: high (H), medium (M), and low (L)

- The qualification required for each occupation

- OFO codes for the identified occupations where they exist in the local context. Additionally, it should be noted that although the OFO has its own occupation categories, to draw lessons, the categories here were adopted from international best practices. As a result, skills are categorised by occupational clusters as follows (PwC, 2022):
  - Engineers (professionals according to the OFO)
  - Technicians and tradespeople (technicians and associated professionals, skilled craftsmen and related tradesmen according to the OFO)
  - Specialists (professionals as per the OFO)
  - Managerial occupations (managers as per the OFO)
  - Elementary-level occupations

PART 6

Table 4 includes the occupations for which corresponding OFO codes exist, while OFO codes could not be identified for the core occupations listed in table 5. Italicised qualifications are those that are currently not offered in South African universities. Further details on these are provided in parts 7.2.1 and 7.3 of this report.

An extensive review of literature was conducted to inform the identification of occupations required for the hydrogen economy, mainly focusing on Australia, Canada, France, and the European Union, where skills needs assessments have been concluded for the hydrogen economy. The qualifications required for these occupations and their categorisation across the hydrogen value chain segments were also informed by the literature review. Where literature was not available, authors' analyses were used.

Additionally, online recruitment platforms such as LinkedIn and PNet were used to map the existing skills (denoted by the colour green in the legend) in the South African hydrogen economy. Occupations categorised as "unsure of existence" (denoted in yellow in the legend) refer to skills that are available on these platforms but where it is not clear if they are currently applicable to South Africa's hydrogen economy. Furthermore, a general online search in addition to online recruitment platforms was used to confirm other hydrogen-related skills whose existence could not be confirmed, and these are categorised as being "non-existent" in the country (denoted in orange in the legend).

TABLE 4: Requirements for green hydrogen skills (occupations with OFO codes and corresponding qualifications), disaggregated by value chain segments

LEGEND
Existing skills
Unsure of existence
Non-existing skills

					Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel, and iron productiown and chemical production)
No.	OFO	Core occupation	Skill level	Qualification							
		ENGINEERS									
1	214501	Chemical engineer	H	Bachelor's degree: Chemical or *electrochemistry engineering*	×	×	×	×		×	×
2	214201	Civil engineer	H	Bachelor's degree: Civil engineering	×	×	×				
3	215101	Electrical engineer	H	Bachelor's degree: Electrical engineering	×	×	×		×	×	
4	215201	Instrumentation engineer	H	*Bachelor's degree: Instrumentation engineering*	×		×		×		
5	214301	Environmental engineer	H	Bachelor's degree: Civil engineering, with environmental engineering	×						
6	214103	Robotics and automation engineer	H	Bachelor's degree: Mechatronics engineering	×	×	×	×	×	×	×
7	214607	Gas engineer	H	Bachelor's degree: *Petroleum*, mechanical, civil, or chemical engineering	×	×	×	×	×	×	×
8	214101	Industrial engineer	H	Bachelor's degree: Industrial engineering	×	×	×	×	×	×	×

LEGEND
Existing skills
Unsure of existence
Non-existing skills

					Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel, and iron productiown and chemical production)
No.	**OFO**	**Core occupation**	**Skill level**	**Qualification**							
		ENGINEERS									
9	214401	Mechatronics engineer	H	Bachelor's degree: Mechatronics engineering	×		×			×	
10	214401	Mechanical engineer	H	Bachelor's degree: Mechanical engineering	×	×	×	×	×	×	×
11	214101	Process engineer	H	Bachelor's degree: Process engineering	×	×	×	×	×	×	×
12	214101	Safety engineer	H	Bachelor's degree: Chemical or process engineering	×	×	×		×	×	×
13	214103	Production engineer	H	Bachelor's degree: Chemical or mechanical engineering	×		×		×	×	
14	251201	Software engineer	H	Bachelor's degree: Computer science, information and technology, electrical and computer engineering	×	×	×		×	×	×
15	214603	Welding engineer	H	Bachelor's degree: Materials, or mechanical engineering specialist training in *welding engineering*		×		×			
16	214907	Materials engineer	H	Bachelor's degree: Materials science and engineering, or a related engineering field	×	×	×	×	×	×	×

LEGEND

- Existing skills
- Unsure of existence
- Non-existing skills

No.	OFO	Core occupation	Skill level	Qualification	Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel, and iron productiown and chemical production)
		ENGINEERS									
17	252301	Systems engineer	H	*Bachelor's degree: System engineering*	×	×	×	×	×	×	×
18	215103	Renewable energy engineer	H	Bachelor's degree: Engineering or science in electrical, chemical, environmental, or mechanical	×				×		
19	214401	Fuel cell engineer	H	Bachelor's degree: Chemical, electrical, or mechanical engineering	×		×		×	×	×
20	315101	Marine engineer	H	Bachelor's degree: Marine engineering or nautical science	×	×	×			×	
21	214201	Hydraulics engineer	H	*Bachelor's degree: Hydraulic engineering*	×		×			×	×
22	214101	Quality engineer	H	Bachelor's degree: Engineering field	×	×	×	×	×	×	×
		TECHNICIANS AND TRADESPERSONS									
23	313301	Chemical process technician	M	Diploma: Chemical engineering	×	×	×	×	×	×	×
24	711201	Plant operator	M	*Certificate: Power engineering or stationary engineering*	×	×			×		

LEGEND
Existing skills
Unsure of existence
Non-existing skills

					Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel, and iron productionand chemical production)
No.	OFO	Core occupation	Skill level	Qualification							
		TECHNICIANS AND TRADESPERSONS									
26	311101	Chemical laboratory technician	M	Diploma: Chemical, process or *petroleum* technology/ laboratory technician	×	×	×	×	×	×	×
27	733201	Truck driver	M	Type C and/or D licenses as a minimum, professional driving permit licence			×			×	
28	671208	Locomotive electrician	M	Certificate of qualification: Electrician, automotive technician			×			×	
29	642603	Gas fitter	M	Certification: Gasfitter and registered apprentice		×		×			×
30	652302	Fitter and turner	M	Diploma: Engineering or related field	×	×	×			×	×
31	671101	Electrician	M	Diploma: Electrical engineering	×	×	×		×		×
32	311401	Instrumentation technician	M	*Diploma: Instrumentation engineering*	×	×	×				
33	311501	Fuel cell technician	M	Certificate or diploma: Electrical or chemical engineering	×		×		×	×	×
34	671203	Mechatronics technician	M	Diploma: Mechatronics engineering	×		×			×	×

LEGEND
Existing skills
Unsure of existence
Non-existing skills

No.	OFO	Core occupation	Skill level	Qualification	Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel, and iron productiown and chemical production)
		TECHNICIANS AND TRADESPERSONS									
35	311702	Materials technician	M	*Diploma: Materials science* or engineering, or related engineering field	×						×
36	311501	Marine engineering technician	M	*Diploma: Marine engineering* or nautical science			×			×	×
37	215104	Renewable energy technologist	M	Bachelor of technology degree or diploma: Renewable energy engineering	×	×					×
38	651202	Welder	M	Diploma: Materials or mechanical engineering, or specialist training in welding engineering	×	×	×	×		×	×
39	313916	Manufacturing production technician	M	Certificate or diploma: Chemical, mechanical, mechatronics, or electrical engineering	×	×	×		×	×	×

LEGEND
Existing skills
Unsure of existence
Non-existing skills

					Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel, and iron productiown and chemical production)
No.	OFO	Core occupation	Skill level	Qualification							
		SPECIALISTS									
40	211401, 211402,	Geoscience professionals: Geologist, geophysicist, geotechnical specialist	H	Bachelor's degree: Geology or *geophysics*		×					
41	2161101	Lawyer	H	Bachelor's degree: Law and legal	×	×	×	×	×	×	×
42	263101	Economist	H	Bachelor's degree: Economics	×	×	×	×	×	×	×
43	263304	Political scientist	H	Bachelor's degree: Political science	×						
		MANAGEMENT									
44	132102	Plant manager	H	Engineering, maintenance, and/or operations experience	×	×					
45	312202	Maintenance planner	H	Certificate or bachelor's degree: Industrial, or instrumentation, electrical, or mechanical engineering	×	×	×			×	
46	121905	Project manager	H	Diploma or bachelor's degree: Project management and related experience	×	×	×	×	×	×	×

LEGEND
Existing skills
Unsure of existence
Non-existing skills

No.	OFO	Core occupation	Skill level	Qualification	Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel, and iron productiown and chemical production)
		MANAGEMENT									
47	122101	Business development manager	H	Bachelor's degree: Business and management or related field	×	×	×	×	×	×	×
48	132401	Supply chain manager	H	Bachelor's degree: Supply chain management, logistics, business, or related field	×	×	×	×	×	×	×
49	122101	Sales and marketing manager	H	Bachelor's degree: Marketing, mathematics, business administration, or related field	×	×	×	×	×	×	×
50	121902	Administrative manager	H	Experience in a related field such as management or financial reporting	×	×	×	×	×	×	×
51	243203	Communications manager	H	Bachelor's degree: Communications, journalism, public relations, or relevant field	×	×	×	×	×	×	×
		ELEMENTARY									
52	811204	Cleaner	L	Certificate: Hygiene and cleaning	×	×	×	×	×	×	×
53	515301	Caretaker (building)	L	Experience in building management	×	×	×	×	×	×	×

LEGEND
Existing skills
Unsure of existence
Non-existing skills

					Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel, and iron productiown and chemical production)
No.	OFO	Core occupation	Skill level	Qualification							
		ELEMENTARY									
54	541401	Guard	L	Security guard training and certification	×	×	×	×	×	×	×
55	861101	Garbage collector	L	Experience in waste management	×						×
56	811201	Sweeper	L	Certificate: Hygiene and cleaning	×	×			×		×
57	8313	Building construction labourer	L	Grade 12 certificate and/or related experience	×	×	×		×	×	×
58	862202	Handyperson	L	Grade 12 certificate and/or related experience	×	×					×
59	8329	Manufacturing labourer	L	Certificate: Manufacturing-related experience	×	×					
60	833301	Freight handler	L	Certificate: Freight handling–related experience			×			×	

Sources: Council for Scientific and Industrial Research (CSIR) (2023); BP and Aberdeen City Council (2022); France Hydrogene (2022); Hufnagel-Smith (2022a, 2022b); Hydrogen Europe Research et al. (2023a); PwC (2022); Queensland Government (2022)

TABLE 5: Requirements for green hydrogen skills (occupations not reflected in the OFO and corresponding qualifications), disaggregated by value chain segments

LEGEND
Existing skills
Unsure of existence
Non-existing skills

					Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel and iron production, and chemical production)
No.	**OFO**	**Core occupation**	**Skill level**	**Qualification**							
		ENGINEERS									
61	–	Commissioning engineer (related to processes and systems)	H	Bachelor's degree: Chemical or mechanical engineering	×	×	×				
62	–	Facility engineer	H	Bachelor's degree: Chemical, process, or mechanical engineering	×				×		
63	–	Grid connection engineer	H	Bachelor's degree: Electrical engineering	×						
64	–	Process control engineer	H	Bachelor's degree: Chemical or *electrical and instrumentation engineering*	×				×		
65	–	Cavern engineer	H	Bachelor's degree: Chemical, geological, mechanical, or *petroleum engineering*		×					
66	–	Drilling engineer	H	Bachelor's degree: Chemical, mechanical, or *petroleum engineering*		×					
67	–	Pipeline engineer	H	Bachelor's degree: Chemical, civil, or mechanical engineering			×				

LEGEND
- Existing skills
- Unsure of existence
- Non-existing skills

					Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel and iron production, and chemical production)
No.	**OFO**	**Core occupation**	**Skill level**	**Qualification**							
		ENGINEERS									
68	–	Research and development engineer	H	Bachelor's or postgraduate degree, or PhD: Engineering	×	×	×	×	×	×	×
69	–	Locomotive (train) engineer	H	Bachelor's degree: *Railway*, mechanical, or electrical engineering						×	
70	–	Refuelling station engineer	H	*Bachelor's degree: Petroleum engineering*			×			×	
71	–	Electrolysis engineer	H	Bachelor's degree: Chemical, electrical, or mechanical engineering	×	×			×		
72	–	Electrochemical engineer	H	Bachelor's degree: Electrochemical or chemical engineering	×	×	×			×	
73	–	Design engineer	H	Bachelor's degree: Chemical, civil, mechanical, or electrical engineering	×	×	×	×	×	×	×

LEGEND
Existing skills
Unsure of existence
Non-existing skills

					Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel and iron production, and chemical production)
No.	**OFO**	**Core occupation**	**Skill level**	**Qualification**							
		TECHNICIANS AND TRADESPERSONS									
74	–	Commissioning technician	M	Diploma: Electrical or mechanical engineering	×	×	×	×			×
75	–	Utility operator	M	Matric certificate or diploma and experience in related field				×			
76	–	Mechanical technician	M	Diploma or bachelor's degree: Mechanical engineering	×	×	×	×	×	×	×
77	–	Test technician	M	Bachelor's degree: Engineering or related field	×	×	×	×			×
78	–	Maintenance technician	M	Diploma: Mechanical engineering	×	×	×	×	×	×	×
79	–	Drilling crew	M	Certificate: Drilling-related field		×					
80	–	Reservoir technologist	M	Diploma: Chemical, *geology*, or *petroleum engineering*		×					
81	–	Well completions operator	M	Bachelor's degree: *Petroleum* or mechanical engineering		×					
82	–	Pipeline technician: Electrical and instrumentation, or mechanical	M	Certificate or diploma: Instrumentation technician or industrial electrician and mechanic		×	×				

LEGEND
Existing skills
Unsure of existence
Non-existing skills

					Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel and iron production, and chemical production)
No.	OFO	Core occupation	Skill level	Qualification							
		TECHNICIANS AND TRADESPERSONS									
83	–	Compression station operator	M	Certificate or diploma: Industrial electrician, or mechanic, electrical, or mechanical engineering		×	×			×	×
84	–	Cylinder technician	M	Certificate or *diploma: Refrigeration and air-conditioning, heavy duty,* or instrumentation engineering		×	×				
85	–	Heavy-duty mechanic (dual fuel)	M	Certificate: Heavy duty and registered apprentice		×	×			×	
86	–	Fuel cell electric vehicle (FCEV) technician	M	Certificate: Heavy-duty mechanic and training on fuel cell stack, electric traction motor, DC/DC converter, hydrogen fuel tank, and thermal system cooling			×			×	
87	–	Heating, ventilation and air-conditioning (HVAC) technician	M	Certificate: Refrigeration and air-conditioning mechanic		×		×			

LEGEND
Existing skills
Unsure of existence
Non-existing skills

					Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel and iron production, and chemical production)
No.	**OFO**	**Core occupation**	**Skill level**	**Qualification**							
		TECHNICIANS AND TRADESPERSONS									
88	–	Utility service technician	M	Diploma: Civil or mechanical engineering or engineering technology				×			
89	–	Refuelling technician	M	*Diploma: Petroleum engineering*			×			×	
90	–	Electrolyser technician	M	Certificate or diploma: Electrical or chemical engineering	×						
91	–	Electrochemical technician	M	Diploma: Electrochemical or chemical engineering	×	×	×			×	×
92	–	Safety technician	M	Diploma: Chemical or process engineering	×	×	×	×	×	×	×
93	–	Operation technician	M	Certificate or diploma: Electrical, mechanical, or industrial engineering	×	×	×	×	×	×	×
94	–	System integration technician	M	*Diploma: System engineering*	×	×	×	×	×	×	×
95	–	Assembly technician	M	Certificate or diploma: Chemical, mechanical, mechatronics, or electrical engineering	×	×	×			×	×

LEGEND
Existing skills
Unsure of existence
Non-existing skills

					Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel and iron production, and chemical production)
No.	OFO	Core occupation	Skill level	Qualification							
		SPECIALISTS									
96	–	Renewable interconnect specialist	H	Bachelor's degree: Electrical engineering	×						
97	–	Automation and control specialist	H	Diploma or bachelor's degree: Instrument technician or *automation, instrumentation, and controls*, or electrical engineering		×	×		×		
98	–	Compression specialist	H	Diploma or bachelor's degree: *Aerospace*, chemical, or mechanical engineering		×			×		
99	–	Corrosion specialist	H	Diploma or bachelor's degree: *Aerospace*, chemical, or mechanical engineering			×				
100	–	Measurement specialist	H	Diploma or bachelor's degree: Chemical, *electrical and instrumentation,* mechanical, or *petroleum engineering*	×	×	×				
101	–	Pipeline integrity specialist	H	Bachelor's degree: Chemical, materials, metallurgical, or mechanical engineering			×				

LEGEND
Existing skills
Unsure of existence
Non-existing skills

No.	OFO	Core occupation	Skill level	Qualification	Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel and iron production, and chemical production)
		SPECIALISTS									
102	–	Tank tester or inspector	H	Certificate, diploma, or degree: Mechanical engineering certification (Southern African Institute of Welding)			×				
103	–	Transportation solutions advisor	H	Bachelor's degree: Chemical or mechanical engineering						×	
104	–	Hydrogen integration specialist	H	Bachelor's degree: Chemical, electrical, or mechanical engineering				×	×		
105	–	Utility inspector	H	Diploma or bachelor's degree: Civil or mechanical engineering or engineering technology				×			
106	–	Economic modelling specialist	H	Bachelor's degree: Economics, econometrics engineering, or sciences	×	×	×	×	×	×	×
107	–	Finance specialist	H	Bachelor's degree: Finance, economics, mathematics, statistics, or related field	×	×	×	×	×	×	×
108	–	Communications and marketing specialist	H	Bachelor's degree: Public relations, communications, marketing, or related field	×	×	×	×	×	×	×
109	–	Safety and hazards specialist	H	Bachelor's degree: Occupational health and safety or related technical field	×	×	×	×	×	×	×

LEGEND
Existing skills
Unsure of existence
Non-existing skills

					Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel and iron production, and chemical production)
No.	OFO	Core occupation	Skill level	Qualification							
		SPECIALISTS									
110	–	Business developer	H	Bachelor's degree: Business and management or related field	×	×	×	×	×	×	×
111	–	Supply chain specialist	H	Bachelor's degree: Supply chain management, business, economics, or related field	×	×	×	×	×	×	×
112	–	Power-to-X technology specialist	H	Master's degree: Process, industrial, or chemical engineering or related field		×	×				×
113	–	Hydrogen value chain expert	H	Bachelor's, master's, or PhD degree: Engineering, science, business, or related field	×	×	×	×	×	×	×
114	–	Public relations specialist	H	Bachelor's degree: Public relations, communications, social science, business, or related field	×	×	×	×	×	×	×
115	–	Administration specialist	M	Bachelor's degree: Business administration or related field	×	×	×	×	×	×	×
116	–	IT specialist	H	Bachelor's degree: Information technology, computer science, or related field	×	×	×	×	×	×	×
117	–	Sustainability specialist	H	Bachelor's degree: Business or environmental science and experience	×		×			×	

LEGEND
Existing skills
Unsure of existence
Non-existing skills

No.	OFO	Core occupation	Skill level	Qualification	Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel and iron production, and chemical production)
		SPECIALISTS									
118	–	Innovation specialist	H	Bachelor's degree: Business, marketing, or related field	×	×	×	×	×	×	×
119	–	Energy storage specialist	H	Bachelor's degree: Electrical engineering, power systems, renewable energy, and/or sustainable energy technology		×					
120	–	Energy transition specialist	H	Bachelor's or master's degree: Engineering, environmental science, economics, or public policy	×			×	×	×	×
121	–	Operation optimisation specialist	H	Bachelor's degree: Business management, project management, or related field	×	×	×	×	×	×	×
122	–	Technology commercialisation specialist	H	Bachelor's or master's degree: Engineering, business development, or related field	×	×	×	×	×	×	×
123	–	Grid operation specialist	H	Bachelor's or master's degree: Electrical engineering professional engineer registration	×				×		

LEGEND
Existing skills
Unsure of existence
Non-existing skills

					Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel and iron production, and chemical production)
No.	**OFO**	**Core occupation**	**Skill level**	**Qualification**							
		SPECIALISTS									
124	–	Balance of plant (BOP) specialist	H	Bachelor's degree: Electrical engineering	×				×		
125	–	Land acquisition specialist	H	Bachelor's degree: Business, real estate, or related field	×	×	×				
126	–	Nanotechnology specialist	H	*Bachelor's degree: Nanotechnology,* engineering technology, materials science, biotechnology, chemistry, biology, or related field	×	×	×				×
127	–	Marine engines expert	H	Bachelor's degree: Marine engineering		×	×				
128	–	Artificial intelligence specialist	H	Bachelor's or master's degree: *Artificial intelligence,* mathematics, *data science,* statistics, or computer science	×	×	×	×	×	×	×
129	–	Cybersecurity specialist	H	Bachelor's degree: Computer science, information technology, engineering, or related field	×	×	×		×	×	×
130	–	Drilling and completions supervisor	H	Several years of completion and drilling experience		×					

LEGEND
Existing skills
Unsure of existence
Non-existing skills

No.	OFO	Core occupation	Skill level	Qualification	Value chain segments						
								End-uses			
					Production	Storage	Distribution and transportation	Heating	Power generation	Transport	Industrial processing (oil refineries, steel and iron production, and chemical production)
		MANAGEMENT									
131	–	Pipeline scheduler	H	Post-secondary training in business, commerce, or related field			×				
132	–	Asset performance manager	H	Bachelor's degree: Mechanical engineering				×			
133	–	Utility services planner	H	Diploma or bachelor's degree: Civil, mechanical engineering, or engineering technology				×			
134	–	Power scheduler	H	Bachelor's degree: Commerce, economics, or engineering					×		
135	–	Operations manager	H	Bachelor's degree: Business, operations management, or related field	×			×	×	×	×
136	–	Investment manager	H	Bachelor's degree or professional certification: Business, statistics, economics, finance, mathematics, or accounting	×	×	×	×	×	×	×
		ELEMENTARY									
137	–	Land clearer	L	Experience in land clearing	×						×
138	–	Assembling labourer	L	Certificate: Manufacturing and assembling-related experience	×	×					

Sources: CSIR (2023); BP and Aberdeen City Council (2022); France Hydrogene (2022); Hufnagel-Smith (2022a, 2022b); Hydrogen Europe Research et al. (2023a); PwC (2022); Queensland Government (2022)

According to the National List of Occupations in High Demand (see figure 13), some of the occupations identified in tables 4 and 5 are already in high demand in South Africa, although not for the hydrogen economy—given its nascency. These occupations include engineers, technicians, geologists, and managers. Tables 6–10 provide a matrix that identifies the skills and knowledge around which upskilling or reskilling can be focused on to ensure individuals currently employed in these occupations, in non-hydrogen-related sectors, are able to participate in the hydrogen economy.

FIGURE 13: Occupations in high demand that would require reskilling or upskilling for the hydrogen economy

- Project manager
- Software developers
- Electrical engineer
- Mechanical engineer (mechatronics, fuel cell)
- Energy engineer
- Civil engineer (hydraulic)
- Industrial engineer (process, safety, chemical)
- Metallurgical engineer (welding)
- Environmental engineer
- Electronics engineer
- Supply and distribution manager
- Electrician
- Fitter and turner
- Economist
- Electronic engineering technician
- Sales and marketing manager
- Geologist

6.2.2 Capabilities required for the green hydrogen economy

Tables 6–10 detail the capabilities for each occupation identified in part 6.2.1 above. These capabilities were adapted from Hufnagel-Smith (2022b) and Hydrogen Europe Research et al. (2023b). However, not all the occupations identified were extracted from these sources; therefore, the Council for Scientific and Industrial Research (CSIR) conducted an analysis for the remaining occupations that were identified from the reports mentioned in part 6.4.5.

Across the five occupational categories, the most required hydrogen capabilities (core and cross-cutting) include:

1. Knowledge of hydrogen properties, behaviour, and potential hazards created
2. Safety when working with or around hydrogen
3. Knowledge of hydrogen-related regulations, standards, and codes
4. Understanding electrochemical reactions, processes, and hydrogen production processes (see tables 6–10)

For engineers, tradespersons, and technicians in particular, the most required hydrogen capabilities include (see tables 6–7):

1. Understanding the properties and characteristics of hydrogen in a liquid and gaseous state
2. Understanding hydrogen compression processes
3. Evaluating performance and production quality, as well as diagnosing and addressing production and process issues relating to hydrogen

Occupational specialists highly require hydrogen capabilities such as (see table 8):

1. Knowledge of hydrogen gas value chains
2. Insights into hydrogen production, economies, risks, technology, renewables, and scaling
3. Knowledge of hydrogen production, distribution, and dispensing technology to meet the needs of different fleets

Over and above the fundamental capabilities like:

1. Knowledge of hydrogen fuel cell technology, how it works, and value proposition relating to emissions targets and cost-effectiveness
2. Knowledge of hydrogen production, distribution, and dispensing technology to meet the needs of different fleets

Management occupations also require knowledge of hydrogen value chains in the manner that specialists would (see table 9).

TABLE 6: Hydrogen capabilities for engineers

HYDROGEN CAPABILITIES	Chemical engineer	Civil engineer	Commissioning engineer	Electrical engineer	Instrumentation engineer	Environmental engineer	Robotics and automation engineer	Facility engineer	Gas engineer	Grid connection engineer	Industrial engineer	Mechatronics engineer	Mechanical engineer	Process engineer	Process control engineer	Safety engineer	Production engineer	Cavern engineer	Drilling engineer	Pipeline engineer	Research and development engineer	Software engineer	Locomotive (train) engineer	Welding engineer	Materials engineer	Systems engineer	Renewable energy engineer	Refuelling station engineer	Electrolysis engineer	Electrochemical engineer	Fuel cell engineer	Marine engineer	Hydraulic engineer	Design engineer	Quality engineer
HYDROGEN PRODUCTION																																			
Understanding hydrogen production processes and electrochemical processes and reactions	×		×				×	×	×	×	×		×	×	×	×	×				×				×		×		×	×	×			×	×
Knowledge of key electrical equipment used to produce hydrogen				×																	×			×					×		×				
Knowledge of key instrumentation and electrical equipment and systems used to produce hydrogen				×	×																×			×		×			×		×				
Knowledge of electrolyser hydrogen production plant control systems and advanced control systems for process optimisation	×										×				×						×			×		×			×						
Optimising rectification arrangement for electrolyser plants				×																	×								×						×
Appropriate selection, design, and maintenance of related production equipment, materials, coatings, and similar			×				×	×	×		×										×			×	×				×					×	×
Appropriate selection, design, and maintenance of electrolysers, vessels, piping systems and fitting, valves, and seals to withstand hydrogen pressure (high/low) and temperatures (hot/cold)			×				×		×				×								×	×		×	×	×			×				×	×	×

HYDROGEN CAPABILITIES	Chemical engineer	Civil engineer	Commissioning engineer	Electrical engineer	Instrumentation engineer	Environmental engineer	Robotics and automation engineer	Facility engineer	Gas engineer	Grid connection engineer	Industrial engineer	Mechatronics engineer	Mechanical engineer	Process engineer	Process control engineer	Safety engineer	Production engineer	Cavern engineer	Drilling engineer	Pipeline engineer	Research and development engineer	Software engineer	Locomotive (train) engineer	Welding engineer	Materials engineer	Systems engineer	Renewable energy engineer	Refuelling station engineer	Electrolysis engineer	Electrochemical engineer	Fuel cell engineer	Marine engineer	Hydraulic engineer	Design engineer	Quality engineer
HYDROGEN PRODUCTION																																			
Appropriate selection, design, and maintenance of combustion, compression, pumping and turbine systems, and equipment to withstand hydrogen pressure (high/low) and temperatures (hot/cold)			×				×		×				×								×					×							×	×	×
Process engineering and control skills specific to hydrogen including hazard risk analysis and reviews, mechanical integrity and instrumented system analysis, and operation readiness inspection																×										×									
Evaluating performance and production quality, diagnosing and addressing production and process issues relating to hydrogen	×		×								×	×		×	×		×				×						×		×		×			×	×
Knowledge of automated process systems and control systems associated with electrolysers							×																						×						
HYDROGEN STORAGE																																			
Understanding of cavern engineering fundamentals for hydrogen injection and well testing, pressure and rate transient analysis, and fluid characterisation																		×																	×

HYDROGEN CAPABILITIES	Chemical engineer	Civil engineer	Commissioning engineer	Electrical engineer	Instrumentation engineer	Environmental engineer	Robotics and automation engineer	Facility engineer	Gas engineer	Grid connection engineer	Industrial engineer	Mechatronics engineer	Mechanical engineer	Process engineer	Process control engineer	Safety engineer	Production engineer	Cavern engineer	Drilling engineer	Pipeline engineer	Research and development engineer	Software engineer	Locomotive (train) engineer	Welding engineer	Materials engineer	Systems engineer	Renewable energy engineer	Refuelling station engineer	Electrolysis engineer	Electrochemical engineer	Fuel cell engineer	Marine engineer	Hydraulic engineer	Design engineer	Quality engineer
HYDROGEN STORAGE																																			
Well design and material choices based on an understanding of the regulatory environment, hydrogen injection stream properties, changes in hydrogen pressure over time, and potential corrosive elements							×		×										×		×														
Pressure, voltage, and temperature characterisation and thermal/flow modelling, specific to sequestered gas and/or liquid composition																		×																	
Migration modelling zone selection and storage design							×		×									×			×	×													×
Modelling hydrogen-water-minerals interactions																		×																	
HYDROGEN DISTRIBUTION AND TRANSPORTATION (FOR EXAMPLE, PIPELINE AND TRUCKS)																																			
Knowledge of key instrumentation, electrical equipment, and systems associated with hydrogen pipeline transmission, including compression				×	×																					×									
Understanding materials behaviour in high-pressure hydrogen		×																		×					×										

HYDROGEN CAPABILITIES	Chemical engineer	Civil engineer	Commissioning engineer	Electrical engineer	Instrumentation engineer	Environmental engineer	Robotics and automation engineer	Facility engineer	Gas engineer	Grid connection engineer	Industrial engineer	Mechatronics engineer	Mechanical engineer	Process engineer	Process control engineer	Safety engineer	Production engineer	Cavern engineer	Drilling engineer	Pipeline engineer	Research and development engineer	Software engineer	Locomotive (train) engineer	Welding engineer	Materials engineer	Systems engineer	Renewable energy engineer	Refuelling station engineer	Electrolysis engineer	Electrochemical engineer	Fuel cell engineer	Marine engineer	Hydraulic engineer	Design engineer	Quality engineer
HYDROGEN DISTRIBUTION AND TRANSPORTATION (FOR EXAMPLE, PIPELINE AND TRUCKS)																																			
Knowledge and selection of materials, coatings, and inhibitors to protect from hydrogen corrosion and embrittlement		×																		×					×										
Knowledge of fuel cell technology, and the ability to inspect vehicles and conduct basic maintenance			×																				×		×						×				
Appropriate selection and design of vessels, compressors, piping systems and fitting, valves, and seals to withstand high hydrogen pressure							×		×											×	×					×							×	×	
Process engineering and controls skills specific to hydrogen including hazard risk analysis and reviews, mechanical integrity and instrumented system analysis, and operation readiness inspection												×	×			×										×									
Understanding hydrogen compression processes	×		×				×				×		×	×	×		×				×						×			×	×				

HYDROGEN CAPABILITIES	Chemical engineer	Civil engineer	Commissioning engineer	Electrical engineer	Instrumentation engineer	Environmental engineer	Robotics and automation engineer	Facility engineer	Gas engineer	Grid connection engineer	Industrial engineer	Mechatronics engineer	Mechanical engineer	Process engineer	Process control engineer	Safety engineer	Production engineer	Cavern engineer	Drilling engineer	Pipeline engineer	Research and development engineer	Software engineer	Locomotive (train) engineer	Welding engineer	Materials engineer	Systems engineer	Renewable energy engineer	Refuelling station engineer	Electrolysis engineer	Electrochemical engineer	Fuel cell engineer	Marine engineer	Hydraulic engineer	Design engineer	Quality engineer
HYDROGEN END-USE APPLICATION (FOR EXAMPLE, HEATING, FUELLING STATIONS, AND POWER GENERATION)																																			
Hydrogen heating application																																			
Knowledge of material rules and welding processes and procedures compatible with hydrogen and hydrogen blending properties																							×	×									×		
Hydrogen fuelling station																																			
Knowledge of electrical equipment and instrumentation systems required for hydrogen fuelling systems				×	×																					×		×							
Understanding hydrogen compression processes	×		×				×				×		×	×	×		×				×						×	×			×				
Understanding cryogenic and gaseous hydrogen storage and delivery systems														×	×											×		×		×					
Design and selection of compression systems for hydrogen pressure and temperatures associated with hydrogen fuelling systems							×		×				×								×	×				×		×						×	
Design and selection of pressure vessels, piping systems and fitting, valves and seals, coatings, and insulation to withstand hydrogen pressure and temperatures associated with hydrogen fuelling systems							×		×				×								×	×				×		×						×	

HYDROGEN CAPABILITIES	Chemical engineer	Civil engineer	Commissioning engineer	Electrical engineer	Instrumentation engineer	Environmental engineer	Robotics and automation engineer	Facility engineer	Gas engineer	Grid connection engineer	Industrial engineer	Mechatronics engineer	Mechanical engineer	Process engineer	Process control engineer	Safety engineer	Production engineer	Cavern engineer	Drilling engineer	Pipeline engineer	Research and development engineer	Software engineer	Locomotive (train) engineer	Welding engineer	Materials engineer	Systems engineer	Renewable energy engineer	Refuelling station engineer	Electrolysis engineer	Electrochemical engineer	Fuel cell engineer	Marine engineer	Hydraulic engineer	Design engineer	Quality engineer
Hydrogen fuelling station																																			
Appropriate selection and maintenance of pressure vessels, piping systems and fitting, valves and seals, coatings, and insulation associated with hydrogen fuelling systems			×										×													×		×					×		
Process engineering and control skills specific to hydrogen including hazard risk analysis and reviews, mechanical integrity and instrumented system analysis, and operation readiness inspection			×													×										×		×							
Experience and knowledge of hydrogen fuelling equipment, technology, and systems including on-site generation, compression, cooling systems, storage, and dispensing																	×											×							
Knowledge of fuelling standards for third-party certification of hydrogen product lines																	×											×							
Hydrogen power generation																																			
Knowledge of high-power electrical equipment associated with power generation using hydrogen blending				×																										×					

HYDROGEN CAPABILITIES	Chemical engineer	Civil engineer	Commissioning engineer	Electrical engineer	Instrumentation engineer	Environmental engineer	Robotics and automation engineer	Facility engineer	Gas engineer	Grid connection engineer	Industrial engineer	Mechatronics engineer	Mechanical engineer	Process engineer	Process control engineer	Safety engineer	Production engineer	Cavern engineer	Drilling engineer	Pipeline engineer	Research and development engineer	Software engineer	Locomotive (train) engineer	Welding engineer	Materials engineer	Systems engineer	Renewable energy engineer	Refuelling station engineer	Electrolysis engineer	Electrochemical engineer	Fuel cell engineer	Marine engineer	Hydraulic engineer	Design engineer	Quality engineer
Hydrogen power generation																																			
Knowledge of key instrumentation and electrical equipment and systems associated with ventilation, leak detection, flame detection, and corrosion prevention system controls for hydrogen blending				×	×																					×									
Understanding combined-cycle power generation using hydrogen blending				×				×			×		×	×	×															×					
Knowledge of equipment and components including compression, turbines, combustion, and such for hydrogen blending								×			×																								
Appropriate selection of materials, coatings, odorants, inhibitors, and such for hydrogen blending								×																×											
Maintenance of ventilation, leak detection, flame detection, corrosion prevention equipment, and systems for hydrogen blending								×	×							×										×									
Knowledge of control systems and advanced control systems for combined-cycle power generation using hydrogen blending				×					×						×											×									

HYDROGEN CAPABILITIES	Chemical engineer	Civil engineer	Commissioning engineer	Electrical engineer	Instrumentation engineer	Environmental engineer	Robotics and automation engineer	Facility engineer	Gas engineer	Grid connection engineer	Industrial engineer	Mechatronics engineer	Mechanical engineer	Process engineer	Process control engineer	Safety engineer	Production engineer	Cavern engineer	Drilling engineer	Pipeline engineer	Research and development engineer	Software engineer	Locomotive (train) engineer	Welding engineer	Materials engineer	Systems engineer	Renewable energy engineer	Refuelling station engineer	Electrolysis engineer	Electrochemical engineer	Fuel cell engineer	Marine engineer	Hydraulic engineer	Design engineer	Quality engineer
Hydrogen power generation																																			
Appropriate selection, design, and maintenance of power generation equipment including compression, turbines and combustion, valves, fittings, piping systems, and such for hydrogen blending				×			×		×				×								×	×				×							×	×	
Process engineering and controls skills specific to hydrogen including hazard risk analysis and reviews, mechanical integrity and instrumented system analysis, and operation readiness inspection			×		×								×	×	×	×										×									
Knowledge of automated process systems and control systems associated with power generation using hydrogen blending							×								×											×									
CROSS-CUTTING CAPABILITIES ACROSS THE HYDROGEN VALUE CHAIN																																			
Hydrogen properties, behaviour, and potential hazards created	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×	×	×	×	×	×	×	×	×	×	×	×	×
Understanding properties and characteristics of hydrogen in a liquid and gaseous state	×		×	×	×		×	×	×	×		×		×	×	×	×	×	×	×	×		×	×	×	×	×	×	×	×	×	×	×	×	×
Safety when working with or around hydrogen	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Knowledge of hydrogen-related regulations, standards, and codes						×	×	×	×	×	×	×	×	×	×	×					×		×	×				×	×	×	×	×	×	×	×

Sources: Hufnagel-Smith (2022b); Hydrogen Europe Research et al. (2023b); CSIR (2023)

TABLE 7: Hydrogen capabilities for technicians and tradespersons

HYDROGEN CAPABILITIES	Commissioning technician	Chemical process technician	Chemical laboratory technician	Mechanical technician	Maintenance technician	Test technician	Cylinder technician	Fuel cell electric vehicle (FCEV) technician	Fuel cell technician	HVAC technician	Electrolyser technician	Refuelling technician	Utility service technician	Instrumentation technician	Mechatronics technician	Materials technician	Marine technician	Electrochemical technician	Safety technician	System integration technician	Operation technician	Renewable energy technologist	Welder	Assembly technician	Manufacturing production technician	Pipeline technician: Electrical and instrumentation, mechanical	Locomotive electrician	Electrician	Drilling crew	Reservoir technologist	Compression station operator	Control room operator	Well completions operator	Plant operator	Utility operator	Heavy-duty mechanic (dual fuel)	Truck driver	Gas fitter	Fitter and turner
HYDROGEN PRODUCTION																																							
Understanding electrochemical reactions, processes, and hydrogen production processes		×	×															×				×			×							×		×					
Appropriate selection and maintenance of key electrical and electronic equipment and systems associated with an electrolyser hydrogen production plant	×	×			×						×																	×											×
Appropriate selection and maintenance of key instrumentation equipment and systems associated with an electrolyser hydrogen production plant	×	×		×	×						×			×																									
Knowledge of appropriate materials, seals, and coatings	×	×		×	×											×																							
Maintenance of vessels, compressors, piping systems and fitting, valves, and such to withstand hydrogen pressure and temperatures	×											×																											

HYDROGEN CAPABILITIES	Commissioning technician	Chemical process technician	Chemical laboratory technician	Mechanical technician	Maintenance technician	Test technician	Cylinder technician	Fuel cell electric vehicle (FCEV) technician	Fuel cell technician	HVAC technician	Electrolyser technician	Refuelling technician	Utility service technician	Instrumentation technician	Mechatronics technician	Materials technician	Marine technician	Electrochemical technician	Safety technician	System integration technician	Operation technician	Renewable energy technologist	Welder	Assembly technician	Manufacturing production technician	Pipeline technician: Electrical and instrumentation, mechanical	Locomotive electrician	Electrician	Drilling crew	Reservoir technologist	Compression station operator	Control room operator	Well completions operator	Plant operator	Utility operator	Heavy-duty mechanic (dual fuel)	Truck driver	Gas fitter	Fitter and turner
HYDROGEN STORAGE																																							
Understanding the properties and characteristics of hydrogen in a liquid and gaseous state		×	×								×	×						×	×			×	×		×					×		×	×						
Operating the machine and equipment used to drill hydrogen injection wells and monitoring wells in deep isolated rock formations																					×								×										
Understanding reservoir data as it relates to hydrogen injection and storage																														×									
Understanding appropriate well-completion solutions for hydrogen																																	×						
Appropriate selection and maintenance of electrical equipment and instrumentation systems required for hydrogen	×				×									×																									×
Maintenance of mechanical equipment to withstand hydrogen pressure and temperatures	×			×	×																																		
Knowledge of appropriate materials, seals, and coatings				×	×											×																							

HYDROGEN CAPABILITIES	Commissioning technician	Chemical process technician	Chemical laboratory technician	Mechanical technician	Maintenance technician	Test technician	Cylinder technician	Fuel cell electric vehicle (FCEV) technician	Fuel cell technician	HVAC technician	Electrolyser technician	Refuelling technician	Utility service technician	Instrumentation technician	Mechatronics technician	Materials technician	Marine technician	Electrochemical technician	Safety technician	System integration technician	Operation technician	Renewable energy technologist	Welder	Assembly technician	Manufacturing production technician	Pipeline technician: Electrical and instrumentation, mechanical	Locomotive electrician	Electrician	Drilling crew	Reservoir technologist	Compression station operator	Control room operator	Well completions operator	Plant operator	Utility operator	Heavy-duty mechanic (dual fuel)	Truck driver	Gas fitter	Fitter and turner
HYDROGEN DISTRIBUTION AND TRANSPORTATION (FOR EXAMPLE, PIPELINE AND TRUCKS)																																							
Appropriate selection and maintenance of compression and turbine systems and equipment to withstand hydrogen pressure	×	×																		×			×	×							×								
Appropriate selection and maintenance of electrical equipment and instrumentation systems required for pipeline transmission of gaseous hydrogen	×																			×						×													×
Appropriate selection and maintenance of stationary and rotating equipment and systems required for pipeline transmission of gaseous hydrogen	×			×	×										×											×													
Understanding hydrogen compression processes	×	×					×											×				×			×						×								
Appropriate selection and maintenance of materials and equipment to withstand hydrogen pressure and temperatures	×						×									×																							

HYDROGEN CAPABILITIES	Commissioning technician	Chemical process technician	Chemical laboratory technician	Mechanical technician	Maintenance technician	Test technician	Cylinder technician	Fuel cell electric vehicle (FCEV) technician	Fuel cell technician	HVAC technician	Electrolyser technician	Refuelling technician	Utility service technician	Instrumentation technician	Mechatronics technician	Materials technician	Marine technician	Electrochemical technician	Safety technician	System integration technician	Operation technician	Renewable energy technologist	Welder	Assembly technician	Manufacturing production technician	Pipeline technician: Electrical and instrumentation, mechanical	Locomotive electrician	Electrician	Drilling crew	Reservoir technologist	Compression station operator	Control room operator	Well completions operator	Plant operator	Utility operator	Heavy-duty mechanic (dual fuel)	Truck driver	Gas fitter	Fitter and turner
HYDROGEN DISTRIBUTION AND TRANSPORTATION (FOR EXAMPLE, PIPELINE AND TRUCKS)																																							
Appropriate selection, design, and maintenance of hydrogen fuel tanks, piping systems and fitting, valves, and seals to withstand hydrogen pressure (high/low) and temperatures (hot/cold)	×	×						×	×							×				×							×									×			
Knowledge of fuel cell technology	×	×		×	×			×	×		×					×		×				×		×	×			×									×		
Knowledge of fuel cell technology and hydro-electric power trains	×	×		×	×			×	×		×					×		×				×		×	×		×	×											
HYDROGEN END-USE APPLICATION (FOR EXAMPLE, HEATING, FUELLING STATIONS, AND POWER GENERATION)																																							
Hydrogen heating application																																							
Understanding aspects of installation and testing procedures that are different due to the nature of hydrogen										×			×																									×	
Knowledge of the materials, equipment, and components to use to withstand hydrogen pressure and temperatures										×						×																						×	
Welding procedures and techniques appropriate for hydrogen										×												×																×	

HYDROGEN CAPABILITIES	Commissioning technician	Chemical process technician	Chemical laboratory technician	Mechanical technician	Maintenance technician	Test technician	Cylinder technician	Fuel cell electric vehicle (FCEV) technician	Fuel cell technician	HVAC technician	Electrolyser technician	Refuelling technician	Utility service technician	Instrumentation technician	Mechatronics technician	Materials technician	Marine technician	Electrochemical technician	Safety technician	System integration technician	Operation technician	Renewable energy technologist	Welder	Assembly technician	Manufacturing production technician	Pipeline technician: Electrical and instrumentation, mechanical	Locomotive electrician	Electrician	Drilling crew	Reservoir technologist	Compression station operator	Control room operator	Well completions operator	Plant operator	Utility operator	Heavy-duty mechanic (dual fuel)	Truck driver	Gas fitter	Fitter and turner
Hydrogen heating application																																							
Knowledge of the practices, technologies, equipment, and systems to control hydrogen corrosion or embrittlement										×					×					×																		×	×
Understanding procedures to trace, locate, and repair hydrogen leaks										×			×						×																×			×	
Knowledge of odorants used to assist with leak detection of hydrogen													×						×																×				
Understanding the materials, coatings, and inhibitors to use and correct application to protect from hydrogen corrosion													×			×																							
Hydrogen fuelling station																																							
Knowledge of appropriate maintenance of hydrogen fuelling systems including pressure vessels, vaporizers, flow, level and pressure control instrumentation, dispensers, pumps, programmable logic controllers (PLC), compressors, human–machine interface, and control software	×				×							×			×					×																			

HYDROGEN CAPABILITIES	Commissioning technician	Chemical process technician	Chemical laboratory technician	Mechanical technician	Maintenance technician	Test technician	Cylinder technician	Fuel cell electric vehicle (FCEV) technician	Fuel cell technician	HVAC technician	Electrolyser technician	Refuelling technician	Utility service technician	Instrumentation technician	Mechatronics technician	Materials technician	Marine technician	Electrochemical technician	Safety technician	System integration technician	Operation technician	Renewable energy technologist	Welder	Assembly technician	Manufacturing production technician	Pipeline technician: Electrical and instrumentation, mechanical	Locomotive electrician	Electrician	Drilling crew	Reservoir technologist	Compression station operator	Control room operator	Well completions operator	Plant operator	Utility operator	Heavy-duty mechanic (dual fuel)	Truck driver	Gas fitter	Fitter and turner
Hydrogen fuelling station																																							
Appropriate selection and maintenance of pressure vessels, compression systems and related instrumentation, and controls equipment and systems associated with hydrogen fuelling system	×	×			×							×																			×								
Troubleshooting and routine maintenance of hydrogen fuel compression and dispensing equipment	×	×				×						×																			×								
Hydrogen power generation																																							
Understanding combined cycle power generation using hydrogen blending																		×							×			×				×							
Appropriate selection and maintenance of key electrical and electronic equipment and systems associated with power generation using hydrogen blending	×				×															×				×				×											
Selection, calibration, and maintenance of key instrumentation equipment and systems associated with power generation using hydrogen blending	×				×									×																									

HYDROGEN CAPABILITIES	Commissioning technician	Chemical process technician	Chemical laboratory technician	Mechanical technician	Maintenance technician	Test technician	Cylinder technician	Fuel cell electric vehicle (FCEV) technician	Fuel cell technician	HVAC technician	Electrolyser technician	Refuelling technician	Utility service technician	Instrumentation technician	Mechatronics technician	Materials technician	Marine technician	Electrochemical technician	Safety technician	System integration technician	Operation technician	Renewable energy technologist	Welder	Assembly technician	Manufacturing production technician	Pipeline technician: Electrical and instrumentation, mechanical	Locomotive electrician	Electrician	Drilling crew	Reservoir technologist	Compression station operator	Control room operator	Well completions operator	Plant operator	Utility operator	Heavy-duty mechanic (dual fuel)	Truck driver	Gas fitter	Fitter and turner
Hydrogen power generation																																							
Maintenance of vessels, compressors, turbines, piping systems and fitting, valves, and such to withstand hydrogen pressure and temperatures	×			×	×																																		
Knowledge of appropriate materials, seals, and coatings to use with hydrogen blending				×	×											×																							
CROSS-CUTTING CAPABILITIES ACROSS THE HYDROGEN VALUE CHAIN																																							
Hydrogen properties, behaviour, and potential hazards created	×	×	×	×	×	×	×	×	×	×		×		×	×	×	×	×	×		×	×			×	×	×	×		×		×	×	×	×	×	×	×	×
Safety when working with or around hydrogen	×	×	×	×	×	×	×	×	×	×		×		×	×		×		×			×			×	×	×	×		×		×	×	×	×	×	×	×	×
Knowledge of hydrogen-related regulations, standards, and codes		×	×		×					×		×	×				×		×		×					×							×		×	×			×
Operating, monitoring, maintaining, and testing hydrogen-related equipment	×				×	×										×					×	×			×														

Sources: Hufnagel-Smith (2022b); Hydrogen Europe Research et al. (2023b); CSIR (2023)

TABLE 8: Hydrogen capabilities for specialists

HYDROGEN CAPABILITIES	Renewable interconnect specialist	Automation and control specialist	Geoscience professional: Geologist, geophysicist, geotechnical specialist	Compression specialist	Corrosion specialist	Measurement specialist	Pipeline integrity specialist	Tank tester or inspector	Transportation solutions advisor	Hydrogen integration specialist	Utility inspector	Economic modelling specialist	Economist	Finance specialist	Communications and marketing specialist	Lawyer	Safety and hazards specialist	Business developer	Supply chain specialist	Power-to-X technology specialist	Hydrogen value chain expert	Public relations specialist	Administration specialist	IT specialist	Sustainability specialist	Innovation specialist	Energy storage specialist	Energy transition specialist	Operation optimisation specialist	Technology commercialisation specialist	Grid operation specialist	BOP specialist	Land acquisition specialist	Nanotechnology specialist	Marine engines expert	Artificial intelligence specialist	Cybersecurity specialist	Political scientist
Hydrogen production																																						
Knowledge of automated process systems and control systems associated with electrolysers		×																								×						×				×	×	
Understanding electrochemical reactions, processes, and hydrogen production						×																				×												
Maintenance of equipment and systems involved in hydrogen production																																						
Understanding hydrogen production process												×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×		×	×	×
Appropriate selection, design, and maintenance of electrolysers, vessels, compressors, piping systems and fitting, valves, and seals to withstand hydrogen pressure and temperatures																		×	×	×	×											×						
Appropriate selection, design, and maintenance of combustion, compression, pumping and turbine systems, and equipment to withstand hydrogen pressure and temperatures																		×	×	×	×											×						
Knowledge of hydrogen gas value chains					×	×						×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×		×		×	×	×

HYDROGEN CAPABILITIES	Renewable interconnect specialist	Automation and control specialist	Geoscience professional: Geologist, geophysicist, geotechnical specialist	Compression specialist	Corrosion specialist	Measurement specialist	Pipeline integrity specialist	Tank tester or inspector	Transportation solutions advisor	Hydrogen integration specialist	Utility inspector	Economic modelling specialist	Economist	Finance specialist	Communications and marketing specialist	Lawyer	Safety and hazards specialist	Business developer	Supply chain specialist	Power-to-X technology specialist	Hydrogen value chain expert	Public relations specialist	Administration specialist	IT specialist	Sustainability specialist	Innovation specialist	Energy storage specialist	Energy transition specialist	Operation optimisation specialist	Technology commercialisation specialist	Grid operation specialist	BOP specialist	Land acquisition specialist	Nanotechnology specialist	Marine engines expert	Artificial intelligence specialist	Cybersecurity specialist	Political scientist
Hydrogen production																																						
Knowledge of key high power electrical equipment and interconnection applications associated with renewable electricity–powered electrolyser produced hydrogen	×																									×					×	×						
Insights on hydrogen production, economies, risks, technology, renewables, and scaling												×	×	×				×	×		×				×			×	×	×			×	×		×	×	×
HYDROGEN STORAGE																																						
Understanding appropriate well completion solutions for hydrogen																																						
Understanding properties and characteristics of hydrogen in a gaseous state			×																								×											
Appropriate selection, design, and maintenance of hydrogen compression, turbine systems, and equipment				×																																		
Understanding measurement equipment and instrumentation associated with hydrogen transmission						×																																

HYDROGEN CAPABILITIES	Renewable interconnect specialist	Automation and control specialist	Geoscience professional: Geologist, geophysicist, geotechnical specialist	Compression specialist	Corrosion specialist	Measurement specialist	Pipeline integrity specialist	Tank tester or inspector	Transportation solutions advisor	Hydrogen integration specialist	Utility inspector	Economic modelling specialist	Economist
HYDROGEN STORAGE													
Understanding hydrogen compression processes				×									
HYDROGEN DISTRIBUTION AND TRANSPORTATION													
Knowledge of hydrogen value chains						×						×	×
Appropriate selection, design, and maintenance of hydrogen compression, turbine systems, and equipment				×									
Understanding hydrogen compression processes		×						×					
Knowledge and selection of the type of materials, coatings, and inhibitors to use to protect from hydrogen corrosion and embrittlement					×		×						
Understanding materials behaviour in high pressure hydrogen							×						
Understanding measurement equipment and instrumentation associated with hydrogen transmission						×							

HYDROGEN CAPABILITIES	Finance specialist	Communications and marketing specialist	Lawyer	Safety and hazards specialist	Business developer	Supply chain specialist	Power-to-X technology specialist	Hydrogen value chain expert	Public relations specialist	Administration specialist	IT specialist	Sustainability specialist	Innovation specialist
HYDROGEN STORAGE													
Understanding hydrogen compression processes													
HYDROGEN DISTRIBUTION AND TRANSPORTATION													
Knowledge of hydrogen value chains	×	×	×	×	×	×	×	×	×			×	×
Appropriate selection, design, and maintenance of hydrogen compression, turbine systems, and equipment													×
Understanding hydrogen compression processes													
Knowledge and selection of the type of materials, coatings, and inhibitors to use to protect from hydrogen corrosion and embrittlement													
Understanding materials behaviour in high pressure hydrogen													
Understanding measurement equipment and instrumentation associated with hydrogen transmission													

HYDROGEN CAPABILITIES	Energy storage specialist	Energy transition specialist	Operation optimisation specialist	Technology commercialisation specialist	Grid operation specialist	BOP specialist	Land acquisition specialist	Nanotechnology specialist	Marine engines expert	Artificial intelligence specialist	Cybersecurity specialist	Political scientist
HYDROGEN STORAGE												
Understanding hydrogen compression processes												
HYDROGEN DISTRIBUTION AND TRANSPORTATION												
Knowledge of hydrogen value chains		×	×	×				×	×			
Appropriate selection, design, and maintenance of hydrogen compression, turbine systems, and equipment												
Understanding hydrogen compression processes												
Knowledge and selection of the type of materials, coatings, and inhibitors to use to protect from hydrogen corrosion and embrittlement								×				
Understanding materials behaviour in high pressure hydrogen								×				
Understanding measurement equipment and instrumentation associated with hydrogen transmission									×			

HYDROGEN CAPABILITIES	Renewable interconnect specialist	Automation and control specialist	Geoscience professional: Geologist, geophysicist, geotechnical specialist	Compression specialist	Corrosion specialist	Measurement specialist	Pipeline integrity specialist	Tank tester or inspector	Transportation solutions advisor	Hydrogen integration specialist	Utility inspector	Economic modelling specialist	Economist	Finance specialist	Communications and marketing specialist	Lawyer	Safety and hazards specialist	Business developer	Supply chain specialist	Power-to-X technology specialist	Hydrogen value chain expert	Public relations specialist	Administration specialist	IT specialist	Sustainability specialist	Innovation specialist	Energy storage specialist	Energy transition specialist	Operation optimisation specialist	Technology commercialisation specialist	Grid operation specialist	BOP specialist	Land acquisition specialist	Nanotechnology specialist	Marine engines expert	Artificial intelligence specialist	Cybersecurity specialist	Political scientist
HYDROGEN DISTRIBUTION AND TRANSPORTATION																																						
Appropriate selection and design of vessels, compressors, piping systems and fitting, valves, and seals to withstand high hydrogen pressure							×																												×			
Appropriate selection and maintenance of materials and equipment to withstand hydrogen pressure and temperatures								×																														
Knowledge of hydrogen fuel cell technology, how it works, and value proposition relating to emissions targets and cost-effectiveness																										×												
Knowledge of hydrogen production, distribution, and dispensing technology to meet the needs of different fleets																		×	×	×	×					×		×	×									
Understanding relevant hydrogen regulations, codes, and standards					×											×		×	×	×	×					×		×	×									
Knowledge of the practices, technologies, equipment, and systems to control hydrogen corrosion or embrittlement				×																																		
Understanding properties and characteristics of hydrogen in a gaseous state							×																															

HYDROGEN CAPABILITIES	Renewable interconnect specialist	Automation and control specialist	Geoscience professional: Geologist, geophysicist, geotechnical specialist	Compression specialist	Corrosion specialist	Measurement specialist	Pipeline integrity specialist	Tank tester or inspector	Transportation solutions advisor	Hydrogen integration specialist	Utility inspector	Economic modelling specialist	Economist	Finance specialist	Communications and marketing specialist	Lawyer	Safety and hazards specialist	Business developer	Supply chain specialist	Power-to-X technology specialist	Hydrogen value chain expert	Public relations specialist	Administration specialist	IT specialist	Sustainability specialist	Innovation specialist	Energy storage specialist	Energy transition specialist	Operation optimisation specialist	Technology commercialisation specialist	Grid operation specialist	BOP specialist	Land acquisition specialist	Nanotechnology specialist	Marine engines expert	Artificial intelligence specialist	Cybersecurity specialist	Political scientist
HYDROGEN HEATING APPLICATION																																						
Understanding technical factors associated with using hydrogen blending for heating																			×	×	×																	
Knowledge of hydrogen related regulations, standards, and codes										×	×								×	×	×																	
Knowledge of odorants used to assist with leak detection of hydrogen																																						
Understanding procedures to trace, locate, and repair hydrogen leaks																																						
Materials, coatings, and inhibitors to use and correct application to protect from hydrogen corrosion																																						
Practices, technologies, equipment, and systems to control hydrogen corrosion or embrittlement											×																											
Strong industry knowledge and experience with hydrogen technologies, processes and equipment, and components to use to withstand hydrogen pressure and temperatures										×									×	×	×					×			×									
Appropriate selection of materials, coatings, odorants, inhibitors, and such for hydrogen blending										×																								×				

HYDROGEN CAPABILITIES	Renewable interconnect specialist	Automation and control specialist	Geoscience professional: Geologist, geophysicist, geotechnical specialist	Compression specialist	Corrosion specialist	Measurement specialist	Pipeline integrity specialist	Tank tester or inspector	Transportation solutions advisor	Hydrogen integration specialist	Utility inspector	Economic modelling specialist	Economist	Finance specialist	Communications and marketing specialist	Lawyer	Safety and hazards specialist	Business developer	Supply chain specialist	Power-to-X technology specialist	Hydrogen value chain expert	Public relations specialist	Administration specialist	IT specialist	Sustainability specialist	Innovation specialist	Energy storage specialist	Energy transition specialist	Operation optimisation specialist	Technology commercialisation specialist	Grid operation specialist	BOP specialist	Land acquisition specialist	Nanotechnology specialist	Marine engines expert	Artificial intelligence specialist	Cybersecurity specialist	Political scientist
HYDROGEN HEATING APPLICATION																																						
Appropriate selection, design, modification to ventilation, leak detection, flame detection, corrosion prevention equipment, and systems for hydrogen blending										×																												
Comprehensive understanding of aspects of installation and testing procedures that are different due to the nature of hydrogen											×								×	×	×																	
Knowledge of materials, equipment, and components to use to withstand hydrogen pressure and temperatures											×								×	×	×													×				
Welding procedures and techniques appropriate for hydrogen											×																											
Understanding the procedures to trace, locate, and repair hydrogen leaks											×																											
HYDROGEN POWER GENERATION APPLICATION																																						
Strong industry knowledge and experience with hydrogen technologies, processes equipment, and components to withstand hydrogen pressure and temperatures										×									×	×	×																	

HYDROGEN CAPABILITIES	Renewable interconnect specialist	Automation and control specialist	Geoscience professional: Geologist, geophysicist, geotechnical specialist	Compression specialist	Corrosion specialist	Measurement specialist	Pipeline integrity specialist	Tank tester or inspector	Transportation solutions advisor	Hydrogen integration specialist	Utility inspector	Economic modelling specialist	Economist	Finance specialist	Communications and marketing specialist	Lawyer	Safety and hazards specialist	Business developer	Supply chain specialist	Power-to-X technology specialist	Hydrogen value chain expert	Public relations specialist	Administration specialist	IT specialist	Sustainability specialist	Innovation specialist	Energy storage specialist	Energy transition specialist	Operation optimisation specialist	Technology commercialisation specialist	Grid operation specialist	BOP specialist	Land acquisition specialist	Nanotechnology specialist	Marine engines expert	Artificial intelligence specialist	Cybersecurity specialist	Political scientist
HYDROGEN POWER GENERATION APPLICATION																																						
Appropriate selection of materials, coatings, odorants, inhibitors, and such for hydrogen blending									×																													
Appropriate selection, design, and maintenance of power generation equipment including compression, turbines, combustion, and such for hydrogen blending				×					×										×	×	×																	
Appropriate selection, design, modification to ventilation, leak detection, flame detection, corrosion prevention equipment, and systems for hydrogen blending									×																													
Understanding combined-cycle power generation using hydrogen blending																																						
Maintenance of equipment and systems involved in combined cycle power generation using hydrogen blending											×																											

HYDROGEN CAPABILITIES	Renewable interconnect specialist	Automation and control specialist	Geoscience professional: Geologist, geophysicist, geotechnical specialist	Compression specialist	Corrosion specialist	Measurement specialist	Pipeline integrity specialist	Tank tester or inspector	Transportation solutions advisor	Hydrogen integration specialist	Utility inspector	Economic modelling specialist	Economist	Finance specialist	Communications and marketing specialist	Lawyer	Safety and hazards specialist	Business developer	Supply chain specialist	Power-to-X technology specialist	Hydrogen value chain expert	Public relations specialist	Administration specialist	IT specialist	Sustainability specialist	Innovation specialist	Energy storage specialist	Energy transition specialist	Operation optimisation specialist	Technology commercialisation specialist	Grid operation specialist	BOP specialist	Land acquisition specialist	Nanotechnology specialist	Marine engines expert	Artificial intelligence specialist	Cybersecurity specialist	Political scientist
HYDROGEN POWER GENERATION APPLICATION																																						
Appropriate selection, design, and maintenance of including steam and combustion turbines, compressors, pressure vessels, valves, steam generators, boilers, pumps, piping systems, and other BOP equipment to withstand hydrogen pressure and temperatures																			×	×	×																	
Knowledge of automated process systems and control systems associated with power generation using hydrogen blending		×																										×										
Knowledge of hydrogen related regulations, standards, and codes									×							×			×	×	×																	
HYDROGEN TRANSPORTATION APPLICATION																																						
Knowledge of hydrogen fuel cell technology, how it works, and value proposition relating to emissions targets and cost-effectiveness									×										×	×	×								×									
Knowledge of hydrogen production, distribution, and dispensing technology to meet the needs of different fleets									×										×	×	×																	

HYDROGEN CAPABILITIES	Renewable interconnect specialist	Automation and control specialist	Geoscience professional: Geologist, geophysicist, geotechnical specialist	Compression specialist	Corrosion specialist	Measurement specialist	Pipeline integrity specialist	Tank tester or inspector	Transportation solutions advisor	Hydrogen integration specialist	Utility inspector	Economic modelling specialist	Economist	Finance specialist	Communications and marketing specialist	Lawyer	Safety and hazards specialist	Business developer	Supply chain specialist	Power-to-X technology specialist	Hydrogen value chain expert	Public relations specialist	Administration specialist	IT specialist	Sustainability specialist	Innovation specialist	Energy storage specialist	Energy transition specialist	Operation optimisation specialist	Technology commercialisation specialist	Grid operation specialist	BOP specialist	Land acquisition specialist	Nanotechnology specialist	Marine engines expert	Artificial intelligence specialist	Cybersecurity specialist	Political scientist
HYDROGEN TRANSPORTATION APPLICATION																																						
Understanding relevant hydrogen regulations, codes, and standards									×							×			×	×	×																	
CROSS-CUTTING CAPABILITIES ACROSS THE HYDROGEN VALUE CHAIN																																						
Hydrogen properties, behaviour, and potential hazards created	×	×			×	×	×	×	×	×	×						×	×	×	×	×					×	×	×	×	×	×	×		×	×			
Safety when working with or around hydrogen	×	×			×	×	×	×	×	×	×									×	×					×	×	×	×	×	×	×		×	×			

Sources: Hufnagel-Smith (2022b); Hydrogen Europe Research et al. (2023b); CSIR (2023)

TABLE 9: Hydrogen capabilities for managers

HYDROGEN CAPABILITIES	Plant manager	Drilling and completions supervisor	Pipeline scheduler	Asset performance manager	Utility services planner	Maintenance planner	Power scheduler	Project manager	Business and technology manager development manager	Supply chain manager	Sales and marketing manager	Administrative manager	Investment manager	Communications manager
HYDROGEN PRODUCTION														
Knowledge of automated process systems and control systems associated with electrolysers														
Understanding electrochemical reactions, processes, and hydrogen production process	×				×			×	×	×				×
Maintenance of equipment and systems involved in hydrogen production	×							×						
Appropriate selection, design, and maintenance of electrolysers, vessels, compressors, piping systems and fitting, valves, and seals to withstand hydrogen pressure and temperatures	×													
Appropriate selection, design, and maintenance of combustion, compression, pumping and turbine systems, and equipment to withstand hydrogen pressure and temperatures														
Knowledge of hydrogen gas value chains	×							×		×				
Knowledge of key high power electrical equipment and interconnection applications associated with renewable electricity–powered electrolyser produced hydrogen								×						
HYDROGEN STORAGE														
Understanding appropriate well completion solutions for hydrogen		×						×						
Understanding properties and characteristics of hydrogen in a gaseous state		×												
Appropriate selection, design, and maintenance of hydrogen compression, turbine systems, and equipment														
Understanding measurement equipment and instrumentation associated with hydrogen transmission														
Understanding hydrogen compression processes	×							×						

HYDROGEN CAPABILITIES	Plant manager	Drilling and completions supervisor	Pipeline scheduler	Asset performance manager	Utility services planner	Maintenance planner	Power scheduler	Project manager	Business and technology manager development manager	Supply chain manager	Sales and marketing manager	Administrative manager	Investment manager	Communications manager
HYDROGEN DISTRIBUTION AND TRANSPO/RTATION														
Knowledge of hydrogen value chains			×					×	×	×	×			×
Appropriate selection, design, and maintenance of hydrogen compression, turbine systems, and equipment														
Understanding hydrogen compression processes														
Knowledge and selection of the type of materials, coatings, and inhibitors to use to protect from hydrogen corrosion and embrittlement														
Understanding materials behaviour in high pressure hydrogen														
Understanding measurement equipment and instrumentation associated with hydrogen transmission														
Appropriate selection and design of vessels, compressors, piping systems and fitting, valves, and seals to withstand high hydrogen pressure														
Appropriate selection and maintenance of materials and equipment to withstand hydrogen pressure and temperatures														
Knowledge of hydrogen fuel cell technology, how it works, and value proposition relating to emissions targets and cost-effectiveness								×	×	×			×	
Knowledge of hydrogen production, distribution, and dispensing technology to meet the needs of different fleets								×	×	×	×		×	
Practices, technologies, equipment, and systems to control hydrogen corrosion or embrittlement														
Understanding properties and characteristics of hydrogen in a gaseous state		×												
HYDROGEN HEATING APPLICATION														
Understanding technical factors associated with using hydrogen blending for heating				×										
Knowledge of hydrogen related regulations, standards, and codes				×	×			×						
Knowledge of odorants used to assist with leak detection of hydrogen					×									

HYDROGEN CAPABILITIES	Plant manager	Drilling and completions supervisor	Pipeline scheduler	Asset performance manager	Utility services planner	Maintenance planner	Power scheduler	Project manager	Business and technology manager development manager	Supply chain manager	Sales and marketing manager	Administrative manager	Investment manager	Communications manager
HYDROGEN HEATING APPLICATION														
Procedures to trace, locate, and repair hydrogen leaks														
Materials, coatings, and inhibitors to use and correct application to protect from hydrogen corrosion					×									
Practices, technologies, equipment, and systems to control hydrogen corrosion or embrittlement					×									
Strong industry knowledge and experience with hydrogen technologies, processes and equipment, and components to use to withstand hydrogen pressure and temperatures								×						
Appropriate selection of materials, coatings, odorants, inhibitors, and such for hydrogen blending														
Appropriate selection, design, modification to ventilation, leak detection, flame detection, corrosion prevention equipment, and systems for hydrogen blending														
Comprehensive understanding of aspects of installation and testing procedures that are different due to the nature of hydrogen								×						
Knowledge of materials, equipment, and components to use to withstand hydrogen pressure and temperatures								×						
Welding procedures and techniques appropriate for hydrogen														
Procedures to trace, locate, and repair hydrogen leaks								×						
HYDROGEN POWER GENERATION APPLICATION														
Strong industry knowledge and experience with hydrogen technologies, processes equipment, and components to withstand hydrogen pressure and temperatures								×						
Appropriate selection of materials, coatings, odorants, inhibitors, and such for hydrogen blending														
Appropriate selection, design, and maintenance of power generation equipment including compression, turbines, combustion, and such for hydrogen blending						×								

HYDROGEN CAPABILITIES	Plant manager	Drilling and completions supervisor	Pipeline scheduler	Asset performance manager	Utility services planner	Maintenance planner	Power scheduler	Project manager	Business and technology manager development manager	Supply chain manager	Sales and marketing manager	Administrative manager	Investment manager	Communications manager
HYDROGEN POWER GENERATION APPLICATION														
Appropriate selection, design, modification to ventilation, leak detection, flame detection, corrosion prevention equipment, and systems for hydrogen blending														
Understanding combined-cycle power generation using hydrogen blending	×					×	×	×						
Maintenance of equipment and systems involved in combined cycle power generation using hydrogen blending														
Appropriate selection, design, and maintenance of including steam and combustion turbines, compressors, pressure vessels, valves, steam generators, boilers, pumps, piping systems, and other BOP equipment to withstand hydrogen pressure and temperatures						×								
Knowledge of automated process systems and control systems associated with power generation using hydrogen blending														
HYDROGEN TRANSPORTATION APPLICATION														
Knowledge of hydrogen fuel cell technology, how it works, and value proposition relating to emissions targets and cost-effectiveness					×			×	×		×		×	×
Knowledge of hydrogen production, distribution, and dispensing technology to meet the needs of different fleets								×						
Understanding relevant hydrogen regulations, codes, and standards								×						
CROSS-CUTTING CAPABILITIES ACROSS THE HYDROGEN VALUE CHAIN														
Hydrogen properties, behaviour, and potential hazards created	×	×	×	×	×	×	×	×	×					
Safety when working with or around hydrogen	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Knowledge of hydrogen-related regulations, standards, and codes				×	×	×			×		×	×	×	×

Sources: Hufnagel-Smith (2022b); Hydrogen Europe Research et al. (2023b); CSIR (2023)

TABLE 10: Hydrogen capabilities for elementary occupation workers

HYDROGEN CAPABILITIES	Cleaner	Helper	Caretaker	Guard	Garbage collector	Sweeper	Labourer	Land clearer	Handyperson	Assembling labourer	Manufacturing labourer	Freight handler
CROSS-CUTTING												
Hydrogen properties, behaviour, and potential hazards created	×		×	×	×	×	×	×	×	×	×	×
Safety when working with or around hydrogen	×	×	×	×	×	×	×	×	×	×	×	×

Sources: Hufnagel-Smith (2022b); Hydrogen Europe Research et al. (2023b); CSIR (2023)

6.3 Supply of skills for the green hydrogen economy

The existing supply of hydrogen skills required for numerous occupations in the hydrogen value chain in South Africa is concentrated in a few chemical companies, and their development is supported by various entities such as the SETAs and research institutions. The former is largely dominated by Sasol as the main producer of hydrogen in the country, while the research institutions are led by Hydrogen South Africa (HySA), which was developed as part of the strategic initiatives driven by DSI from 2007. On-the-job training and upskilling are mechanisms adopted by chemical companies such as Sasol, Air Liquide, and Air Products for developing hydrogen-specific skills. On the other hand, research institutions use postgraduate research opportunities to develop hydrogen-related skills. The SETAs develop and implement sector skills plans and support the provisioning of learning programmes in their respective sectors. The petroleum and gas industry has skills that can be transferrable to the hydrogen value chain.

Tables 4 and 5 give an indication of the available supply of skills for the hydrogen economy in South Africa. These skills are colour-coded in green. However, upskilling or reskilling will be required for these occupations to ensure that they incorporate green hydrogen–related capabilities as outlined in tables 6–10.

6.3.1 Sasol

Sasol, a chemical and energy company, has approximately 70 years of experience using Fischer-Tropsch (FT) technology, which is feedstock-agnostic and used to produce synthetic fuels and chemicals. This technology produces approximately 2.4 Mt per year of grey hydrogen, making Sasol the largest producer in the country (Hydrogen Council, 2023). Beyond hydrogen-related engineers, technicians, and tradespeople, Sasol has FT speciality capabilities which, among others, include:

- Reaction engineering and kinetics
- FT synthesis (catalyst, product analysis, and product upgrading)
- Conventional and compact multi-tubular fixed-bed reactor modelling
- Slurry bubble column reactor modelling
- Slurry reactor hydrodynamics
- Microchannel reactor modelling
- Speciality wax testing and analysis
- Batch hydrogeneration
- Synthetic fuel production, gas generation (autothermal reforming, steam methane reforming, and partial oxidation processes), and gas clean-up

6.3.2 Hydrogen South Africa and research institutions

Working in collaboration with North-West University (NWU), the Council for Scientific and Industrial Research (CSIR), the University of Cape Town (UCT), and the University of the Western Cape (UWC), HySA promotes research and development skills in hydrogen. The institution also encourages postgraduate students mainly in the field of engineering and science to develop their skills in hydrogen by participating in its postgraduate opportunities programme targeted for this field (SAASTA et al., 2015; UCT, 2023). The hydrogen skills set of this collaboration includes technical skills such as research, project, test and mechanical engineer, research technician, machine operator and technician, key technology specialist, fuel cell technologist, and artisan assistant, as well as commercial and support skills such as facility manager, financial officer, and commercialisation officer (HySA Infrastructure, 2023). This programme has also led to the development of fuel cell and electrolyser technologies that have subsequently been patented.

Stellenbosch University (SU), through its Centre for Renewable and Sustainable Energy Studies (CRSES), offers short courses in renewable energy and green hydrogen, including hydrogen in the energy system, green hydrogen technology, and green hydrogen project engineering (CRSES, 2023a).

6.3.3 The sector education and training authorities

The SETAs support skills development through the creation and implementation of their sector skills plans and the funding of skills development programmes, WBL programmes, bursaries for occupations in high demand, and qualifications development, among others. These interventions focus on technicians and tradespeople such as electricians, fuel cell technicians, gas fitters, HVAC technicians, and instrumentation technicians. Such SETAs include CHIETA, MerSETA, EWSETA, the Local Government Sector Education and Training Authority (LGSETA), and the Wholesale and Retail Sector Education and Training Authority (W&R SETA) (EWSETA, 2023).

6.3.4 The petroleum and gas industry

South Africa has the potential to transfer several skills from the petroleum and gas industry into the green hydrogen economy. The industry is led by the South African Petroleum Industry Association (SAPIA), with its members including the Petroleum Oil and Gas Corporation of South Africa (PetroSA), Astron Energy, BP, Engen Petroleum, Shell, TotalEnergies, and Royal Vopak, among others.

PetroSA, for example, is the national oil company and owns the world's third-largest gas-to-liquid (GTL) refinery plant. Its business spans the full petroleum value chain, and one of its core activities includes the production of synthetic fuels using the GTL refinery plant in Mossel Bay, located in the country's Western Cape province (PetroSA, 2023). Many technical skills from this industry that are required for occupations such as engineering, project management, and data analysis are transferrable (BP & Aberdeen City Council, 2022). However, additional training may be required to adapt to new practices and procedures related to green hydrogen value chains.

6.4 Skills imbalances predicted for the green hydrogen economy

As explained above, skills imbalances arise when there is misalignment between the skills that are demanded by employers and the skills supplied by individuals in the labour market. This section of the report discusses three types of imbalances (skills shortages, skills surpluses, and skills mismatches) as they relate to South Africa's green hydrogen economy.

6.4.1 Skills shortages

The Organisation for Economic Co-operation and Development's (OECD) report on *Skills Imbalances in the South African Labour Market* (Vandeweyer and Verhagen, 2022) highlights the top 20 occupations in shortage. Among them are mechanical, industrial, production, and mining engineers, physicists, chemists, geologists, geophysicists, mathematicians, and statisticians, all who are critical in the green hydrogen value chain. These occupations are also currently included in the Department of Home Affairs' 2022 Critical Skills List, which indicates a shortage of these skills to service existing industries. As the green hydrogen economy becomes established, there is a risk that the skills demanded by the industry will exceed the supply of individuals in the labour market who possess the required skills.

6.4.2 Skills surpluses

Skills surpluses refer to when the skills supplied exceed the skills demanded. As outlined in part 6.3, the existing supply of hydrogen skills required for numerous occupations in the hydrogen value chain in South Africa is largely concentrated in a few chemical companies, and to a much smaller extent, in several research institutions. In part 6.2.1, the existence of occupations required for the hydrogen economy in South Africa was confirmed through recruitment platforms such as LinkedIn and PNet. While the existence could be confirmed for 75 of the 138 occupations, the numbers were very low. Since the hydrogen economy is still emerging in the country, an initial assumption can therefore be made that there is currently no surplus of hydrogen-related skills in South Africa — however, to confirm this, a deeper analysis of quantitative data would be required.

6.4.3 Skills mismatches

In part 6.1, skills mismatches were defined as occurring when the "skills demanded by employers and the skills supplied by individuals in the labour market are not aligned" (Vandeweyer and Verhagen, 2022). With the emergence of the green hydrogen industry, the demand for high- and medium-skilled workers is set to increase. The country is currently characterised by low-level skilled workers (DHET and UCT, 2022). It is therefore essential to ensure that workers in the current labour force are appropriately upskilled or reskilled to include hydrogen-specific capabilities (see tables 6–10). The following two types of mismatches were considered in this study:

- **Field-of-study mismatch:** Defined as the discrepancy between the qualification attained and the employee's job role (Stoevska, 2017).
- **Qualification mismatch:** Includes over- or underqualification (ROBLES, 2022). Overqualification is when an individual's level of education is higher than what is required for an occupation. Meanwhile, underqualification is when the level of education is lower than that required for an occupation.

According to Vandeweyer and Verhagen (2022), qualification mismatch is already high among workers with engineering, manufacturing, and construction qualifications. Additionally, workers possessing natural science, mathematics, and statistics qualifications are likely to be employed in different fields than their fields of specialisation. To proactively manage the materialisation of skills mismatches, the curriculum at university level and in the TVET college ecosystem needs to include green hydrogen–related topics (see tables 11, 14, 17, and 19). This inclusion will assist in ensuring that the country's high unemployment levels are not further exacerbated, and that employment opportunities created by the emerging economy are realised.

PART 7

Education and Training to Support the Hydrogen Economy

7.1 Schooling

Basic education plays a crucial role in developing the foundation for the country's green hydrogen economy, because it provides elementary-level skilled individuals and enables other learners to enter the PSET system. It empowers learners to gain skills in numerical and computer literacy as well as in reading, writing, communication, leadership, critical thinking, decision-making, problem-solving, and personal management, among other skills that are key for individuals who will not enter the PSET system but have ambitions of participating in the green hydrogen economy.

In today's rapidly evolving world, which incorporates green hydrogen in the global energy mix, science, technology, engineering, and mathematics (STEM) contributes to shaping the country's future and its ability to participate in the growing hydrogen economy. STEM subjects equip students with the skills and knowledge required to advance an economy that is driven by technology and innovation. To build key competencies for the hydrogen economy, hydrogen-related aspects need to be incorporated into the basic education curriculum. Learners should be encouraged to enroll for STEM subjects, which include both theoretical and practical teaching methods to increase their exposure to the green hydrogen field.

Challenges for STEM in South Africa include the dwindling interest in STEM subjects at primary and secondary levels. School subjects such as mathematics and physical science enable learners to select a wide variety of university courses. However, low pass rates are recorded nationally in mathematics, with only 55% achieving above 30% in 2022 (Department of Basic Education, 2022). Many learners end up taking mathematical literacy as opposed to mathematics (NSTF, 2022).

The Department of Higher Education and Training (DHET) also highlights inadequate representation of foundational knowledge and skills such as communication, literacy, and numeracy in the existing skills profile of the labour force (DHET and UCT, 2022). Additionally, learners are not adequately exposed to the career opportunities that would encourage them to select courses in fields that are emerging and in high demand (Hannan et al., 2020). These challenges need to be addressed to ensure that students enroll for STEM subjects given that they form a significant portion of PSET green hydrogen–related qualifications.

7.2 Higher education institutions

Higher educational institutions (HEIs) are well-positioned to play a critical role in progressing green hydrogen skills and technologies, thereby supporting the country's energy transition. They play a pivotal role in developing green hydrogen skills, with their contributions extending to education, research, innovation, and collaboration with industry players.

The hydrogen economy requires skills in engineering, technical fields, specialisations, trades (manufacturing and construction), and management (PwC, 2022). The basic foundations of these skills can be obtained from some of the qualifications currently offered through South African institutions. The question of whether these qualifications can enable South Africa to fully meet the requirements of the hydrogen economy is answered in part 7.2.1–7.3.3.

7.2.1 Comparison of qualifications required for green hydrogen versus those offered by HEIs in South Africa

Previous studies identified unique capabilities for occupations in the hydrogen value chain, as outlined in part 6.2.2 of this report. Hydrogen capabilities are listed below and are broadly categorised into general hydrogen capabilities and those specific to hydrogen-related qualifications, with general capabilities being those that are required across all occupations in the value chain:

- Hydrogen properties, behavior, and potential hazards created
- Hydrogen safety
- Hydrogen production process
- Hydrogen gas value chains
- Hydrogen storage and delivery
- Comprehension of hydrogen-related guidelines, principles, and codes
- General capabilities

An analysis of the unique requirements that HEI qualifications should have to support the hydrogen economy shows that only a few South African HEIs have introduced hydrogen-related topics in their institutions as follows:

1. As aforementioned, through CRSES, SU offers short courses in renewable energy and green hydrogen, including hydrogen in the energy system, green hydrogen technology, and green hydrogen project engineering (CRSES, 2023a). In 2022, SU signed a memorandum of understanding with Teesside University in England, allocating R12 million towards establishing research expertise in green hydrogen. The research activities would include hydrogen production technologies, hydrogen conversion technologies such as fuel cells and gas turbines, and techno-economic analysis of hydrogen projects such as the production of hydrogen for the export market, among other areas (SU, 2022).
   Furthermore, two Sasol-NRF Research Chairs in Green Hydrogen were awarded to engineering faculty professors at SU and at the University of Johannesburg (UJ). The purpose of the awards is to strengthen and improve research and innovation capacity of public universities to produce high-quality postgraduate students and research outputs (UJ News, 2023).
2. The DSI's HySA Infrastructure Centre of Competence, co-hosted by NWU and CSIR, is focused on developing cost-competitive solutions for generating hydrogen using renewable energy and other chemical carriers, as well as for storing and distributing hydrogen (NWU, 2023).
3. The Tshwane University of Technology (TUT) also established a task team to carry out research on hydrogen. The university also plans curriculum development to enable upskilling in hydrogen, starting with government employees (Tshisikhawe, 2023).
4. UCT collaborated with the Fraunhofer Institute for Solar Energy Systems ISE to accelerate the development of hydrogen and fuel cell technology (Moore, 2018). The university also conducts research to advance the hydrogen economy. Through its Catalysis Institute, which has a research group that covers FT technology, UCT secured a collaboration with Sasol through which research on the conversion of carbon dioxide and green hydrogen to green chemicals and jet fuel is carried out (Shabalala, 2021). In addition, the university has an Electrolyser Research Group at the HySA Catalysis Competence Centre.
5. UWC hosts the South African Institute for Advanced Materials Chemistry (SAIAMC), which runs various programmes including the HySA's Systems Integration and Technology Validation Competence Centre and the Green Hydrogen Programme (Chidziva, 2022). These programmes focus on hydrogen technology and skills development to upskill HEI and TVET graduates and other professionals for better transition from academia to the hydrogen industry (Karen Energy, 2022).

6. The University of Pretoria (UP) has been involved in educating graduates from TVET colleges in hydrogen fuel cell systems, funded by EWSETA and the DSI (Mathibela, 2020a). The university's Department of Electrical, Electronic and Computer Engineering also focuses on hydrogen-related education in its Just Energy Transition research group (Smith, 2022).
7. The University of South Africa's (UNISA) Institute for Catalysis and Energy Solutions (formerly known as the Institute for the Development of Energy for African Sustainability) has projects that include green hydrogen production (Gumbi, 2023).
8. The University of the Witwatersrand's (Wits) Materials for Energy Research Group's current research focus includes hydrogen production and storage (Wits, 2020).
9. The Vaal University of Technology (VUT) received funding from CHIETA to enable engineering students to conduct research into fuel cell innovations (CHIETA, 2023). Although there are several hydrogen-related initiatives at South African universities, they are mostly focused on research at the postgraduate level.

The DHET and the Council on Higher Education (CHE) defined the Classification of Education Subject Matter (CESM), which details all the fields of study that are currently offered and/or may be offered in future in South Africa (DHET et al., 2010). The CESM's approved programmes were used in the assessment of the qualifications offered by South African universities and in the analysis of whether they are appropriate for the hydrogen economy. Table 11 compares the qualifications offered by South African HEIs with those required for the hydrogen economy. In the table, the general hydrogen capabilities are grouped as 'All general hydrogen capabilities'.

The development of Table 11 included the following steps:

- Identifying qualifications required for the hydrogen value chain using tables 4 and 5 and the unique green hydrogen capabilities obtained from Hufnagel-Smith (2022b).
- Conducting an in-depth analysis of all the courses offered by 25 South African public and private universities, using the list of universities provided by the DHET (2023b).
- Analysing the 25 universities' websites to identify whether they offer the qualifications required for green hydrogen, as identified in tables 4 and 5 of this report.
- Defining the related unique capabilities of the qualifications required for green hydrogen using the hydrogen workforce assessment tool developed for Canada's hydrogen economy.
- Comparing the identified university qualifications with what is offered by the South African universities studied. The missing qualifications are highlighted in table 11.

The analysis confirmed that the qualifications offered in South African universities are similar in name to those required in the green hydrogen sector, as outlined in table 11. However, as aforementioned, the nascency of the industry in South Africa means that hydrogen-specific topics are currently not adequately embedded in the existing programmes. In their current form, they might address some but not all of the capabilities required for the hydrogen economy. For example, chemical engineering degrees are required in the hydrogen value chain. As such, the current chemical engineering programmes offered through South African institutions will need to be augmented to include hydrogen-specific capabilities. In parallel, the DHET ought to facilitate numerous international scholarships in countries with which it has agreements. A list of available scholarships is available on the DHET's website.

Table 11 provides guidance on hydrogen-related capabilities that may be included in existing programmes. There are also a few qualifications in, for example, petroleum, welding, systems, information, and instrumentation engineering that are not offered by South African universities and that may need to be introduced.

TABLE 11: Comparison of the qualifications required for green hydrogen versus those offered by higher education institutions in South Africa

QUALIFICATIONS REQUIRED FOR GREEN HYDROGEN	UNIQUE CAPABILITIES REQUIRED FOR GREEN HYDROGEN	QUALIFICATION OR PROGRAMMES OFFERED BY SOUTH AFRICAN UNIVERSITIES	HYDROGEN QUALIFICATIONS MISSING IN SOUTH AFRICAN HEIS
BACHELOR'S DEGREE: CHEMICAL OR ELECTROCHEMISTRY ENGINEERING	○ All general hydrogen capabilities ○ Comprehension of electrochemical reactions and procedures ○ Comprehension of combined cycle power generation using hydrogen blending ○ Hydrogen-related guidelines, principles, and codes ○ Hydrogen fuelling systems and technology and covering the whole value chain ○ Materials behaviour, design, and selection of vessels, pipes, compressors, and such in high- and low-pressure hydrogen ○ Cavern engineering fundamentals for hydrogen ○ Modelling hydrogen-water-minerals interactions	Bachelor's degree: Chemical engineering	Bachelor's degree: Electrochemistry
BACHELOR'S DEGREE: CIVIL ENGINEERING	○ All general hydrogen capabilities ○ Comprehension of electrochemical reactions and procedures ○ Hydrogen corrosion or embrittlement ○ Materials behaviour, design, and selection of vessels, pipes, compressors, coatings, and such in high- and low-pressure hydrogen ○ Hydrogen leakages management ○ Welding in hydrogen environment ○ Systems and technologies to minimise hydrogen corrosion or embrittlement	Bachelor's degree: Civil engineering	
BACHELOR'S DEGREE: MECHANICAL ENGINEERING	○ All general hydrogen capabilities ○ Electrochemical reactions and processes ○ Design and maintenance of hydrogen-related equipment ○ Materials characteristics, design, and selection of vessels, pipes, compressors, coatings, and such in high- and low-pressure hydrogen and hot/cold temperatures ○ Design and maintenance of hydrogen equipment ○ Hydrogen leakages management ○ Welding procedures and techniques	Bachelor's degree: Mechanical engineering	

QUALIFICATIONS REQUIRED FOR GREEN HYDROGEN	UNIQUE CAPABILITIES REQUIRED FOR GREEN HYDROGEN	QUALIFICATION OR PROGRAMMES OFFERED BY SOUTH AFRICAN UNIVERSITIES	HYDROGEN QUALIFICATIONS MISSING IN SOUTH AFRICAN HEIS
BACHELOR'S DEGREE: ELECTRICAL ENGINEERING	○ All general hydrogen capabilities ○ Knowledge of key electrical and instrumentation equipment for hydrogen processes ○ Knowledge of key high power electrical requirements for renewable energy generation ○ Design and maintenance of electrical and electronic systems ○ Knowledge of electricity generation for and using hydrogen ○ Power flow simulations, energy modelling, design of renewable energy plants, and networks	Bachelor's degree: Electrical engineering	
BACHELOR'S DEGREE: INSTRUMENTATION ENGINEERING	○ All general hydrogen capabilities ○ Knowledge of instrumentation systems for hydrogen processes ○ Comprehension of power generation using hydrogen blending	Not available	Bachelor's degree: Instrumentation engineering
	○ Comprehension of control systems for hydrogen systems ○ Design and maintenance of key instrumentation equipment for hydrogen processes		
DIPLOMA OR BACHELOR'S DEGREE: CIVIL ENGINEERING, WITH ENVIRONMENTAL ENGINEERING	○ All general hydrogen capabilities ○ Comprehension of environmental laws and regulations for hydrogen environments ○ Comprehension of local and international environmental, energy and climate change policies, and regulations	Diploma and bachelor's degree: Civil engineering	
BACHELOR'S DEGREE: MECHATRONICS	○ All general hydrogen capabilities ○ Knowledge of controls and automation for hydrogen processes	Bachelor's degree: Mechatronics	
BACHELOR'S DEGREE: PROCESS ENGINEERING	○ All general hydrogen capabilities ○ Understanding electrochemical reactions and processes ○ Comprehension of high-pressure gas systems and vessels ○ Understanding processes and controls for hydrogen ○ Understanding gaseous hydrogen storage and delivery systems at low temperatures	Bachelor's degrees: Chemical, process, and mechanical engineering	

QUALIFICATIONS REQUIRED FOR GREEN HYDROGEN	UNIQUE CAPABILITIES REQUIRED FOR GREEN HYDROGEN	QUALIFICATION OR PROGRAMMES OFFERED BY SOUTH AFRICAN UNIVERSITIES	HYDROGEN QUALIFICATIONS MISSING IN SOUTH AFRICAN HEIS
BACHELOR'S DEGREE: PETROLEUM ENGINEERING OR RELATED FIELD SUCH AS MECHANICAL, CIVIL, OR CHEMICAL ENGINEERING	○ All general hydrogen capabilities ○ Design and material selection for storage wells considering surrounding environmental laws, method of hydrogen transportation, and hydrogen characteristics	Bachelor's degrees: Mechanical, chemical, and civil engineering	Bachelor's degree: Petroleum engineering
	○ Comprehension of cavern engineering fundamentals for hydrogen storage ○ Comprehension of reservoir engineering fundamentals for gas storage ○ Migration modelling, zone selection, and storage design ○ Pressure, voltage, and temperature characterisation and modelling for stored hydrogen ○ Reservoir geochemistry and modelling gas-water-mineral interactions ○ Technology and options for gas storage and monitoring ○ Conversion specifications for gases ○ Knowledge of characteristics of hydrogen in various fluid states		
BACHELOR'S DEGREE: INDUSTRIAL ENGINEERING	○ All general hydrogen capabilities ○ Comprehension of guidelines, principles, and codes for hydrogen processes	Bachelor's degree: Industrial engineering	
BACHELOR'S DEGREE: GEOLOGICAL ENGINEERING	○ Capabilities covered under bachelor's degree in petroleum engineering	Bachelor of Science (BSc) degree: Engineering and environmental geology	

QUALIFICATIONS REQUIRED FOR GREEN HYDROGEN	UNIQUE CAPABILITIES REQUIRED FOR GREEN HYDROGEN	QUALIFICATION OR PROGRAMMES OFFERED BY SOUTH AFRICAN UNIVERSITIES	HYDROGEN QUALIFICATIONS MISSING IN SOUTH AFRICAN HEIS
BACHELOR'S DEGREE: COMPUTER SCIENCE, INFORMATION ENGINEERING, ENGINEERING TECHNOLOGY, ELECTRICAL ENGINEERING, OR COMPUTER ENGINEERING	○ All general hydrogen capabilities ○ Artificial intelligence	Bachelor's degrees: Computer science, computer science and information technology, computer engineering, computer science and electronics, computer and electronic engineering, information engineering, and electrical and electronic engineering with information technology	

QUALIFICATIONS REQUIRED FOR GREEN HYDROGEN	UNIQUE CAPABILITIES REQUIRED FOR GREEN HYDROGEN	QUALIFICATION OR PROGRAMMES OFFERED BY SOUTH AFRICAN UNIVERSITIES	HYDROGEN QUALIFICATIONS MISSING IN SOUTH AFRICAN HEIS
BACHELOR'S DEGREE: MATERIALS, OR MECHANICAL ENGINEERING SPECIALIST TRAINING IN WELDING ENGINEERING	○ All general hydrogen capabilities ○ Selection and use of materials, coatings, and inhibitors for hydrogen corrosion ○ Hydrogen corrosion or embrittlement ○ Withstanding hydrogen pressure and temperatures, and materials behaviours	Bachelor's degrees: Materials engineering in polymer technology, and metallurgy and materials engineering (covers welding procedure) Bachelor of Engineering (Honours) degree: Metallurgical engineering, with the option of welding engineering	Bachelor's degree: Welding engineering
BACHELOR'S DEGREE: SYSTEMS ENGINEERING	○ All general hydrogen capabilities	Not available	Bachelor's degree: Systems engineering
BACHELOR'S DEGREE: ENGINEERING OR SCIENCE, FOCUSING ON ENVIRONMENTAL ENGINEERING	○ All general hydrogen capabilities ○ Knowledge of electrical equipment and systems for renewable energy generation ○ GHG emissions assessments and reduction strategies	BSc degrees: Environmental sciences, and engineering and environmental geology	

QUALIFICATIONS REQUIRED FOR GREEN HYDROGEN	UNIQUE CAPABILITIES REQUIRED FOR GREEN HYDROGEN	QUALIFICATION OR PROGRAMMES OFFERED BY SOUTH AFRICAN UNIVERSITIES	HYDROGEN QUALIFICATIONS MISSING IN SOUTH AFRICAN HEIS
BSC DEGREE: GEOLOGY OR GEOPHYSICS	○ All general hydrogen capabilities ○ Knowledge of how to use geoscience databases to determine suitable aquifers and caverns for gas storage	BSc degrees: Geology, geological science, applied geology, geosciences (geography and geology), engineering and environmental geology	BSc degree: Geophysics
BACHELOR'S DEGREE: AEROSPACE ENGINEERING	○ All general hydrogen capabilities ○ Operation of hydrogen-powered aircrafts ○ Hydrogen as a fuel source in aviation	Bachelor's degree: Aeronautical engineering	
BACHELOR'S DEGREE: MARINE ENGINEERING	○ All general hydrogen capabilities ○ Design, construction, operation, and maintenance of hydrogen transporting ships	Bachelor of Marine Engineering degree Bachelor of Technology in Marine Engineering degree	
BACHELOR'S DEGREE: NAUTICAL SCIENCE	○ All general hydrogen capabilities	Bachelor's degree: Nautical science	
BACHELOR'S DEGREE: HYDRAULIC ENGINEERING	○ All general hydrogen capabilities ○ Installation, maintenance, troubleshooting, and modification of hydraulic systems in a hydrogen environment ○ Characteristics and behaviour of gases in their various states	Not available	Bachelor's degree: Hydraulic engineering

QUALIFICATIONS REQUIRED FOR GREEN HYDROGEN	UNIQUE CAPABILITIES REQUIRED FOR GREEN HYDROGEN	QUALIFICATION OR PROGRAMMES OFFERED BY SOUTH AFRICAN UNIVERSITIES	HYDROGEN QUALIFICATIONS MISSING IN SOUTH AFRICAN HEIS
DIPLOMA OR BACHELOR'S DEGREE: RAILWAY OPERATIONS	○ All general hydrogen capabilities ○ Fuel cell technology ○ Maintenance of vehicles or locomotives ○ Environmentally sustainable driving methods including their codes and standards	Bachelor's degree: Civil engineering (railway engineering research)	Diploma or bachelor's degree: Railway operations
BACHELOR'S DEGREE: MATERIALS SCIENCE	○ All general hydrogen capabilities ○ Optimising the properties of materials for the design, use, and maintenance of equipment in the hydrogen value chain	Bachelor's degrees: Materials science, and metallurgical engineering Bachelor's degree (Hons): Materials science	
DIPLOMA: CHEMICAL ENGINEERING	○ All general hydrogen capabilities ○ Electrochemical reactions, processes and hydrogen production, conversion, and storage	Diploma: Chemical engineering	
DIPLOMA: POWER (OR STATIONARY) ENGINEERING	○ All general hydrogen capabilities ○ Processes involved in hydrogen production, conversion, transportation, and storage	Diploma: Electrical engineering	
DIPLOMA: CHEMICAL OR PROCESS ENGINEERING	○ All general hydrogen capabilities ○ Processes involved in hydrogen production, conversion, transportation, and storage	Diploma: Chemical engineering and process control engineering	

QUALIFICATIONS REQUIRED FOR GREEN HYDROGEN	UNIQUE CAPABILITIES REQUIRED FOR GREEN HYDROGEN	QUALIFICATION OR PROGRAMMES OFFERED BY SOUTH AFRICAN UNIVERSITIES	HYDROGEN QUALIFICATIONS MISSING IN SOUTH AFRICAN HEIS
DIPLOMA: PETROLEUM TECHNOLOGY OR PETROCHEMICAL ENGINEERING	○ All general hydrogen capabilities ○ Gas properties and behaviour in various states ○ Processes involved in the hydrogen value chain ○ Properties of natural and petroleum fluids ○ Technologies for gas injection, storage, and monitoring	Not available	Diplomas: Petroleum technology, petroleum engineering technology, and petrochemical engineering
DIPLOMA: INDUSTRIAL ENGINEERING	○ All general hydrogen capabilities ○ Knowledge of processes, systems, and controls in the hydrogen value chain	Diploma: Industrial engineering Higher certificate: Industrial engineering	
DIPLOMA: MECHANICAL ENGINEERING	○ All general hydrogen capabilities ○ Fixed and moving mechanical equipment and systems required in the hydrogen value chain ○ Material selection for hydrogen use	Diploma: Mechanical engineering	
DIPLOMA: ELECTRICAL ENGINEERING	○ All general hydrogen capabilities ○ Electrical equipment and instrumentation systems in the hydrogen value chain	Diploma: Electrical engineering	
DIPLOMA: INSTRUMENTATION ENGINEERING	○ All general hydrogen capabilities ○ Knowledge and maintenance of mechanical, instrumentation and electrical equipment, and systems for hydrogen processes	Not available	Diploma: Instrumentation engineering
DIPLOMA: CIVIL ENGINEERING	○ All general hydrogen capabilities	Diploma: Civil engineering	

QUALIFICATIONS REQUIRED FOR GREEN HYDROGEN	UNIQUE CAPABILITIES REQUIRED FOR GREEN HYDROGEN	QUALIFICATION OR PROGRAMMES OFFERED BY SOUTH AFRICAN UNIVERSITIES	HYDROGEN QUALIFICATIONS MISSING IN SOUTH AFRICAN HEIS
DIPLOMA: ELECTRICAL AND INSTRUMENTATION ENGINEERING	○ All general hydrogen capabilities ○ Knowledge, design, and maintenance of instrumentation equipment and systems	Diploma: Electrical engineering (with instrumentation option)	Diploma: Electrical and instrumentation engineering
DIPLOMA: REFRIGERATION AND AIR-CONDITIONING, OR HEAVY-DUTY ENGINEERING	○ All general hydrogen capabilities ○ Heating and cooling requirements for hydrogen processes ○ Materials and equipment suitable for hydrogen pressure and temperatures ○ Gas leak detection and repairs ○ Maintenance procedures and techniques appropriate for hydrogen	Not available	Diplomas: Refrigeration and air-conditioning, and heavy-duty engineering
DIPLOMA: MARINE ENGINEERING	○ All general hydrogen capabilities ○ Design, construction, operation, and maintenance of hydrogen transporting ships	Not available	Diploma: Marine engineering
DIPLOMA: NAUTICAL SCIENCE	○ All general hydrogen capabilities	Diploma: Nautical studies	
DIPLOMA: AUTOMATION AND CONTROLS ENGINEERING	○ All general hydrogen capabilities ○ Automated systems and control systems for hydrogen processes	Diploma: Process control engineering	Diploma: Automation and controls engineering
DIPLOMA: AEROSPACE ENGINEERING	○ All general hydrogen capabilities ○ Operation of hydrogen-powered aircrafts ○ Hydrogen as a fuel source in aviation	Not available	Diploma: Aerospace engineering
DIPLOMA: GEOLOGY	○ All general hydrogen capabilities ○ Properties of gases in gaseous and liquid state ○ Rock characteristics during hydrogen injection and storage ○ Characterisation of subsurface geology for gas storage	Not available	Diploma: Geology

QUALIFICATIONS REQUIRED FOR GREEN HYDROGEN	UNIQUE CAPABILITIES REQUIRED FOR GREEN HYDROGEN	QUALIFICATION OR PROGRAMMES OFFERED BY SOUTH AFRICAN UNIVERSITIES	HYDROGEN QUALIFICATIONS MISSING IN SOUTH AFRICAN HEIS
DIPLOMA: MATERIALS SCIENCE	○ All general hydrogen capabilities ○ Understanding materials behaviour when in contact with liquid and gaseous CO_2, hydrogen, ammonia, and methanol ○ Understanding design and selection of materials in equipment used in hydrogen processes ○ Analyse the performance of materials used for hydrogen production	Not available	Diploma: Materials science
DIPLOMA: SYSTEMS ENGINEERING	○ All general hydrogen capabilities ○ Knowledge of processes, systems, and controls in the hydrogen value chain	Diploma: Industrial engineering	Diploma: Systems engineering
DIPLOMA OR BACHELOR'S DEGREE: PROJECT MANAGEMENT	○ All general hydrogen capabilities	Diploma and bachelor's degree: Project management	
BACHELOR'S DEGREE: COMMERCE	○ All general hydrogen capabilities	Bachelor's degree: Commerce	
BACHELOR'S DEGREE: ECONOMICS OR ECONOMETRICS	○ All general hydrogen capabilities	Bachelor's degree: Economics or econometrics	
BACHELOR'S DEGREE: FINANCE	○ All general hydrogen capabilities	Bachelor of Commerce degree in finance or financial management	
BACHELOR'S DEGREE: STATISTICS	○ All general hydrogen capabilities	Bachelor's degree: Statistics	

QUALIFICATIONS REQUIRED FOR GREEN HYDROGEN	UNIQUE CAPABILITIES REQUIRED FOR GREEN HYDROGEN	QUALIFICATION OR PROGRAMMES OFFERED BY SOUTH AFRICAN UNIVERSITIES	HYDROGEN QUALIFICATIONS MISSING IN SOUTH AFRICAN HEIS
BACHELOR'S DEGREE: PUBLIC RELATIONS, COMMUNICATIONS, OR MARKETING	○ All general hydrogen capabilities	Bachelor's degrees: Public relations management, communication science, and marketing	
BACHELOR'S DEGREE: LAW	○ All general hydrogen capabilities	Bachelor's degree: Law	
BACHELOR'S DEGREE: OCCUPATIONAL HEALTH AND SAFETY	○ All general hydrogen capabilities	Bachelor's degrees: Occupational and environmental health sciences, and health and safety management (construction)	
BACHELOR'S DEGREE: BUSINESS AND MANAGEMENT	○ All general hydrogen capabilities	Bachelor's degree: Business management	
BACHELOR'S DEGREE: SUPPLY CHAIN MANAGEMENT OR LOGISTICS	○ All general hydrogen capabilities	Bachelor's degrees: Supply chain and operations management, and transport and logistics	

QUALIFICATIONS REQUIRED FOR GREEN HYDROGEN	UNIQUE CAPABILITIES REQUIRED FOR GREEN HYDROGEN	QUALIFICATION OR PROGRAMMES OFFERED BY SOUTH AFRICAN UNIVERSITIES	HYDROGEN QUALIFICATIONS MISSING IN SOUTH AFRICAN HEIS
BACHELOR'S DEGREE: BUSINESS ADMINISTRATION	○ All general hydrogen capabilities	Bachelor's degree: Business administration	
BACHELOR'S DEGREE: MARKETING	○ All general hydrogen capabilities	Bachelor's degrees: Marketing, and marketing management	
BACHELOR'S DEGREE: REAL ESTATE	○ All general hydrogen capabilities	Bachelor's degrees: Real estate, business administration in real estate, and property studies	
BACHELOR'S DEGREE: NANOTECHNOLOGY	○ All general hydrogen capabilities	Not available	Bachelor's degree: Nanotechnology
BACHELOR'S OR MASTER'S DEGREE: ARTIFICIAL INTELLIGENCE, MATHEMATICS, OR DATA SCIENCE	○ All general hydrogen capabilities	Bachelor's degree: Mathematical sciences (with computer science) Master's degrees: Artificial intelligence, mathematics, and data science	Bachelor's degrees: Artificial intelligence, and data science
BACHELOR'S DEGREE: JOURNALISM	○ All general hydrogen capabilities	Bachelor's degree: Journalism	

7.3 Technical and vocational education and training (TVET)

In December 2022, the South African Institute of International Affairs published the *South African Green Hydrogen TVET Ecosystem Just Transition Strategic Framework,* which seeks to create "a just and inclusive hydrogen TVET ecosystem that cultivates a transversal skills commons and fosters economic well-being and ecological resilience by 2050" (Cloete et al., 2022). According to the framework, at the onset of the hydrogen economy, there will be a demand for high-level skills—developed through HEI programmes. However, after the hydrogen and related industries are established, the demand for artisans and technicians—developed through the TVET college system—will rise (Cloete et al., 2022). The framework further indicates that TVET colleges will play an important role in creating "scalable employment impacts, ensuring that the economic recovery and energy transition are just and inclusive", with imperatives set by the national Economic Reconstruction and Recovery Plan, the HSRM, and the draft JET IP.

Based on the framework's assumption, this section presents a gap analysis in the South African TVET college system with respect to qualifications and/or programmes that could support the development of a local hydrogen economy. This analysis is derived from the availability (or lack thereof) and quality of the qualifications required for the 'technicians and tradespersons' occupations in South Africa, as identified in tables 4 and 5. Furthermore, the TVET qualifications can be augmented using a list of hydrogen capabilities adapted from PwC (2022d). This list has been selected because it covers a wide range of technical hydrogen capabilities that are best suited for the 'technicians and tradespersons' category.

The *White Paper on Post-School Education and Training* states that "the purpose of these colleges is to train young school leavers, providing them with the skills, knowledge, and attitudes necessary for employment in the labour market" (DHET, 2013). South African TVET colleges focus on developing skills for occupations in the engineering and construction, tourism and hospitality, and general business and management industries. TVET colleges should, by design, be responsive to changes in labour market skills requirements, which they can achieve by keeping close links with employers, industry bodies, and the SETAs. To this end, these colleges offer programmes that provide students with theoretical knowledge but with a large focus on practical applications through workshop training and/or WBL. Currently, the South African TVET college system offers three main qualifications, explained in table 12 below.

TABLE 12: The three main types of programmes offered by the TVET college system

PROGRAMME	DESCRIPTION
REPORT 191 OR NATIONAL ACCREDITED TECHNICAL EDUCATION DIPLOMA (NATED)	○ Offered at six National N Diploma Levels (N1–6) for engineering studies, and three or four N levels (Introductory, N4–6) for business and general studies ○ Requires work experience for conferment of the N Diploma qualification: 24 months (2,670 hours) for engineering studies, and 18 months (2,000 hours) for business and general studies ○ Has 19 programmes
NATIONAL CERTIFICATE (VOCATIONAL) (NC(V))	○ General vocational programme including both academic and vocational subjects; practical components of curriculum are based on workshops rather than work-placement ○ Programmes offered at three NQF levels: NQF Levels 2–4 ○ Has 19 programmes
OCCUPATIONAL QUALIFICATIONS	○ Inclusive of a workplace learning component (though alternatives such as simulations are currently being introduced and are closely linked to workplace skills demands and opportunities) ○ Mainly offered through community education and training colleges, TVET colleges, private colleges, skills development providers, and universities ○ Mainly funded by the SETAs and the National Skills Fund through the levy grant system ○ Offered at multiple NQF levels, namely NQF Levels 1–8

Sources: DHET (2021); Busaries SA (2022)

Note: Mapping of N levels to NQF levels: N1 = NQF Level 2, N2 = NQF Level 3, N3 = NQF Level 4, N4–N6 = NQF Level 5, N6 with required work experience = NQF Level 6.

7.3.1 NC(V) programmes and the hydrogen economy

Of the nineteen NC(V) programmes available in the TVET college system, seven have been identified that can help develop the foundational knowledge and skills necessary to support the hydrogen economy in South Africa. These programmes are detailed in table 13, which also highlights the subjects that are required for the completion of each programme. The programmes equip learners with the fundamental knowledge and skills of areas such as electrical, mechanical, and industrial engineering and have been designed for a specific number of specialisations that address critical skills needs in South Africa, such as welding and boilermaking.

In their current form, the programmes are able to hone some but not all of the skills needed for the hydrogen economy. For example, welding is offered and required in the hydrogen value chain. Therefore, these programmes will need to be augmented to include hydrogen-specific capabilities either through the addition of hydrogen capabilities to the legacy programmes or through the creation of new hydrogen-specific NC(V) programmes. Regarding the former, table 14 indicates hydrogen capabilities that would need to be developed for each of the NC(V) qualifications listed in table 13.

From table 14, the 'process plant operations' NC(V) programme has been identified as being applicable for occupations in multiple hydrogen value chain segments such as production, storage, and conversion. As such, it would need to be augmented with many of the hydrogen capabilities to produce the competent workers that are required in the aforementioned value chain segments. On the other hand, the 'information technology and computer science (programming and robotics)' NC(V) qualification needs minimal augmentation because the capabilities for the qualification holders would not vary much, whether they work within the hydrogen value chain or not.

TABLE 13: NC(V) programmes from the TVET system that could support the development of the hydrogen economy

NC(V) PROGRAMME	NQF LEVEL 2 SUBJECTS	NQF LEVEL 3 SUBJECTS	NQF LEVEL 4 SUBJECTS
1. ELECTRICAL INFRASTRUCTURE CONSTRUCTION	Electrical principles and practice, electronic control and digital electronics, and workshop practice	Electrical principles and practice, electronic control and digital electronics, and electrical workmanship	Electrical principles and practice, electronic control and digital electronics, and electrical workmanship
	Optional: Electrical systems and construction, physical science, or renewable energy technologies	Optional: Electrical systems and construction, physical science, or renewable energy technologies	Optional: Electrical systems and construction, physical science, or renewable energy technologies
2. ENGINEERING AND RELATED DESIGN	Engineering fundamentals, engineering systems, and engineering technology	Engineering practice and maintenance, engineering graphics and design, and materials technology	Engineering processes, applied engineering technology, professional engineering practice
	Optional: Automotive repair and maintenance, engineering fabrication, fitting and turning, physical science, refrigeration principles, or welding	Optional: Automotive repair and maintenance, engineering fabrication (boiler making), engineering fabrication (sheet metal work), fitting and turning, physical science, refrigeration practice, or welding	Optional: Automotive repair and maintenance, engineering fabrication (boiler making), engineering fabrication (sheet metal work), fitting and turning, physical science, refrigeration and air-conditioning processes, or welding
3. INFORMATION TECHNOLOGY AND COMPUTER SCIENCE (PROGRAMMING AND ROBOTICS)	Electronics and digital concepts for robotics, robotics fundamental, and basic principles of computer programming and computer literacy	Electronics and digital concepts for robotics, introduction to robotics, and introduction to technical programming	Electronics and digital concepts for robotics, robotics and industrial automation, and technical programming

NC(V) PROGRAMME	NQF LEVEL 2 SUBJECTS	NQF LEVEL 3 SUBJECTS	NQF LEVEL 4 SUBJECTS
3. INFORMATION TECHNOLOGY AND COMPUTER SCIENCE (PROGRAMMING AND ROBOTICS)	Optional: Physical science, engineering graphics and technology, electrotechnology, mechatronic systems, or instrumentation technology	Optional: Physical science, engineering graphics and design, electrotechnology, mechatronic systems, or instrumentation technology	Optional: Physical science, mechanical draughting and technology, electrotechnology, mechatronic systems, or instrumentation technology
4. MECHATRONICS	Electro-technology, introduction to computers, and manual manufacturing	Electro-technology, stored programme systems, and machine manufacturing	Electro-technology, stored programme systems, and computer-integrated manufacturing
	Optional: Mechatronic systems	Optional: Mechatronic systems	Optional: Mechatronic systems
5. PROCESS INSTRUMENTATION	Electronic control and digital electronics, engineering fundamentals, physical science	Electronic control and digital electronics, engineering practice and maintenance, and physical science	Electronic control and digital electronics, engineering processes, and physical science
	Optional: Instrumentation technology	Optional: Instrumentation technology	Optional: Instrumentation technology
6. PROCESS PLANT OPERATIONS	Engineering fundamentals, physical science, and process technology	Process control, physical science, and process technology	Process control, physical science, and process technology
	Optional: Process chemistry, or pulp and papermaking technology	Optional: Process chemistry, or pulp and papermaking technology	Optional: Process chemistry, or pulp and papermaking technology
7. TRANSPORT AND LOGISTICS	Freight logistics, transport economics, and transport operations	Freight logistics, transport economics, and transport operations	Freight logistics, transport economics, and transport operations
	Optional: Entrepreneurship, or new venture creation	Optional: Project management, or new venture creation	Optional: Project management, or new venture creation

Source: DHET (2023)

Note: Optional subjects can also be chosen from any other streams.

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TABLE 14: Augmenting the identified NC(V) programmes suitable for the hydrogen economy with hydrogen capabilities

HYDROGEN CAPABILITIES	ELECTRICAL INFRASTRUCTURE CONSTRUCTION	ENGINEERING AND RELATED DESIGN	INFORMATION TECHNOLOGY AND COMPUTER SCIENCE (PROGRAMMING AND ROBOTICS)	MECHATRONICS	PROCESS INSTRUMENTATION	PROCESS PLANT OPERATIONS	TRANSPORT AND LOGISTICS
Understanding hydrogen properties	×	×	×	×	×	×	×
Reading and interpreting technical drawings with hydrogen equipment	×	×		×	×	×	
Calibrating, testing, and maintaining hydrogen equipment	×	×		×	×	×	
Knowledge of high-pressure gas systems and vessels		×			×	×	
Hydrogen storage techniques: Compressed hydrogen						×	
Hydrogen storage techniques: Conversion to hydrogen carriers						×	
Knowledge of conversion requirements for gases and their interchangeability						×	
Identifying and managing hydrogen hazardous areas (safety and risk)	×	×	×	×	×	×	×
Knowledge of hydrogen embrittlement		×					
Oversight of control modules for hydrogen processes					×	×	
Producing hydrogen: Understanding cooling systems						×	
Hydrogen production techniques: Steam methane reforming (SMR)						×	
Hydrogen production techniques: Coal gasification						×	
Hydrogen production techniques: Electrolysis, biofuels, and photolysis						×	
Handling cryogenic materials						×	×
Knowledge of power electronics	×			×			
Understanding co-firing in natural gas and hydrogen-fuelled gas turbines						×	

HYDROGEN CAPABILITIES	ELECTRICAL INFRASTRUCTURE CONSTRUCTION	ENGINEERING AND RELATED DESIGN	INFORMATION TECHNOLOGY AND COMPUTER SCIENCE (PROGRAMMING AND ROBOTICS)	MECHATRONICS	PROCESS INSTRUMENTATION	PROCESS PLANT OPERATIONS	TRANSPORT AND LOGISTICS
Fuel cells: Operating and maintaining fuel cells	×	×		×			
Fuel cells: Diagnosing and replacing fuel cells	×	×		×			
Hydrogen storage techniques: Liquid hydrogen						×	
Integrating hydrogen equipment from various original equipment manufacturers (OEMs) into a process	×	×		×	×	×	
Inspection, maintenance, and modification of hydrogen vehicles	×	×		×			
Management of hydrogen logistical movement across a supply chain							×
Recognition of hydrogen and waste product interchangeability in other industries						×	

Source: NC(V) qualifications and hydrogen capabilities augmentation matrix based on authors' analysis

Note: Hydrogen capabilities adapted from PwC (2022).

7.3.2 NATED programmes and the hydrogen economy

Like the NC(V) programmes, there are currently 19 NATED programmes that equip students with knowledge and skills to participate in multiple sectors of the national economy. As highlighted in table 12, the NATED qualifications are offered at six N Levels (N1–N6) for engineering studies, and three N Levels (N4–N6) for business and general studies (N1–N3 have been phased out and are set to be replaced by the 'foundational learning competence' programme). Due to the structure of the programmes, students who complete Levels N4–N6 and the work-placement (practical) period obtain the National N Diploma (NatNDip). Of these certifications, the NATED qualification for engineering studies has been identified as the most relevant for the hydrogen economy. There are three NatNDips for engineering studies that are listed on the DHET's website: electrical engineering, mechanical engineering, and civil engineering. (However, private colleges such as Berea Technical College also offer a National N Diploma in Chemical Engineering.)

As mentioned above, conferment of these qualifications requires 24 months of work experience, and during this period, students need to keep a record of their activities in logbooks. The DHET provides a logbook template with a list of recognised occupations and trades that students can undertake to fulfil the work experience requirement. Table 15 below lists the occupations and trades that are recognised for the electrical, mechanical, and civil engineering diplomas. It is important to note that not all these occupations are applicable to the hydrogen economy. No logbook template was found for the chemical engineering qualification; as such, no occupations recognised for work experience could be found, so this qualification is excluded from this analysis.

TABLE 15: Occupations and trades listed in the National N Diploma logbooks for electrical, mechanical, and civil engineering

NATNDIP: ELECTRICAL ENGINEERING		NATNDIP: MECHANICAL ENGINEERING		NATNDIP: CIVIL ENGINEERING	
OFO CODE	TRADE	OFO CODE	TRADE*	OFO CODE	TRADE
642701	Air-conditioning and refrigeration mechanic	651202	Welder	641201	Bricklayer
642702	Refrigeration mechanic	651302	Boilermaker	641301	Stonemason
671101	Electrician	651404	Structural plater	641303	Refractory mason
671202	Millwright	651501	Rigger	641501	Carpenter and joiner
671206	Electrical equipment mechanic	652302	Fitter and turner	641503	Joiner
671207	Armature winder	653109	Automotive engine mechanic	652201	Toolmaker
671208	Transportation electrician	653307	Heavy equipment mechanic	642302	Plasterer
671301	Electrical line mechanic	671202	Millwright	642601	Plumber
671302	Cable jointer	671203	Mechatronics technician	682201	Cabinet maker
672104	Electronic equipment mechanician	671204	Lift mechanic	682303	Wood machinist
672105	Instrument mechanician	684904	Panel beater	682304	Wood turner
672107	Special class electrician	684908	Shipwright	652206	Die sinker

Note: *This is a sample of the trades listed in the NatNDip logbook template for mechanical engineering, out of a total of 41.

To analyse the applicability of the NATED qualifications for the green hydrogen economy occupations listed in tables 4 and 5 (using only the 'technicians and tradespersons' category from part 6.2), the following two methods were employed:

1. The OFO codes of the hydrogen economy occupations listed in part 6.2 were matched with the OFO codes of the occupations and trades that students undertaking an N diploma must fill to meet the work experience requirement. For example, using this method, the OFO code 671101 for 'electrician' appears in both the hydrogen economy occupations list (table 4) and in the N Diploma: Electrical engineering trades list in table 15 above.
2. The second method involves an in-depth analysis of the capabilities required to successfully complete tasks related to the occupations tabulated in table 15 above, and whether these could be useful in the hydrogen economy. Using this method, occupations such as welders, heavy equipment mechanics, and millwrights were identified as being suitable for the hydrogen economy and were matched with the hydrogen economy occupations from part 6.2 that required similar capabilities.

Table 16 below provides the final matching between the hydrogen economy occupations from part 6.3.5 and the occupations related to the NatNDip qualifications in table 15. It is worth noting that using both methods, none of the NatNDip: Civil engineering–related occupations could be matched with those required for the hydrogen economy. This misalignment might be because civil engineering qualification holders would be needed in the construction phases of hydrogen projects, and these do not need hydrogen capabilities. Therefore, the civil engineering NATED qualification will not be considered further in the analysis.

TABLE 16: Matching the green hydrogen economy occupations with the occupations related to the National N Diploma engineering qualifications

GREEN HYDROGEN ECONOMY OCCUPATION	NATNDIP-RELATED OCCUPATION	NATNDIP PROGRAMME	OFO CODE
CYLINDER TECHNICIAN	Air-conditioning and refrigeration mechanic	Electrical engineering	642701
	Refrigeration mechanic	Electrical engineering	642702
ELECTRICIAN	Electrician	Electrical engineering	671101
HEAVY DUTY MECHANIC (DUAL FUEL)	Heavy equipment mechanic	Mechanical engineering	653307
LOCOMOTIVE ELECTRICIAN	Transportation electrician	Electrical engineering	671208
FCEV TECHNICIAN	Transportation electrician	Electrical engineering	671208
	Heavy equipment mechanic	Mechanical engineering	653307
MAINTENANCE TECHNICIAN	Millwright	Electrical engineering, mechanical engineering	671202
PIPELINE TECHNICIAN (MECHANICAL)	Millwright	Electrical engineering, mechanical engineering	671202
COMPRESSION STATION OPERATOR	Millwright	Electrical engineering, mechanical engineering	671202
WELDER	Welder	Mechanical engineering	651202
FITTER AND TURNER	Fitter and turner	Mechanical engineering	652302
ELECTRICAL INSTRUMENTATION MECHANICIAN	Instrument mechanician	Electrical engineering	672105
MECHATRONICS TECHNICIAN	Mechatronics technician	Mechanical engineering	671203

Sources: Based on authors' analysis; green hydrogen economy occupations collated from Hufnagel-Smith (2022a) and PwC (2022)

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The curricula of the electrical and mechanical engineering NATED programmes and the occupations that students must undertake for work experience are presently not hydrogen-specific. As such, to develop the required hydrogen capabilities, these programmes must either be augmented with hydrogen capabilities or new hydrogen-specific NATED programmes must be developed. On the former suggestion, table 17 below provides an augmentation matrix with a list of hydrogen capabilities that can be incorporated into the electrical and mechanical engineering NATED programmes. The capabilities marked '×' could be added to the curricula of these NATED qualifications to ensure that, for example, students have an 'understanding of hydrogen properties' and can 'inspect, maintain, and modify hydrogen vehicles'. These capabilities would be critical across different segments of the hydrogen value chain and for different occupations such as those highlighted in table 16.

TABLE 17: Augmentation matrix of the NATED engineering programmes with hydrogen capabilities

HYDROGEN CAPABILITIES	NATNDIP: ELECTRICAL ENGINEERING	NATNDIP: MECHANICAL ENGINEERING
Understanding hydrogen properties	×	×
Reading and interpreting technical drawings with hydrogen equipment	×	×
Calibrating, testing, and maintaining hydrogen equipment	×	×
Knowledge of high-pressure gas systems and vessels		×
Identifying and managing hydrogen hazardous areas (safety and risk)	×	×
Knowledge of hydrogen embrittlement		×
Knowledge of power electronics	×	
Fuel cells: Operating and maintaining fuel cells	×	×
Fuel cells: Diagnosing and replacing fuel cells	×	×
Integrating hydrogen equipment from various OEMs into a process	×	×
Inspection, maintenance, and modification of hydrogen vehicles	×	×

Sources: Qualification and hydrogen capability augmentation matrix based on authors' analysis

Note: Hydrogen capabilities adapted from PwC (2022).

7.3.3 Occupational qualifications and the hydrogen economy

According to the Occupational Qualifications Sub-Framework (OQSF), an occupational qualification is "a qualification that consists of a minimum of 25 credits associated with a trade, occupation, or profession" (QCTO, 2013). An occupational qualification comes from WBL, consists of three components: knowledge, practical skills, and work experience, and has an external summative assessment. Most of the occupational qualifications discussed in the report are funded by SETAs that cover activities linked to the hydrogen value chain, such as CHIETA and EWSETA.

Table 18 matches the 'technicians and tradespersons' occupations from tables 4 and 5 with the occupational qualifications available in South Africa, thereby highlighting the qualifications that are available in the country for each occupation, their South African Qualifications Authority (SAQA) identification numbers, NQF levels, and the respective SETA they are funded by.

Firstly, the qualification requirements for the 'technicians and tradespersons' occupations and their key activities were reviewed. Secondly, the country's occupational qualifications whose exit level outcomes and industrial applicability closely matched those of international occupations were selected. The QCTO and SAQA databases were then used to find these qualifications. Of the 39 'technicians and tradespersons' occupations, relevant South African qualifications were found for 25. In many cases, due to similarities in the qualification requirements and activities, an occupational qualification was found to be applicable to more than one occupation.

Due to the green hydrogen economy being in the early stages of development in South Africa, none of the qualifications in table 18 have been developed for hydrogen-specific applications but are instead used in other industries and sectors that are linked to the hydrogen value chain. The lack of hydrogen specificity is illustrated by the capabilities developed for each qualification (see the last column of table 18). For example, the qualifications developed by CHIETA are in response to the skills needs in the chemicals industry of which hydrogen production and use is a part but not a major activity, so the qualifications may not directly apply to hydrogen. Similarly, MerSETA's automotive qualifications are predominantly for internal combustion engine vehicles (ICEVs), not fuel cell electric vehicles (FCEVs). Nevertheless, some of the knowledge, skills, and dexterities developed through these qualifications could be applied to hydrogen-specific occupations. However, it is necessary to embed hydrogen-specific capabilities and skills into the structure of these qualifications. Furthermore, new programmes and qualifications can also be developed, especially for nuanced hydrogen applications. This has already been demonstrated by EWSETA registering a skills programme for hydrogen fuel cell system practitioners in early 2023 (this is, however, a *skills programme* and not an occupational qualification according to the classifications used by the QCTO).

Table 19 shows the hydrogen-specific capabilities that would need to be embedded into the South African occupational qualifications listed in table 18. The hydrogen capabilities have been matched to the occupational qualifications using the '×' symbol. The results in table 19 indicate that the most cross-cutting or core capabilities are 'Understanding hydrogen properties' and 'Identifying and managing hydrogen hazardous areas (safety and risk)'. Furthermore, the occupational qualifications that require the most augmentation include the 'chemical plant operator', 'chemical plant controller', 'chemical production machine operator', and 'gas practitioner' qualifications. This result is directly related to the occupational requirements in the hydrogen value chain for the professions that these occupational qualifications have been matched with.

TABLE 18: Mapping the hydrogen economy occupations requiring at least a 'certificate of occupation' with occupational qualifications available in South Africa

HYDROGEN ECONOMY OCCUPATION	SOUTH AFRICAN OCCUPATIONAL QUALIFICATION	SAQA ID	NQF LEVEL	SETA	CAPABILITY DEVELOPED
CONTROL ROOM OPERATOR	Chemical plant operator	102156	4	CHIETA	○ Start a chemical process in a chemical plant. ○ Control, maintain, and monitor the chemical processing plant and the equipment of a chemical plant to a specified state. ○ Shut down a chemical process in a chemical plant to a specified state. ○ Maintain the quality of the chemical product in a chemical process. ○ Assess risks and respond to hazardous conditions, emergencies, and abnormal conditions.
CONTROL ROOM OPERATOR	Chemical plant controller	111359	5	CHIETA	○ Control operations according to a production schedule. ○ Perform plant operations per the standard operating procedures and/or work instructions. ○ Perform quality controls as per quality standards.
CHEMICAL LABORATORY TECHNICIAN	Chemical laboratory analyst	101569	4	CHIETA	○ Take samples for specific operational processes. ○ Prepare samples for analysis. ○ Analyse samples in a chemical laboratory by applying basic analytical methods and equipment. ○ Analyse samples in a chemical laboratory by applying advanced analytical processes and using complex equipment.
MAINTENANCE PLANNER	Maintenance planner	101874	5	CHIETA	○ Identify work through notifications or work requests. ○ Scope and plan work in accordance with identified notifications or work requests. ○ Schedule planned activities. ○ Coordinate the execution of tasks. ○ Close out documentation. ○ Review the execution outcomes of the work management process. ○ Maintain master data.
MAINTENANCE TECHNICIAN	Millwright	97585	4	MerSETA	○ Fit, adjust, and maintain industrial machinery. ○ Diagnose, find, and repair faults in industrial machinery. ○ Install, test, and commission industrial machinery.

HYDROGEN ECONOMY OCCUPATION	SOUTH AFRICAN OCCUPATIONAL QUALIFICATION	SAQA ID	NQF LEVEL	SETA	CAPABILITY DEVELOPED
DRILLING CREW	Driller	99379	2	Mining Qualifications Authority (MQA)	Operate a drilling machine for mining and construction operations.
	Driller (directional driller)	98908	3	MQA	Operate a directional drilling machine for mining and construction operations.
	Driller (exploration driller)	98823	3	MQA	Operate an exploration drilling machine to drill holes for exploration.
PIPELINE TECHNICIAN (ELECTRICAL AND INSTRUMENTATION	Measurement, control, and instrumentation	74530	2	Multiple	○ Understand the fundamentals of field process instrumentation. ○ Conduct basic maintenance and calibration of field instrumentation and equipment. ○ Demonstrate knowledge of relevant organisational standards, policies, and procedures.
PIPELINE TECHNICIAN (ELECTRICAL AND INSTRUMENTATION	Measurement, control, and instrumentation	74532	3	Multiple	○ Maintain programmable field instrumentation. ○ Demonstrate knowledge of the principles of field instrumentation. ○ Comply with manufacturer's specifications, organisational policies, procedures, standards, and applicable legislative requirements.
	Measurement, control, and instrumentation	74531	4	Multiple	○ Maintain process control systems. ○ Maintain PLCs. ○ Demonstrate an understanding of the principles of process communication systems. ○ Maintain and support policies and procedures to solve a variety of problems within a measurement, control, and instrumentation field.
PIPELINE TECHNICIAN (MECHANICAL)	Millwright	97585	4	MerSETA	Refer to maintenance technician above.

HYDROGEN ECONOMY OCCUPATION	SOUTH AFRICAN OCCUPATIONAL QUALIFICATION	SAQA ID	NQF LEVEL	SETA	CAPABILITY DEVELOPED
COMPRESSION STATION OPERATOR	Millwright	97585	4	MerSETA	Refer to maintenance technician above.
CYLINDER TECHNICIAN	Air-conditioning and refrigeration mechanic	103277	4	MerSETA	○ Install air-conditioning, refrigeration, and ventilation systems. ○ Commission air-conditioning, refrigeration, and ventilation systems. ○ Maintain, service, troubleshoot, and repair air-conditioning, refrigeration, and ventilation systems.
CYLINDER TECHNICIAN CYLINDER TECHNICIAN	Refrigeration control fitter	103271	4	MerSETA	○ Install commercial and industrial refrigeration systems. ○ Commission refrigeration systems. ○ Maintain, service, troubleshoot, and repair refrigeration systems.
	Refrigeration mechanic	103270	4	MerSETA	○ Install refrigeration systems. ○ Commission refrigeration systems. ○ Maintain, service, troubleshoot, and repair refrigeration systems.
HEAVY-DUTY MECHANIC (DUAL FUEL)	Heavy equipment mechanic	97582	4	MerSETA	○ Perform preventative and scheduled maintenance on heavy equipment. ○ Dismantle, assess, repair, and reassemble heavy equipment engine and power train system components. ○ Diagnose and repair faults in heavy equipment diesel engine and power train systems.
TRUCK DRIVER	Truck driver	93793	3	Transport Education Training Authority	○ Plan and prepare a truck for transportation. ○ Operate a truck. ○ Maintain operational documents and records.

HYDROGEN ECONOMY OCCUPATION	SOUTH AFRICAN OCCUPATIONAL QUALIFICATION	SAQA ID	NQF LEVEL	SETA	CAPABILITY DEVELOPED
FCEV TECHNICIAN	Heavy equipment mechanic	97582	4	MerSETA	Refer to heavy duty mechanic above.
	Transportation electrician (automotive electrician)	117042	4	MerSETA	○ Remove and install a range of original, aftermarket, or auxiliary auto-electrical equipment and/or components/systems.
FCEV TECHNICIAN	Transportation electrician (automotive electrician)	117042	4	MerSETA	○ Test, diagnose, replace, and service automotive batteries and related components. ○ Test, diagnose, and repair automotive starting and charging systems. ○ Conduct basic vehicle service operations in an auto-electrical environment. ○ Test, diagnose, and repair automotive networking and data transfer systems and supplemental restraint systems. ○ Test, diagnose, and repair systems for integrated engine management (fuel injection and ignition), vehicle stability, traction and drive control, transmission, anti-lock braking, and driver assistance. ○ Test, diagnose, and repair systems HVAC, climate control, convenience, security, and telematics.
LOCOMOTIVE MECHANICS (FIELD AND SHOP)	Heavy equipment mechanic	97582	4	MerSETA	Refer to heavy duty mechanic above.
LOCOMOTIVE ELECTRICIAN	Transportation electrician (automotive electrician)	117042	4	MerSETA	Refer to FCEV technician above.
GAS FITTER	Gas practitioner	117233	5	CHIETA	○ Construct and install gas systems as per scope of work. ○ Perform commissioning activities on gas systems. ○ Conduct handover sessions when required by the scope of work with the end-user.

HYDROGEN ECONOMY OCCUPATION	SOUTH AFRICAN OCCUPATIONAL QUALIFICATION	SAQA ID	NQF LEVEL	SETA	CAPABILITY DEVELOPED
GAS FITTER	Gas practitioner	117233	5	CHIETA	○ Inspect, maintain, and repair gas systems to required legal requirements. ○ Modify gas systems according to engineering management of change requirements.
HVAC TECHNICIAN	HVAC control fitter	104620	2	MerSETA	○ Install air-conditioning, refrigeration, and ventilation systems. ○ Commission air-conditioning, refrigeration, and ventilation systems. ○ Maintain, service, troubleshoot, and repair refrigeration systems.
FITTER AND TURNER	Fitter and turner	94020	4	MerSETA	○ Apply hand skills to fabricate mechanical components using engineering tools. ○ Perform engineering maintenance on mechanical components, subassemblies, and machines. ○ Repair, install, and commission subassemblies and machines. ○ Machine mechanical components using machining tools and equipment.
ELECTRICIAN	Electrician	91761	4	LGSETA	○ Plan and prepare work site, equipment, tools, consumables, and materials for electrical activities and operations. ○ Install, wire, and connect electrical equipment and control systems.
ELECTRICIAN	Electrician	91761	4	LGSETA	○ Test and inspect electrical equipment, control systems, and installations. ○ Commission control systems and installations. ○ Maintain and repair electrical equipment, control systems, and installations.
ELECTRICAL INSTRUMENTATION TECHNICIAN	Measurement, control, and instrumentation	74530	2	Multiple	Refer to pipeline technician (electrical and instrumentation) above.
	Measurement, control, and instrumentation	74532	3	Multiple	Refer to pipeline technician (electrical and instrumentation) above.

HYDROGEN ECONOMY OCCUPATION	SOUTH AFRICAN OCCUPATIONAL QUALIFICATION	SAQA ID	NQF LEVEL	SETA	CAPABILITY DEVELOPED
ELECTRICAL INSTRUMENTATION TECHNICIAN	Measurement, control, and instrumentation	74531	4	Multiple	Refer to pipeline technician (electrical and instrumentation) above.
	Instrument mechanician	94701	5	EWSETA	○ Calibrate instrumentation equipment. ○ Install and remove instrumentation equipment. ○ Optimise process control loops. ○ Troubleshoot and repair instrumentation equipment. ○ Maintain instrumentation equipment.
REFUELLING TECHNICIAN	Service station attendant	99708	2	W&R SETA	○ Sell and dispense fuel, lubricants, and other automotive accessories. ○ Perform minor checks on motor vehicles at a service station and process payments.
FUEL CELL TECHNICIAN	Hydrogen fuel cell system practitioner	–	5	EWSETA	○ Prepare to install hydrogen fuel cell system.
FUEL CELL TECHNICIAN	Hydrogen fuel cell system practitioner	–	5	EWSETA	○ Install hydrogen fuel cell system. ○ Operate the hydrogen fuel cell system. ○ Maintain the hydrogen fuel cell system.
MECHATRONICS TECHNICIAN	Mechatronics technician	102004	5	MerSETA	○ Interpret task requirements, plan, and design and construct single- and three-phase alternating current motor control circuits. ○ Diagnose, find, and repair electrical, mechanical, and electronic faults in industrial machinery. ○ Install, test, and commission electrical, mechanical, and electronic system components in industrial machinery. ○ Install, test, modify, and commission equipment and related control, data and communication networks, and systems on integrated industrial systems.

HYDROGEN ECONOMY OCCUPATION	SOUTH AFRICAN OCCUPATIONAL QUALIFICATION	SAQA ID	NQF LEVEL	SETA	CAPABILITY DEVELOPED
WELDER	Welder	94100	4	CHIETA	○ Cut, gouge, and gas weld ferrous materials. ○ Weld ferrous materials including stainless steel using the shielded metal arc welding process.
WELDER	Welder	94100	4	CHIETA	○ Weld ferrous and non-ferrous materials using the gas metal arc welding process. ○ Weld ferrous and non-ferrous materials using the gas tungsten arc welding process.
PRODUCTION TECHNICIAN	Chemical production machine operator	117307	2	CHIETA	○ Apply safety, health, and environmental principles and practices in the processing environment. ○ Describe and apply the procedures for monitoring, measuring, and transferring materials in a safe manner. ○ Prepare, operate, and control the plant process to manufacture materials. ○ Conduct materials sampling for process quality control.
ASSEMBLY TECHNICIAN	Production process machine operator and assembler	102580	3	MerSETA	○ Plan and prepare for part manufacturing to initiate production sequence. ○ Operate, monitor, set, and adjust equipment to produce parts to specification. ○ Assemble, inspect, and test produced parts or components to conform to specification.

Sources: The matching of hydrogen 'technicians and tradespersons' occupations with occupational qualifications is based on the authors' analysis. Occupations are collated from Hufnagel-Smith (2022a) and PwC (2022).

Notes: These qualifications are recognised as 'occupational certificate' according to the OQSF nomenclature. Details about each of the South African occupational qualifications can be found on the SAQA catalogue of registered qualifications.

TABLE 19: Augmentation matrix of the occupational qualifications and hydrogen capabilities that need to be embedded in each qualification

HYDROGEN CAPABILITIES	Chemical plant operator	Chemical plant controller	Chemical laboratory analyst	Maintenance planner	Millwright	Measurement, control, and instrumentation	Measurement, control, and instrumentation	Measurement, control, and instrumentation	Instrument mechanician	Driller	Driller (directional driller)	Driller (exploration driller)	Air-conditioning and refrigeration mechanic	Refrigeration control fitter	Refrigeration mechanic	Heavy equipment mechanic	Truck driver	Transportation electrician (automotive electrician)	Electrician	Gas practitioner	HVAC control fitter	Fitter and turner	Service station attendant	Mechatronics technician	Welder	Chemical production machine operator	Production process machine operator and assembler
Understanding hydrogen properties	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Calibrating, testing, and maintaining hydrogen equipment	×	×		×	×	×	×	×	×				×	×	×	×		×	×	×	×			×		×	×
Handling cryogenic materials													×	×	×						×						
Identifying and managing hydrogen hazardous areas (safety and risk)	×	×	×	×	×															×							
Knowledge of high-pressure gas systems and vessels	×	×		×	×								×	×	×	×				×	×		×		×	×	×
Fuel cells: Operating and maintaining fuel cells																		×	×					×			
Fuel cells: Diagnosing and replacing fuel cells																		×	×					×			
Reading and interpreting technical drawings with hydrogen equipment	×	×		×	×	×	×	×	×				×	×	×	×		×	×	×	×	×		×	×	×	×
Producing hydrogen: Understanding cooling systems	×	×	×	×																						×	
Hydrogen production techniques: SMR	×	×	×	×																						×	
Hydrogen production techniques: Coal gasification	×	×	×	×																						×	
Hydrogen storage techniques: Compressed hydrogen	×	×											×	×	×					×	×					×	
Hydrogen storage techniques: Liquid hydrogen	×	×																								×	
Hydrogen storage techniques: Conversion to hydrogen carriers	×	×											×	×	×					×	×					×	

HYDROGEN CAPABILITIES	Chemical plant operator	Chemical plant controller	Chemical laboratory analyst	Maintenance planner	Millwright	Measurement, control, and instrumentation	Measurement, control, and instrumentation	Measurement, control, and instrumentation	Instrument mechanician	Driller	Driller (directional driller)	Driller (exploration driller)	Air-conditioning and refrigeration mechanic	Refrigeration control fitter	Refrigeration mechanic	Heavy equipment mechanic	Truck driver	Transportation electrician (automotive electrician)	Electrician	Gas practitioner	HVAC control fitter	Fitter and turner	Service station attendant	Mechatronics technician	Welder	Chemical production machine operator	Production process machine operator and assembler
Hydrogen production techniques: Electrolysis, biofuels, and photolysis	×	×	×	×																						×	
Knowledge of conversion requirements for gases and their interchangeability	×	×											×	×	×					×	×					×	
Knowledge of hydrogen embrittlement													×	×	×					×	×	×					
Oversight of control modules for hydrogen processes	×	×	×																×						×		×
Inspection, maintenance, and modification of hydrogen vehicles																		×						×			
Knowledge of power electronics																×		×	×					×			
Management of hydrogen logistical movement across a supply chain																	×										
Integrating hydrogen equipment from various OEMs into a process																×		×						×			×
Understanding co-firing in natural gas and hydrogen-fuelled gas turbines	×	×																		×						×	
Communicating the risks, benefits, and safety considerations of hydrogen	×	×	×	×	×								×	×	×					×	×					×	

Source: Qualification and hydrogen capability augmentation matrix based on the authors' analysis.

Note: Hydrogen capabilities adapted from PwC (2022).

Beyond the augmentation of currently existing programmes such as the NC(V), NATED, and occupational qualifications highlighted above, to develop such hydrogen capabilities, South Africa can adapt international best practices. For example, as part of Australia's *Gas Industry Training Package,* there are units of competency that have been specifically developed for working with hydrogen. These are:

- Apply safety practices, procedures, and compliance standards for handling hydrogen gas
- Fault-find and repair hydrogen storage equipment
- Inject hydrogen gas into distribution networks
- Monitor and control hydrogen in gas distribution networks
- Undertake routine hydrogen storage applications

South Africa could adapt these and other competencies from other countries that have established green hydrogen economies and incorporate them into training programmes to support the local hydrogen economy. Such programmes could be in the form of 'skills programmes' and not full qualifications.

7.3.4 Non-technical TVET qualifications and the hydrogen economy

There are other occupations that were identified in part 6.3.5 that are required to develop a green hydrogen economy and that are not technical. These occupations include, for example, those in sales, marketing, communications, and administrative work. Therefore, these were not included in the preceding discussions of TVET qualifications and occupations for the green hydrogen economy.

Given that they are required for the hydrogen value chain, table 20 provides a list of the TVET qualifications that can be undertaken to develop competencies and knowledge for non-technical green hydrogen economy occupations. The list provided is for illustrative purposes and may not cover all the non-technical qualifications available in the OQSF that are relevant for the green hydrogen economy, especially with respect to the occupational qualifications. However, it does highlight the diverse range of vocational education and training opportunities available in the country.

TABLE 20: Non-technical TVET qualifications that can be augmented to support the development of skills for the green hydrogen economy

QUALIFICATION NAME	QUALIFICATION TYPE
Finance, economics, and accounting	NC(V)
Management	NC(V)
Marketing	NC(V)
Office administration	NC(V)
Business management	NatNDip
Financial management	NatNDip
Human resource management	NatNDip
Management assistant	NatNDip
Marketing management	NatNDip
Public management	NatNDip
Public relations	NatNDip
Management assistant	Occupational certificate

QUALIFICATION NAME	QUALIFICATION TYPE
Marketing coordinator	Occupational certificate
Office administrator	Occupational certificate
Recruitment manager	Occupational certificate
Project manager	Occupational certificate
Commercial cleaner	Occupational certificate

7.4 Community education and training

Community education and training (CET) colleges were established with the goal of improving the literacy, numeracy, and vocational skills of adults and youth who do not qualify for TVET colleges and universities. Unlike TVET colleges and universities, which tend to train individuals to participate in the broader economy, community colleges, as the name suggests, were developed to train individuals to be better able to address community needs. The programmes and subjects offered include ancillary healthcare, applied agriculture and agricultural science, information communication technology, mathematics, natural sciences, and language literacy and communication, among others. CET college studies result in the conferment of the General Education and Training Certificate for Adults, which is at NQF Level 1—thus the knowledge and the skills developed in CET colleges are elementary.

In the context of the hydrogen economy, CET colleges can be used to educate youth and adults about hydrogen as an energy carrier and feedstock, ensuring that, for example, individuals understand hydrogen properties and can communicate the risks, benefits, and safety considerations of hydrogen. Hydrogen-specific information can be added to the curricula under the unit standard 'Understand and use energy in technological product and systems', or it can be developed into an independent unit standard that can be part of either the 'natural sciences' or 'technology' CET courses.

7.5 Other considerations

7.5.1 Train the trainer

As previously stated, the green hydrogen economy is still emergent both globally and in South Africa. As such, the human talent that would otherwise impart the requisite knowledge, skills, and industry experience to students at schools, CET colleges, TVET colleges, and universities is undeveloped or presently inadequate. This gap is a challenge that has been flagged in other hydrogen skills strategies such as the European Hydrogen Skills Strategy (Hydrogen Europe Research et al., 2023a). In South Africa, the knowledge gap is significant in the TVET college ecosystem in particular, where there are currently no programmes being offered (with the exception of the DSI/EWSETA-funded training programme). In contrast, the knowledge and skills required for the green hydrogen value chain (especially those relating to upstream and midstream activities) are currently being developed at a few South African universities, primarily through postgraduate studies, as outlined in part 7.2.

Some of the ways in which teachers and lecturers in schools and HEIs can be capacitated with the relevant knowledge and skills required to effectively train South Africa's green hydrogen workforce include:

- Increasing collaboration between industry and education institutions: Lecturers can receive practical training from industry professionals so that they are capacitated and have up-to-date knowledge regarding industry practices and standards that they can disseminate to their students. An example of such an initiative is the 'work-integrated learning for lecturers project', which was conducted by the Swiss–South African Cooperation Initiative and the Education, Training and Development Practices SETA.
- Establishing relationships with international private and public institutions: Fostering relationships between South African TVET colleges and their international counterparts and/or to international companies can open up opportunities for information-sharing and work-integrated learning for lecturers. This collaboration would allow lecturers to gain continuous professional development (CPD) and ensure that they are updated and informed about the international hydrogen landscape.

7.5.2 Soft (non-cognitive) skills

Soft skills are becoming increasingly critical skills for future employment. They encompass how individuals interact with others—their intrapersonal skills that relate to self-awareness and self-management. Soft skills are neither technical nor job-related and are at times developed over time. The interaction between the inborn characteristics of an individual (personality and abilities) and the surrounding context will determine how their soft skills develop (Poláková et al., 2023).

As discussed by BP and Aberdeen City Council (2022), the green hydrogen economy requires soft skills such as:

- Integrity
- Teamwork
- Leadership
- Collaboration
- Communication
- Adaptability
- Creativity
- Time management
- Problem-solving
- Concern for others
- Conflict management
- Critical thinking

According to Cloete et al. (2022), these skills are underdeveloped in South African graduates, resulting in the delayed employment of graduates. Soft skills can be developed at the basic education level, in institutions of higher learning, or in upskilling offered in the workplace, and should be included in existing curricula (Hydrogen Europe Research et al., 2023a).

PART 8

Opportunities for Workplace-Based Learning

This section assesses the availability of workplace-based learning (WBL) opportunities for skills relating to the hydrogen economy. According to Government Gazette No. 42037 published on 16 November 2018, the *SETA Workplace Based Learning Programme Agreement Regulations* state that WBL means "an educational component of an occupational qualification that provides students with real-life work experience where they can apply academic and technical skills and increase the prospect of employability" (DHET, 2018). The DHET's skills strategy report (2022) lists nine categories of WBL, which are tabulated in table 21.

TABLE 21: Categories of workplace-based learning

CATEGORY	DEFINITION
APPRENTICESHIP	A period of WBL culminating in a listed trade.
CANDIDACY	A period of WBL undertaken by a graduate as part of their professional designation, as stipulated by a professional body
GRADUATE INTERNSHIP	A period of WBL for the purpose of allowing a person who has completed a post-school qualification to gain workplace experience or exposure to enhance competence and/or employability.
INTERNSHIP FOR A NATNDIP	A period of WBL undertaken for an N diploma
LEARNERSHIP	A period of WBL culminating in an occupational qualification or part-qualification.
STUDENT INTERNSHIP	A period of WBL for a student enrolled at an education and training institution for a qualification that is registered on the NQF, which may include vacation work.
STUDENT INTERNSHIP: CATEGORY A	A period of WBL undertaken as part of the requirements for a diploma, national diploma, higher certificate, or advanced certificate for vocational qualifications, as stipulated in the Higher Education Qualifications Sub-Framework.
STUDENT INTERNSHIP: CATEGORY B	A period of WBL undertaken as a requirement for a professional qualification.
STUDENT INTERNSHIP: CATEGORY C	A period of WBL undertaken as part of the requirements for a QCTO occupational qualification.

Source: DHET (2022)

PART 8

8.1 Local opportunity assessment

8.1.1 Apprenticeships, learnerships, National N Diplomas, and category C student internships

The structure of technical qualifications such as engineering degrees, diplomas, and occupational qualifications includes a work experience component that students must complete as a precondition for conferment of the qualifications. The type of applicable WBL varies by qualification type, as highlighted in table 21. For qualifications that develop skills related to the hydrogen economy—that is, those that would require little augmentation with hydrogen capabilities—and result in the hydrogen value chain occupations listed in tables 4 and 5, WBL opportunities exist in the country. Such occupations with WBL opportunities include mechatronics, electrical, and mechanical engineers, and electricians.

However, the country currently has limited WBL opportunities to develop the hydrogen-specific capabilities listed in table 19 due to the nascency of its hydrogen economy, and because there is only a small number of companies, organisations, and institutions involved in the hydrogen value chain. For instance, Sasol, the main producer of grey hydrogen in South Africa, offers learnerships for chemical plant operations, instrumentation and control, electrical operations, fitting and turning, and rigging, but there is no indication of whether or not these learnerships exist within the company's hydrogen business operations (Sasol, 2023). Other WBL opportunities include UWC's Green Hydrogen Programme, an apprenticeship at SAIAMC (Chidziva, 2022). The DSI and EWSETA have also funded graduate training at UP, where unemployed chemical and electrical engineering graduates were trained on installation, operation, and maintenance of hydrogen fuel cell systems (Mathibela, 2020b). After this training, selected graduates were to be absorbed into the trainer Bambili Energy's fuel cell manufacturing facility.

8.1.2 Candidacy and internships (graduate, categories A and B)

Candidacy programmes are designed for candidates working towards professional registration as professional engineers, engineering technologists, or engineering technicians with the Engineering Council of South Africa. This process involves CPD, which is mainly conducted in the workplace. Therefore, because hydrogen value chains are still emergent in South Africa, candidates develop skills that could potentially be transferred to the hydrogen value chains but would require upskilling for full functionality in hydrogen-specific occupations.

A review of online job postings for hydrogen-related internships and entry-level jobs in South Africa on websites such as LinkedIn, Indeed, and PNet indicated that there are hardly any candidacy and graduate internship opportunities that would equip candidates with hydrogen-related skills.

8.2 International opportunity assessment

Internationally, WBL opportunities for hydrogen-related skills exist, especially in countries where the hydrogen value chain is more developed. For example, in Germany, Linde plc, which is among the top 10 hydrogen producers globally, offers multiple opportunities for WBL ranging from apprenticeships to internships, to trainee and graduate programmes.

PART 9

Conclusion

Globally, countries are seeking to decarbonise their energy systems, particularly in the hard-to-abate sectors, which have less easy-to-address emission sources. Green hydrogen is emerging as a crucial energy source that can enable the decarbonisation of these sectors in line with the 2050 net zero targets. South Africa is actively pursuing sizeable green production both for domestic consumption and for the global export market, seeking to capture a 4% global market share by 2050. Catalytic projects identified in the HSRM have the potential to create 20,000 and 30,000 jobs annually by 2030 and 2040, respectively.

There is currently no skills shortage in the South African green hydrogen economy due to the nascency of the industry. The existing supply of hydrogen skills is concentrated in a few chemical companies and research institutions (although in small quantities), and there is potential to augment and transfer several skills from the petroleum and gas industry to the green hydrogen industry. As the industry is established, there is a risk that the skills demanded by the industry will exceed the supply of individuals in the labour market who possess the required skillset. The objective of the skills needs assessment was to therefore assist government and non-government stakeholders in the green hydrogen economy to proactively plan for the development of the talent and expertise required for the establishment, growth, and long-term sustainability of the emerging green hydrogen economy.

It is also necessary to develop industry-endorsed standards for the development of green hydrogen skills. The lack of standards hinders the advancement of relevant training, including in emerging occupations. When considering the HEIs and TVET college ecosystem, the assessment found that South African institutions offer most of the qualifications required to support the development of occupations in the green hydrogen value chain. The degree, diploma, occupational qualifications, NC(V), and NATED programmes would, however, need to be augmented to include hydrogen-related capabilities, and new qualifications would need to be introduced (to a smaller extent) as outlined in parts 7.2 and 7.3. In parallel, lecturers and trainers need to be capacitated to deliver the curricula, and this can be achieved through increased collaboration between the industry and educational institutions, and by establishing relationships with international institutions (both public and private) to foster information-sharing between countries.

Nevertheless, the demand for specialised skills will materialise before the longer-term project of updating curricula can be concluded, and South Africa needs to consider some of the following initiatives to enhance the readiness of a green hydrogen workforce:

1. Develop CPD programmes that incorporate green hydrogen capabilities, and improve access to foster hydrogen-related skills in the existing workforce.
2. Promote learner and trainer mobility to other countries as it provides them with access to a wide range of educational and training opportunities that may not be available in South Africa, given the nascency of the industry in the country.
3. Encourage learners in the school system to enrol for STEM subjects at primary and secondary level, since these subjects form a significant portion of PSET green hydrogen-related qualifications, and they promote green hydrogen as an industry of choice to attract students and workers in declining sectors who may be interested in participating in the green hydrogen economy.

PART 10

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